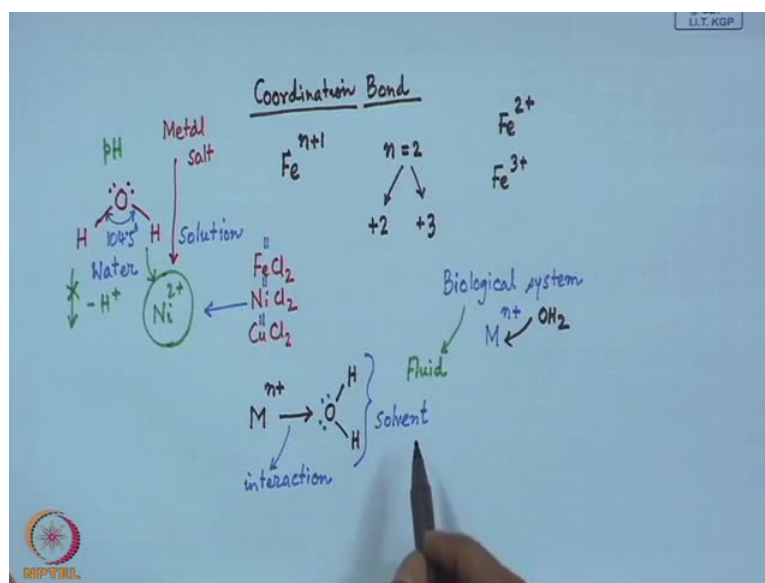


Coordination Chemistry
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Lecture - 1
Introduction

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Good evening everybody. So, in this class of coordination chemistry we will talk something related to the coordination bond, which is forming particularly, when we see that a particular metal centre say if iron is there and it is not the metallic iron, but it is iron in some oxidation state n or $n + 1$. So, when n is equal to 2, we get both the plus 2 as well as plus 3 oxidation states. So, if we just consider how the ferrous ion as well as the ferric ion will form such coordinate bond. How these coordinate bonds form? Because this is the basis of this particular topic of chemistry where we will find from the very simple molecule, from our very early days from the studies in school level we all know what is the typical water molecule.

Why we are so interested about knowing the molecule of water? Because we all the time whenever we start any reaction related to any metal salt we see that we have a metal salt, any metal salt it can be our ferrous chloride, it can be our nickel chloride or it can be our copper chloride so we have some corresponding oxidation states on it depending upon the number of Cl groups attached to the metal salt. So, all of them are bivalent. So,

interesting thing happens basically when we try to do this reaction it is not simply reaction, but we try to do or try to get the corresponding solution of those metal salts in say a typical solvent which is our water.

So, what is happening is a very simple reaction where we just try to dissolve this salts say nickel chloride in water. So, will it stay as this nickel chloride form or will it form something else? That is very important that means how these dipoles, this water molecules are behaving it has a angular shape we all know. So, it has a angle of 104.5 degree.

Where this O H bonds two O H bonds are in some typical angle and these are not going for any kind of dissociation that means the proton is not losing from there. So, minus H plus is not taking place. So, we can have that means we know the typical pH of the solution that means it is a neutral pH. So, at neutral pH if we have some amount of water and we try to dissolve this nickel chloride, what is happening there? That means how this Ni 2 plus will be present there in an environment of these water molecules? So, these are very simple and some basic questions what we can think in our mind.

Similarly, in our system or any biological system, any living organisms in our body also so if we have any biological system where the metal centre is present say M is present in some oxidation state, M can be 2, 3 or anything. So, in biological system the environment is very much related to the water environment, but in this particular case we have some other groups available within the biological fluid that means we can have instead of the water environment we can have a biological fluid environment. And this particular fluid environment can also have water molecules.

So, from the biological system also how these water molecules present over there can go and interact with the metal ion. So, basically the formation of these coordination bond will lead us to some kind of study where we see that a typical coordinate bond will form between a metal centre. The metal in some positive oxidation state in M n plus and this particular water molecule, so, from here just what we see that if M n plus is there and is going to interact with the water molecule and obviously you can have two atoms on water molecule, one is the oxygen atom and the other is the hydrogen atom and the possibility for interacting with this is that we have the lone pair of electrons, we all know on the water molecules.

So, this arrow what we are showing is the corresponding interaction, how it is interacting? It is not the corresponding direction what we will show occasionally in showing all these coordinate bond where we see that this lone pair of electrons will be donated to the metal centre because the metal is in positive oxidation state. It has some vacant orbital's available that means it can accept the electron density from these water molecule particularly from the lone pair electron density from this oxygen atom.

So, in this introductory class today what we are just going to see that how these interactions are taking place that means the very simple interaction what we can all the time can ask our students that what type of interaction you can have, where you have this particular water molecules are present say in some test tube as the typical solvent. We can go from one solvent to the other that means we can go from water molecule to alcohol, we can go to alcohol to acetone, we can go to alcohol to acetonitrile.


So, if we can fully understand the corresponding interaction that what type of interaction the metal centre can a give you with that of our water molecule then only we can extend further the corresponding interactions what are possible with other type of solvent molecules which are having some amount of lone pair of electron density.

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Coordination Chemistry

Introduction

It emerged from the works of Alfred Werner (1866-1919), a Swiss chemist who examined different compounds composed of cobalt(III) chloride and ammonia.

