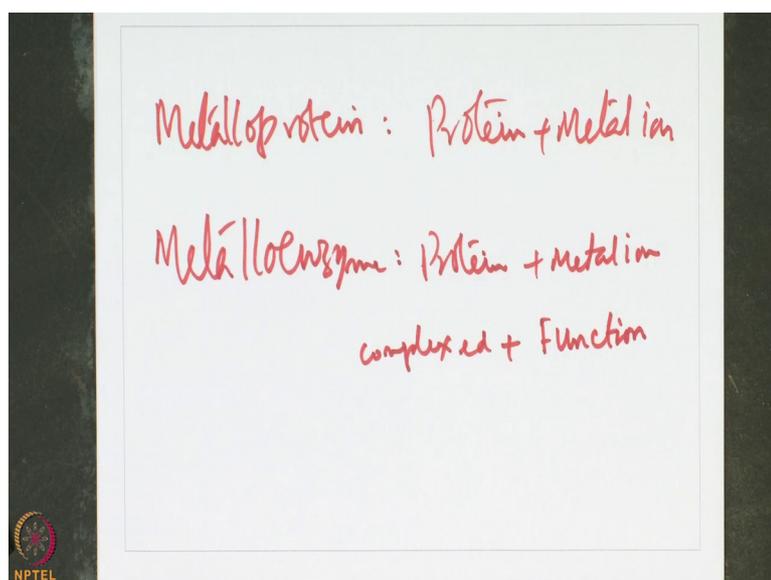


Inorganic Chemistry of Life Principles & Properties
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Lecture - 09
Coordination chemistry aspects - An introduction

Good Morning, welcome you all to this next lecture on the Inorganic Chemistry of Life Principles and Perspectives. In the previous classes, we have learnt quite a few things; particularly the main theme of all what we have learnt is that the Metalloprotein; the metal ion is present like a metal ion complex and the protein surrounds this and then provides a property that is required to the exhibit.

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This may be probably can be seen to recapitulate what I said earlier; a Metalloprotein is a protein plus metal ion and a Metalloenzyme a protein plus metal ion complexed plus function. So, this is what I wanted you to keep in mind is that the Metalloenzyme, the metal centre acts like a coordination complex, but not like the one which is present in the test tube or usual a request medium, but the properties have been very well modified by the presence of the protein, because is the protein conformation, because the protein hydrophobic hydrophilic various aspects of this.

Then we have also looked at certain biological aspects related to this biomolecules; particularly the proteins and the nucleic acid, then we also have looked at a few

biochemical process like the protein synthesis, Metalloprotein synthesis, etcetera. So, in this particular class let us look at some coordination characteristics of this.

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Coordination Complexes

- Coordination complexes consists of central metal atom or ion surrounded by ligands
- Charge on the metal centre is referred to as its oxidation state
- Number of ligands bonded to the metal centre is called as coordination number

Central metal ion: Co³⁺

Ligand: NH₃

Coordination Number: 6

Coordination Number: 6

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The reason is that you are going to look at the metalloenzyme; a part of the metalloenzyme which is in the vicinity of the metal center as the coordination complex. Therefore, it becomes essential for us to look at a few details. I am sure most of you even those who are studied the chemistry 12th level must have studied certain coordination chemistry aspects, but nevertheless this particular discussion now will give you recapitulation what a coordination complex, what are the things that we need to remember in order to understand the metalloenzymes in Metalloproteins. So, let us focus at the slide shown over here as coordination complexes.

So obviously in any coordination complex you have a metal ion and the metal ion is surrounded by the ligands, that is what is basically is referred as a coordination complex. Then the metal ion has certain charge, certain oxidation state, and ligands may have charge may not have a charge either. So therefore, that overall charge is defined by or determined by the oxidation state as well as the charges present on the individual ligands. So, it is a summation of all this which I am sure your all aware of it.