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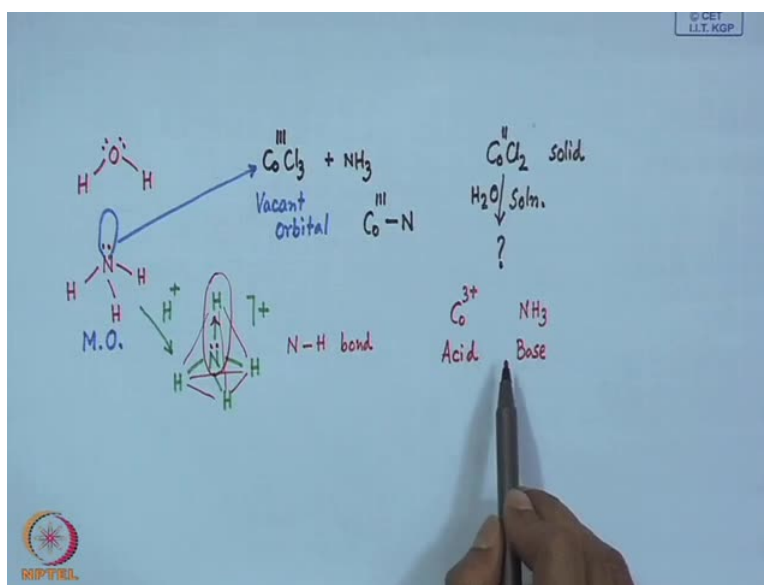
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So, this particular class of coordination chemistry in the introduction part what we can see that it is the person which is Alfred Werner is a Swiss chemist and he was there during the period of 1866 to 1919. So, whatever worked he did based on that basically so

he is the pioneer in this particular area of giving the information's related to the corresponding reaction basically the inorganic chemist the inorganic chemist and what we can see that we can interact, we can see some of the reactions what we have just now telling you that it is the interaction of any metal salt, any chloride salt like iron chloride, copper chloride or nickel chloride with that of our water.

And he first studied the corresponding interaction of cobalt 3 chloride that means cobalt in plus 3 oxidation state, the means the elemental cobalt, the metallic cobalt has lost its 3 electron to give in the trivalent state and the corresponding inorganic metallic salt is isolated as its corresponding chloride version. So, this cobaltic chloride when it reacts with ammonia that means liquor ammonia, it is not the ammonia gas, but it is the ammonia which is present in liquor that means in solution. So, how it is interacting with the ammonia molecule? In ammonia molecule we have large amount of water also available. So, whether specifically this cobalt, the trivalent cobalt which is present over there as cobalt 3 plus is interacting with ammonia.

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So, whatever we are just talking to see is that interaction of cobalt 3 chloride with ammonia. So, this has two aspects that it is not in the plus 2 oxidation states which we occasionally find that means the solid cobalt 2 chloride is a cobalt task chloride which can be solid and if it is in solution we make this in solution in water. So, in solution of water what is forming? So, if we have this one so these are the problems still at the

particular time and we do not know much about all these things that cobalt task chloride is our hand and we are adding water molecule to it and what type of interaction can take place with the cobalt task chloride with that of our water molecule.

And then we are adding a very simple molecule of ammonia. So, when we are having these water just now we have seen that we have the water molecule which has two lone pair of electrons and this is now getting changed. So, we are bringing another molecule as ammonia. So, in one particular molecule we have two lone pair of electrons and in another case we have a single lone pair of electron.

So, if this particular metal centre particularly the cobalt in plus 3 oxidation state which has some vacant orbital and if this electron density is donated to the cobalt, so, if it goes to the cobalt centre which has some vacant orbital. So, what we expect that this particular one also available in some orbital. So, electron density is there depending upon the corresponding molecular orbital, if we know all is very simple treatment for the corresponding molecular orbital treatment for the formation of ammonia molecule from the individual atoms. That means 1 nitrogen is forming the molecule by interacting with 3 hydrogen atoms.

So, after forming those molecular orbital's so this is a typical treatment for getting the corresponding molecular orbital picture of the ammonia molecule and where we find that one particular orbital will be there, which is our vacant non-bonding orbital that means it is not engaged in forming some bond with hydrogen or anybody else. So, these two orbital's will be available for forming a new bond. So, this lone pair of electrons are available for forming a new bond like a cation most simple cation is the proton. So, ammonia we all know very easily and we all know from our school days, from our childhood days that ammonia when reacting with H plus is forming the very simple, the cationic species the ammonium ion and we have the corresponding over all charge of one positive, one unit of positive charge is there which is due to the presence of the charge on the proton.

So, this tetrahedral ammonium ion formation which can also tells us that this particular lone pair of electron which has been donated for a very simple system, if we consider that this is the hydrogen because after formation of ammonium ion is not possible to distinguish the hydrogen atoms which were already present in the ammonia molecule

and which has newly reached there to attach to the nitrogen atom. So, all these four are indistinguishable. So, in this tetrahedral molecule, ammonium tetrahedral molecule, what we see that a new bond is forming.

So, this is basically our N H bond and why this new N H bond is formed? It is due to the availability of the non bonding electron pair and that non bonding electron pair has been donated to the hydrogen orbital because the proton has no electron. So, it is only a positively charged species. So, this that is why it is called also as a proton and which has a vacant orbital which can accept nicely the electron pair from the donor atom. So, the donor acceptor reaction can take place.

In other words we also consider these reaction is as the corresponding acid base reaction. So, we get a corresponding new N H bond. So, a new N H bond is formed and which is of coordinate type because both the electrons have been donated from the nitrogen lone pair and which has the accepted by the hydrogen. So, if we can extend this particular idea, is a very simple idea of reaction of cobalt chloride with ammonia that the same type of reaction can also take place when cobalt chloride is reacting with the corresponding ammonia molecule and if we see that this particular cobalt that means the trivalent cobalt is definitely then forming a new bond which is our cobalt nitrogen bond.

So, that is the question for all this sort of study in this coordination chemistry class that whether we should have some cobalt nitrogen bond like that N H bond which is forming from the reaction of the proton with that of our ammonia. So, it took several years to know, is not so easy at that particular time because the analytical chemistry, the analytical techniques and all these things were not available during this period. So, about more than 100 years back people were trying to speculate this things, is basically the history of coordination chemistry where we see that whether this particular type of cobalt nitrogen bond will be formed or not that was a basically a mere speculation.

So, what we see that if we consider like that of your interaction like nitrogen with hydrogen that means the proton so your H plus is the well known proton. So, our metal centre that means the cobalt in the trivalent state that particular thing that means the centre which is trivalent should also function as an acid centre and our ammonia therefore, is also can be considering as a base. So, basically what we are talking during the formation of this cobalt nitrogen bond is that cobaltic ion, the cobalt in trivalent state

is interacting with ammonia forming a corresponding salt type of things. So, definitely it will form a salt type of thing if one counterpart of this is a typical acid and another is a typical base. So, between an acid and base the reaction will take place and we should get a corresponding salt as the product.


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Coordination Chemistry

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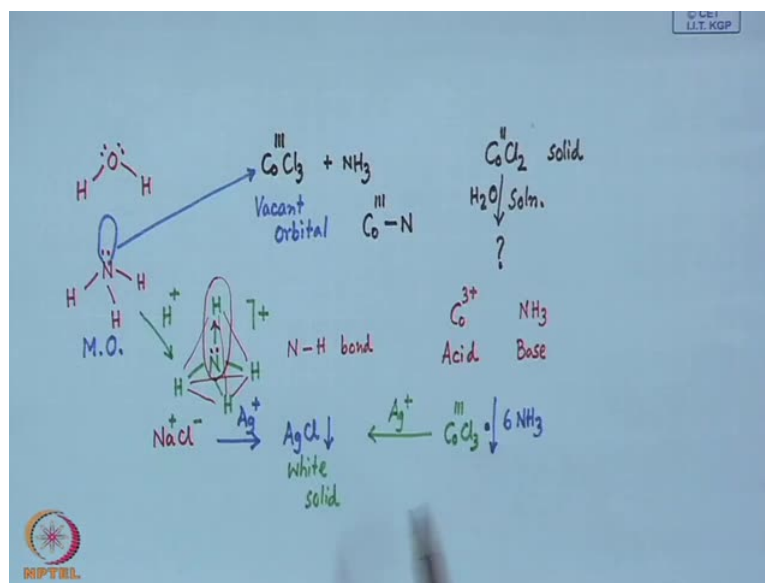
When silver nitrate was added to $\text{CoCl}_3 \cdot 6\text{NH}_3$, all three chlorides were converted to silver chloride. Whereas, when silver nitrate was added to $\text{CoCl}_3 \cdot 5\text{NH}_3$, only 2 of the 3 chlorides formed silver chloride. Also, when $\text{CoCl}_3 \cdot 4\text{NH}_3$ was treated with silver nitrate, one of the three chlorides precipitated as silver chloride.

 16/2013 1

So, this reaction this person studied with ammonia to identify this particular reaction, but when Alfred Werner got the product of these and analysis of this product because this simple reactions what we can have is that when we react this cobalt chloride with ammonia we get a particular product where the stoichiometry we can analyze because some amount of analytical technique was that time available that means it is based on the amount of nitrogen present in the molecule.

So, this was the corresponding entity, typical entity that means the cobalt chloride is already present which was their original formula and 6 equivalent of ammonia has been added to it giving a corresponding compound depending upon its different form, it has different color and they are solid in nature. So, if we just consider what just now we have discussed that if it is a typical acid base reaction and we are getting some clue for the formation of the cobalt nitrogen bond then what is happening with these chlorides presents already with the cobalt salt.

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So, we all know that a typical salt like this the any chloride salt, if this particular thing is that when we get that any salt from our school days or anywhere what we see that the chloride identification that means the chloride is as present as sodium chloride. So, this Cl minus present in sodium chloride can be identified very easily by the addition of silver nitrate and within that silver nitrate we have the Ag plus and that Ag plus will react with sodium chloride forming AgCl as its corresponding white precipitate that means the base.

So, what does it mean basically for this very simple reaction, what we have learnt from our school days is that if we have any anionic chloride so this is a typical corresponding salt. So, is ionic salt, is ionic solid also sodium chloride is a solid. So, this ionic solid where we have discrete Na plus and Cl minus is present, so, is ionic compound and it has a electrovalent bond we consider. So, we have Cl minus and this Cl minus can be reacted with the silver ion present in silver nitrate giving you the silver chloride precipitation.