In this particular example we have a central ion is a cobalt, there are 6 ammonia, and you know ammonia is a neutral ligand, therefore it is charge is 0 that cobalt is an cobalt 3 plus the total charge is 3 plus as the cobalt oxidation state. So, this is the coordination

number, this is the ligand, this is the metal center. And you take another example somewhere here shown over there cobalt with 4 ammonias and 2 chlorides and 1 chloride outside this bracket. I will explain you this as for as the you know kind of a coordination complex definition of the Varner, you have those ligands which are directly bounded is called secondary valance is not secondary coordination sphere secondary valance and those which are outside this called primary valance ok.

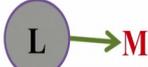
So, this will compensate the charge plus 1 will be minus 1 and this basically tells you the 4 neutral ligands to anionic ligands and there is a positive charge, therefore cobalt is 3 plus. So, cobalt oxidation state is again 3 plus and the total coordination number is 6 and it has a one plus charge and then compensated by chloride ion oxide. So, in this what we have seen the ligand binds to the meal center; so L to M. This is ligand binds to the metal center ligand can be neutral as a said ligand can be anionic ok.

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Nature and types of ligands

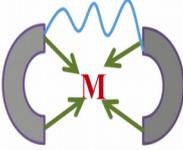
- Ligands are usually negatively charged or neutral molecules
- Depending upon the number of ligating centre, ligands can be monodentate, bidentate, tridentate and polydentate



Monodentate ligand



Bidentate ligand



Polydentate ligand

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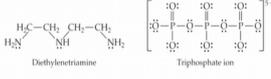
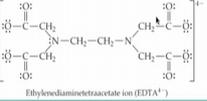
This is a hardly any cationic kind of a thing, but there are some extended kind of a cationic we note be at the center where it binds, but so where else. But such special cases let us not worry in this particular case, in this particular course is a mean ok. So, you can have ligand bound to the metal by one connectivity, single connectivity is called Monodentate a ligand just like this may be connected to the metallo center by a 2. So, therefore, it is called Bidentate or it could be connected by more than 2 tri, tetra, penta and or can even polydentate ok. So, ligand can be monodentate, bidentate, trydentate,

tetradentate, variety of things; ligand could be neutral or anionic kind of things and some examples when you have some free time you can see it and look into these ones.

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Examples of ligands

Ligand Type	Examples
Monodentate	H_2O : Water NH_3 : Ammonia F^- : Fluoride ion Cl^- : Chloride ion $[\text{C}\equiv\text{N}]^-$: Cyanide ion $[\text{S}\equiv\text{C}=\text{N}]^-$: Thiocyanate ion $[\text{O}=\text{N}=\text{O}]^-$: Nitrate ion $[\text{O}=\text{N}=\text{O}]^-$: Nitrite ion
Bidentate	 Ethylenediamine (en) Bipyridine (bipy) Ortho-phenanthroline (o-phen) Oxalate ion Carbonate ion
Polydentate	 Diethylenetriamine Triphosphate ion
	 Ethylenediaminetetraacetate ion (EDTA^{4-})

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These are all monodentate; that means, they bind to the metal center through only one connectivity, single connectivity. And these are the some examples for bidentate. You see, the nitrogen here of the amine nitrogen here of amine both of these can bind. So therefore, when both of them binds it is called the bidentate. Even if though there are 2 centers and only one binds, then it is still amino dentate; it is not; cannot be end by the indent ok. For example, bipyridil; this is 2 nitrogens; if both of them bind to the others they simultaneously it is a bidentate, then you have a phenanthroline kind of thing and you have other kinds of ligands too.

You have more dentates here, what I mean another 3 it will be tridentates. So, you can have a oxo oxo ions, so therefore, this can be. And here you have a carboxylic moieties 4 such carboxyltae moieties and 1 nitrogen another nitrogen, it is a very famous ligand famous chelator which is called EDTA. So, EDTA is a famous chelator because it is non selective and it can bind to many metal ions and chelated. So, the highest coordination number for a EDTA is 6: 1 here, 2, 3, 4, then 5 and 6. Sometimes, some other carboxyl it can act either as a monodentate or even as a bidentate or it can act as a bridging bidentate too ok.