So, what about the simple cobalt chloride salt? So, like sodium chloride this is also cobalt 3 chloride. So, it has also the same type of Cl minus that means the chloride ion present in the sodium chloride is same as that is present in cobalt chloride that means the cobaltic chloride. So, the same reaction with Ag plus with definitely go for the

precipitation of silver chloride as white solid in solution because that is getting precipitated out from the solution.

Now, the situation is a little bit different because we have added to this cobalt chloride salt 6 ammonia molecules and we got some composition of these which is $CoCl_3 \cdot 6H_2O$. Now, the puzzle has come that how these cobalt chloride bonds are there, whether it is similar to that of our chloride ion or if it is something forming over there? So, what we see that if we have already the cobalt chloride bond present in it that means it is not like sodium chloride, it is some amount of covalent character is there or we have the cobalt nitrogen bond. So, that can be tested.

How the same silver nitrate solution can be used? In one case we see that whatever amount of Cl^- was present in cobalt chloride salt is coming out from that particular complex, we consider it as the reaction product which is a completely different compound having no character of the original cobaltic chloride salt. So, it is definitely a new product, a new reaction product we have.

In this particular case depending upon the stoichiometry of the silver nitrate utilized for removal of all the chloride anions and the amount of silver chloride is precipitated out tells us that all the 3 chloride ions are converted to silver chloride. That means all the chloride ions are present in this particular species as Cl^- that means the anionic Cl^- they are. So, it is not directly attaching to the cobalt centre giving some covalent bond, this is giving a typical ionic bond and all the chloride ions can be removed, but we also get to other compounds where we get the stoichiometry which is typically different one where cobaltic chloride has 5 ammonia molecules and in another case we have cobaltic chloride with 4 ammonia molecules.

In the formal, in this case that means where we have 5 ammonia molecules so this number of ammonia molecules present in the molecule of this compound is important. So, when it is 6 we get 3 chloride anions as silver chloride, when it is 5 we get at one case 2 molecules of silver chloride. In another case 3 molecules of silver chloride that means we are able to remove 2 of these chlorides at Cl^- that means we have all together 3 chloride anions, we could remove 2 of them that means 1 we are unable to remove.

That is the most important and fascinating observation what Alfred Werner made that time and an another case also like that the previous case where the stoichiometry was different, but we could remove 3 of these chlorides as silver chloride. So, the third variety where we have only thing is that the stoichiometry is different here now you have 4 N H 3 groups and when we treat it with 1 of the 3 chlorides can be precipitated as silver chloride. Now, we are not getting 3 we are not getting 2, but we are able to remove only 1 of these 3 chlorides as silver chloride that means we have two types of chloride groups present in these molecules. The type which is present as the ionic one can be removed by reaction with silver ion and the type what is not present as chloride ion cannot be removed as silver chloride.

(Refer Slide Time: 28:07)

The resulting observations made by Werner suggested the formation of **complex or coordination compounds**.



So, what basically we are getting there what Alfred Werner made that particular time, he made by these observation and he was compared to suggest at the particular time that the formation of complex or coordination compounds have taken place. So, whatever thing we are getting as the reaction product of cobalt chloride with ammonia is a new species what is forming over there, which he leveled as a complex. Definitely the situation is complex one because we are unable to observe what is happening over there depending upon the number of chloride anions are getting removed from the molecule as silver chloride. So, they are complex or coordination compounds because the coordinate bond by that time, the little bit information we can have in our hand that how this coordinate bond can formed between two species x and y, between metal and the ligand what we

will just define what is ligand afterwards, between the cobalt and the ammonia, between the iron and the water, between the nickel and the water molecules.

So, some connectivity we can have between the species like metal salt as the corresponding and corresponding cation and the species like water or the ammonia. So, we have in our hand the corresponding complex or coordination compounds.

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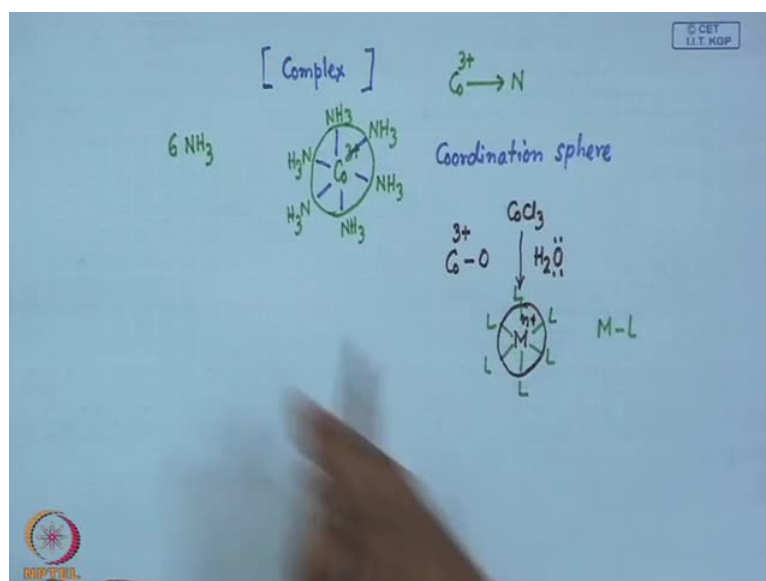
The resulting observations made by Werner suggested the formation of **complex or coordination compounds**.

In the **inner coordination sphere**, which is also referred to in some texts as **first sphere**, ligands are directly bound to the central metal.



And since we have the coordination compound we must have a coordination sphere.

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What does it mean that we have this particular coordinate bond and if we consider the cobalt is forming this coordinate bond with the nitrogen and the stoichiometry of the molecule what we see just now that we have 6 ammonia molecules and they are not loosely attached to the molecule like our solvent of crystallization rather they are tightly attached to the system that means they are providing some amount of environment around the cobalt centre. So, if we get that a particular environment is forming by using all these ammonia. So, we have 6 such so we have 6 water molecules, ammonia molecules and we have the cobalt centre.

So, this particular environment which is surrounding the cobalt ion, so, cobalt this is the trivalent cobalt. So, this cobalt is present as the trivalent cobalt. So, we get a corresponding environment and this particular environment we call it as corresponding coordination environment. We have the corresponding coordination bond and we are thinking that this is all the 6 ammonia molecules are interacting with the cobalt centre. So, all of them are forming this cobalt nitrogen bond. So, we have 6 such cobalt centers sorry this 6 such cobalt nitrogen groups are there and thus we can have 6 cobalt nitrogen bonds.

So, we have the coordination sphere and interestingly now we can compare how this coordination sphere looks like that if we just consider, just now what we are discussing that we had cobalt as the corresponding cobalt chloride salt and we dissolve it in water as a solvent. So, if like ammonia the water molecule can also behave like interacting with the cobalt centre forming the same type of cobalt oxygen bond with the trivalent cobalt. So, dissolving any such salt, any metal salt whether it is a cobalt chloride salt, a nickel chloride or a copper chloride salt we should have a similar environment which is made up of water that is very important observation at that particular time.

So, whatever metal salt we are dissolving in a test tube, in a beaker or in a round bottom flask in a chemistry laboratory class we should have a corresponding coordination sphere around the metal salt. So, metal will be there as $n+$ and will be having large number of water molecules whether this water molecules we have added for making the solution or these water molecules are coming from the living system, the living organisms in our body. So, from the living system also these water molecules will try to surround in the same fashion surrounding this particular metal centre.

And these water molecules having the lone pair of electrons on these molecules as the corresponding lone pairs on the oxygen atom will start interacting in a similar fashion with that of our metal centre. So, large number of water molecules will be surrounding this particular metal centre, but only few can directly interact to give rise to the corresponding coordinate bond and will be responsible for giving rise to the corresponding coordination sphere is due to the formation of some of these direct metal oxygen bonds.

So, the formation of these metal oxygen bonds are therefore, important for even the dissolution of any metal salt in water to get the corresponding right solution of that particular metal salt. So, when we have the coordination sphere we consider that this is the first sphere of interaction or first sphere of attraction between the metal and the water or between the metal and the ammonia molecule. So, we consider that in this first coordination sphere we have the ligands. So, this is the new term what we are introducing.

So, afterwards in next class we will discuss about of these ligands and what these ligands basically mean and right now we can consider is that which is related to something which is basically going to bind to the metal centre. If it is the water molecule which can bind to the metal centre then the water will be over ligand and if it is ammonia molecule which is going to bind to the metal centre then ammonia will be our ligand, so, which is directly bound to the central metal. So, when these water molecules are surrounding there. So, we now call them as the corresponding ligands.

So, if they are there so ligands are basically surrounding the metal centre through some interaction of M L type. So, which is the basic important point of this particular coordination chemistry that whenever we have the metal present over there we must have the corresponding metal ligand interactions. So, metal ligand interaction everywhere if we try to dissolve the corresponding metal in solution in water or if with the metal is present in some biological fluid in our body.

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The resulting observations made by Werner suggested the formation of **complex or coordination compounds**.

In the **inner coordination sphere**, which is also referred to in some texts as **first sphere**, ligands are directly bound to the central metal.

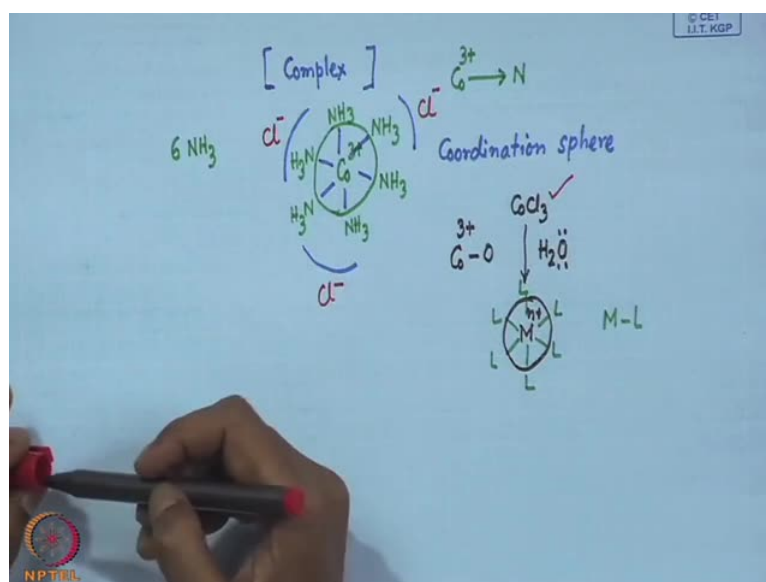
In the **outer coordination sphere (second sphere)**, other ions are attached to the complex ion. Werner was awarded the Nobel Prize in 1913 for his Coordination Theory.



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So, we have the central metal and we have the corresponding initial binding in the first coordination sphere. So, what is there in the outer coordination sphere what we now call as the second sphere? In the second sphere other ions are attached to the complex ion that means already we had this Cl^- so in the first sphere which is forming the direct coordination to the metal centre.

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So, we have therefore, another layer at this particular point and these layers will give us some information that we have already the corresponding Cl^- ions. So, Cl^- minus

will be here, C l minus will be here and this C l minus will be here. So, this is the first sphere of attraction, this is the second sphere of attraction, where we do not have any cobalt chlorine bond. Since, this cobalt chlorine bond is not there cobalt though it is interacting with the ammonia molecules, but it has no interaction with C l minus. So, C l minus is present as sodium chloride and this can be removed nicely with the reaction of silver plus silver ion to give you this corresponding silver chloride.

So, that is why for this particular formulation when all the 6 ammonia groups are attached to the cobalt centre and all the 3 chloride anions are in the second sphere of attraction we can remove all the 3 chlorides and we do not have any direct cobalt chlorine bond present in it and for this sort of thing that means the corresponding bonding pattern, spectroscopic, color and all these thing has been identified by Alfred Werner during this particular period and for that particular reason he has been awarded the Nobel Prize in chemistry in 1913.

For his contribution in coordination theory or theory related to develop for the identification of different coordination complexes or coordination compounds. So, exactly about 100 years back the subject has been developed and the Nobel Prize was given in 1913 for its recognition for understanding of this particular species in its regular form at that particular point.

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| Composition | Complex |
|------------------------------------|-----------------------------------------------------------|
| $\text{CoCl}_3 \cdot 6\text{NH}_3$ | $[\text{Co}(\text{NH}_3)_6]^{3+}(\text{Cl}^-)_3$ |
| $\text{CoCl}_3 \cdot 5\text{NH}_3$ | $[\text{Co}(\text{NH}_3)_5\text{Cl}]^{2+}(\text{Cl}^-)_2$ |
| $\text{CoCl}_3 \cdot 4\text{NH}_3$ | $[\text{Co}(\text{NH}_3)_4\text{Cl}_2]^+(\text{Cl}^-)$ |
| $\text{CoCl}_3 \cdot 3\text{NH}_3$ | $[\text{Co}(\text{NH}_3)_3\text{Cl}_3]$ |

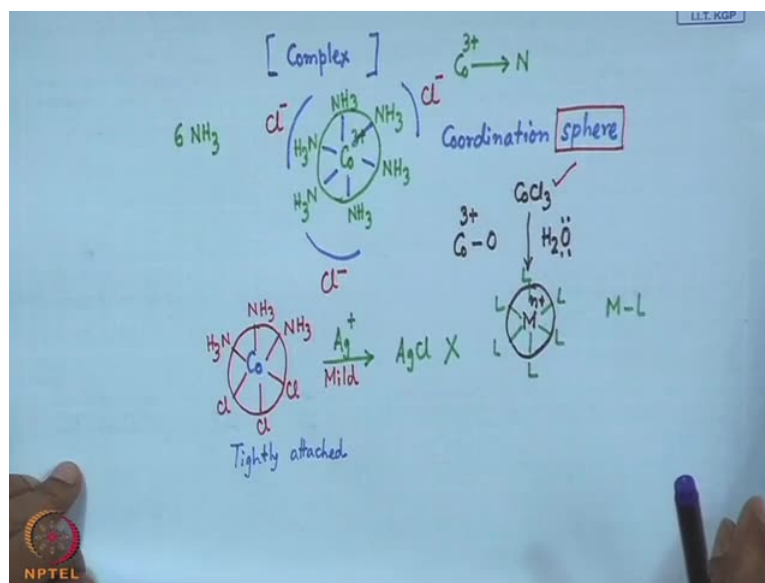
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So, what we have, now we can summarize this particular thing what was reacting in this, all this cases, that the first case what we see that this was the composition what we are trying to analyze that cobalt chloride with 6 ammonia molecules then we have two other and again we have a another one which is the fourth one. So, this can be considered as the first sphere of attraction, we have 6 ammonium groups attached to the cobalt and we have something where we write in square bracket and this square brackets tells us that within the square brackets not only we have the cobalt, but also we have the ammonia molecules and the stoichiometry of cobalt and ammonia is 1 is to 6.

That means whenever we have 1 cobalt centre we have 6 ammonia groups surrounding this particular cobalt centre and in the second sphere of attraction we have 3 chloride anions. So, from this particular analogy we just go for the second stoichiometric product for the corresponding coordination compound where we have 5 ammonia molecules. So, we have 5 ammonia molecules or the ligands. Now, we have defined them as ligand. So, cobalt is surrounded by 5 ammonia ligands and 1 C l as present as the corresponding ligand within the coordination sphere. So, this is basically a corresponding coordination sphere where we have 5 N H 3 and 1 C l and 2 of the C l is present as C l minus so the nature of these two C l groups are different.

First one is forming a direct cobalt chlorine bond which is present in the first sphere of attraction that means the first coordination sphere which cannot be removed by reacting with silver ion that means silver plus, but 2 other C l minus is present in the second sphere which can be removed by silver ion as silver chloride. So, this particular species is different from the first one in the same that it has 6 ammonia surrounding the centre, the metal centre, here one of them is not ammonia, but it is a C l that means we have the C l group directly attaching to the cobalt centre. So, for the second stoichiometry where we have 1 ammonia less further. So, in the same way we see that we have 4 N H 3 groups and 2 C l groups and we have 1 anionic chloride which can be removed by silver ion and the last example is that the 3 chloride and 3 ammonia that means we have a another species which we are writing in square bracket as 3 ammonia and 3 C l minus.

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So, which is the very interesting example for all this discussions that whenever we have this cobalt centre and now we have the corresponding coordination sphere and this coordination sphere we have this, we are not going to is a, plane of paper we are drawing, but is a 3 dimensional one because we are considering as a sphere because this is our sphere. So, we should have a spherical 3 dimensional arrangement of this.

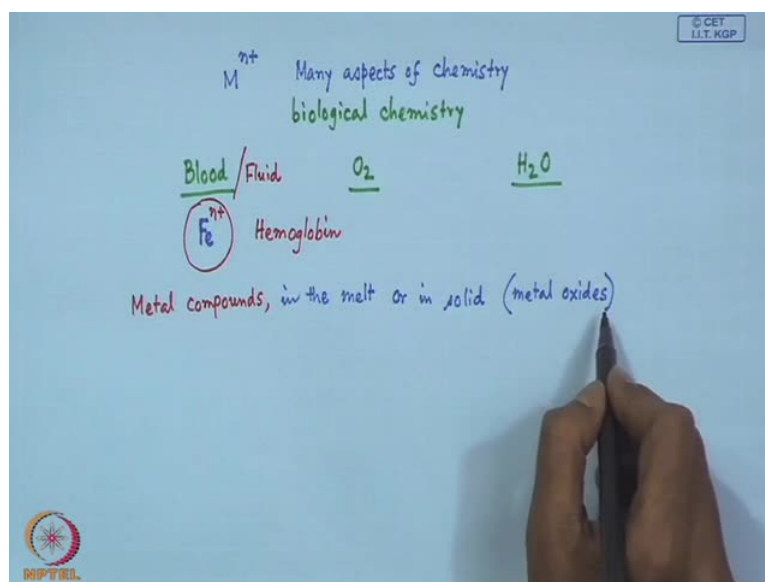
So, spherical 3 dimensional arrangement of these that means these ammonia groups as ligands, but in this particular case what we see that we have ammonia we have ammonia, but all the 3 what were present as the cobalt salt is now attaching to the cobalt centre giving a different type of species where less ammonia stoichiometry because now if these three ammonia groups are close to this cobalt centre so we have some interaction or some cobalt nitrogen bond of 3 number.

Similarly, the chlorides are directly attaching to the cobalt and the proof for that is the direct proof is that if we react with silver ion, silver chloride is not formed over there because we are unable to remove which is a very interesting observation for that, that we do not have under mild condition, the condition should be mild that will discussed as our classes progress that if the condition is mild.

That means simple room temperature reaction and mere addition. Just we are simply adding drop by drop of this silver ion as a solution of silver nitrate, we are not getting these as the corresponding precipitation of silver chloride that means these chloride ions

is now tightly attached. They are tightly attached to the cobalt centre. So, this salt of observations for these compounds gives us some information's that basically we can interpret many aspects of chemistry where we have metal is present as the corresponding metal ion.

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So, many aspects of chemistry we can consider can be explained. Aspects of chemistry can be explained as well as some interactions in biological chemistry which is very important because all we know very basic thing from our early childhood that we have blood in our system. So, which is a very important species, all of us should know about blood and all of us should know about the oxygen present because we are surviving on oxygen as well as we are surviving on water molecule. So, we will discuss afterwards though, but in this introductory class that how we see these things that means all we know the very basic thing is that that contains iron.

So, the presence of this blood in iron and this particular thing is that is also a fluid. So, blood is present as a fluid and that fluid is basically giving some environment around iron. So, forget about everything. We have iron is in some oxidation state and which has some other interactions with this that means in terms of this particular theory for the chemistry we can see that this fluid can start interacting like that of our first coordination sphere in the blood and when we go for respiration using oxygen, we also see that there is some interaction so that is the knowledge what we can have from this study that

dioxygen molecule that means the oxygen molecule in air when we breath basically it goes to blood and some molecule is present over there which can be oxygenated due to the interaction of iron with dioxygen.

What is that? This is nothing but our hemoglobin. So, by knowing this we can study the corresponding interactions of hemoglobin with the biological fluid that means the biological environment as well as interaction with dioxygen molecule and also the interaction with the water molecule. So, not only the biological system many metal compounds whether they are present in solution or in the solid state, the metal compounds present in the melt that means in some molten condition or in the solid state as the different oxides, that means the metal oxides.

So, all these can be very nicely studied in terms of the metal and their corresponding interaction with the donor atoms. And donor atoms we have the defined as the corresponding ligand system. So, they all can be identified, they all can be studied, they all can be experimentally say explained for their corresponding studies in the form of the corresponding coordination chemistry.

(Refer Slide Time: 52:04)

Formation of complexes and coordination compounds

Formation of complexes is a characteristic property of transition metals.

- The most easily observed property of transition metal complexes is color.
- The color is dependent on the identity of the central atom, its oxidation state and the type of ligand.

Coordination compounds.
Those that include one or more complexes.

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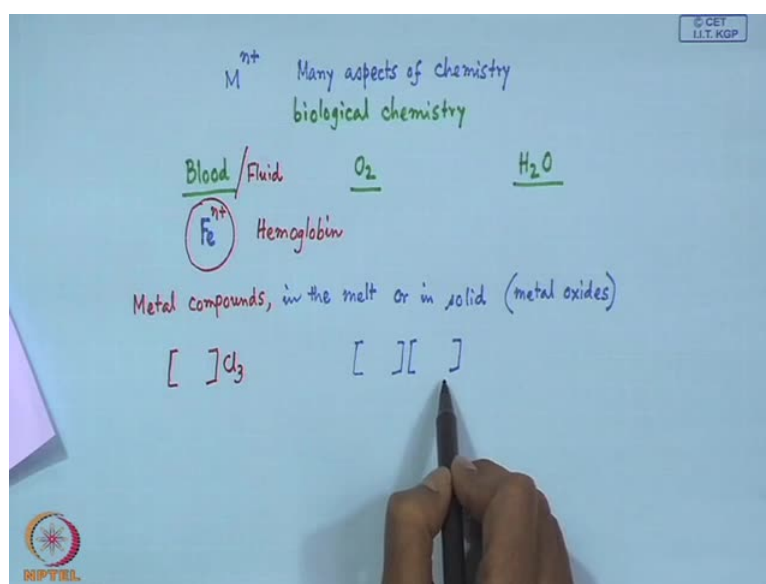
So, once we have all these examples for this and we have seen that we can have the formation of complexes and coordination compounds. So, we have the transition metals, the transition metal ions are present and during the interaction with these ligands the formation of complexes is therefore, is a characteristic property of the transition metals.

That means all the transition metals now we are isolating these metals from the periodic table because this cobalt and other examples that we are giving for this particular class they are the typical transition metals.

So, we will see in our next class that what are the transition metals, how we define the transition elements, but for today we should see that these transition metals I have the first and for most characteristic is that they will form complexes. So, if we have any transition metal from the periodic table. So, immediately we can see in terms of their property, in terms of their behavior, in terms of their reactions that they have the immediate property for reactions, the chemical reactions is that they will form complex.

So, most easily observed is that particular property and all these properties are also seen when you find that metal complexes are all in colored. So, metal salts are also colored. So, why they are colored that will see and how we can identify a particular metal complex formation in a particular environment. That means one typical metal salt can be colored in water and we when we add ammonia the color whether can change or not that also can give some information about the formation of new type of complex and this color is dependent on the nature of the central atom and the oxidation state and the type of the ligand. So, when one metal centre is interacting with the ligand we get the corresponding complex species and if we have more than one such species present in a single compound we call them as coordination compound.

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That means whatever we write in the form of a square bracket like cobalt salt and it has a corresponding anion is balanced. So, this we will call as a corresponding complex, but in some cases it can so happen that it can have two parts and both the cationic part and the anionic part both of them are the complex part. Here the cationic part, this is the cationic part. Cationic part is giving us the corresponding complex species, but the anionic part is simple inorganic anion coming from the corresponding chloride ion.

But when the cationic part is a complex species and the anionic part is also a complex species we call them as getting a corresponding coordination compound where both the two parts are made up from the complex species. And we will have the corresponding examples for that also and we will see that in our next class as well.

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The compounds have a coordination number of 6, which is a common coordination number for many complexes.

Coordination numbers for complex compounds usually range from 1 to 16.

Monodentate ligands

Some aqua complexes

$\text{Ag}(\text{H}_2\text{O})_2^+$
 $\text{Cu}(\text{H}_2\text{O})_4^{2+}$
 $\text{Fe}(\text{H}_2\text{O})_6^{3+}$

The charge and coordination number are NOT related.

$\text{Fe}(\text{H}_2\text{O})_6^{2+}$ also exists.

NPTEL 16/2013 24 - 27 5

So, in this particular case what we see that the compound for these where we have the 6 ammonia molecule surrounding the cobalt centre we consider these as a typical thing that we consider this as the formation of such number of corresponding coordination bonds and since 6 such new coordination bond that means new cobalt nitrogen bonds are formed, we consider these numbers as the corresponding coordination number.

So, most of the complexes because this number has some unique property that we will see in our next class that why 6 is so common for a spherical arrangement of ligands surrounding the metal centre. So, this is very common for many metal complexes and coordination numbers for complex compounds usually it can range from 1 to 16. So, one

after another we can consider that we how we can go from the most common coordination number of 6 and little bit of beyond that because for getting the 16, 12 and 14 coordination number we need some bigger metal centre where large number of metal ions can be surrounded, the corresponding metal centre.

So, first thing that what we are discussing that will continue in our next class also that we will having some monodentate ligand that means one point of attachment to the metal centre, giving these species basically and there is no charge. So, this charge on the species and the coordination number these two are not related to each other and we can have this particular species where ferrous ion can bind 6 water molecules that means the coordination number is 6, in this case coordination number also 6, but this case it is 2 and the other case is also 6. So, we have introduced something like that the denticity of the ligand, what is ligand and the metal centre that we will elaborate more in our next class.

Thank you very much.