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Geometries		
Coordination Number	Complex Geometry	Example
2	Linear	$[\text{Ag}(\text{CN})_2]^-$, $[\text{Ag}(\text{NH}_3)_2]^+$
3	Triangular planar	$[\text{HgI}_3]^-$
4	Tetrahedral Square planar	$[\text{Zn}(\text{NH}_3)_4]^{2+}$, $[\text{Ni}(\text{CO})_4]$ $[\text{PtCl}_4]^{2-}$, $[\text{Cu}(\text{NH}_3)_4]^{2+}$
5	Trigonal bipyramidal Square pyramidal	$[\text{Fe}(\text{CO})_5]$ $[\text{VO}(\text{acac})_2]$
6	Octahedral Trigonal prismatic	$[\text{Mo}(\text{CO})_6]$ $[\text{Mo}(\text{SCHCHS})_3]$
7	Pentagonal bipyramidal Trigonal prismatic Capped octahedral	$[\text{IF}_7]$ $[\text{TaF}_7]^{2-}$ $[\text{Ho}(\text{PhCOCHCOPh})_3(\text{H}_2\text{O})]$

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So, these are the somethings which you need to learn. So, having such kind of a connectivity to the metal center, this will lead to different kind of a geometries. And let us look at this particular table with a little you know focus. There are 2 coordination number 3 coordination number 4, 5, 6, 7. The coordination numbers beyond 7 are they not possible; they are impossible, they are mostly possible for lanthanides and actinides.

And he has you know none of the essential element is a lanthanide and actinide, but we have some elements in 4 d and 5 d like molybdenum and tungsten. Therefore, we need to consider up to 7 coordination but not beyond. Therefore for this course, I have restricted the table only up to the 7 coordination. This does not mean the coordination complexes exhibit only 7 coordination maximum that is not, correct. Let us now look at one by one. The complex geometry with a 2 is linear, you can also have bend like an water H OH kind of thing, we are looking at the inorganic examples Ag CN 2 minus etcetera, Ag ammonia twice plus this kind of things would give, then triangular planar H g I 3 minus, then you have a tetrahedral, then 4 coordinated, and another geometry of the 4 coordinated most commonly shown by the transition metals is square planar.

So, some of the transition metals preferred to be square planar, particularly those of the 8 kind of a systems would tend to give more of the square planar. This does not mean other de configurations do not show that it is not the correct deduction; the 8s most often tend to show the square planar. The reasons are not explained here with that forms a worked

hard core inorganic chemistry explanations; coordination chemistry explanations in that. So, tetrahedral and square planar when it comes to the 5 coordinated, you have a trigonal bipyramidal you have a square pyramidal ok. So, there are 5 coordinate and both for the square pyramidal and trigonal bipyramidal.

When it comes to the 6 coordinate you can have the octahedral; you can have a trigonal prismatic; octahedral is nothing, but trigonal anti prismatic. So, anti prismatic and the prismatic, there are 2 kinds of things or there ok. So, the corresponding examples of given more here and for 7 coordination, then you have a pentagonal bipyramid; what does it mean? Fine, in 1 plane, the 2 1 above 1 below; so, 5 plus 2; they are 7. So, pentagonal bipyramid ok; trigonal prismatic and the example is the T a F 7 2 minus and the capped octahedral. So, the capped octahedral is an example where the primary coordination type is the like an octahedral one of the face of the octahedral is kept by a particular ligand ok.

So, these are different kinds of geometries and primarily, I took the examples of the transition metals primarily ok. So, that they are of most important to us in our the bio inorganic chemistry or biological inorganic chemistry aspect whatever I said earlier in the previous slide can be seen bit more with more clarity here.

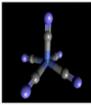
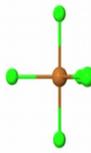
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Inorganic Chemistry of Life			
Geometries (Coordination Number -2,3,4)			
Number	Geometry	Polyhedron	Examples
Linear (2)			$[\text{Ag}(\text{NH}_3)_2]^+$
Trigonal plane (3)			$[\text{HgI}_3]^-$
Square planar (4)			$[\text{Ni}(\text{CN})_4]^{2-}$
Tetrahedral (4)			$[\text{Zn}(\text{NH}_3)_4]^{2+}$, $[\text{FeCl}_4]^-$

The 2 coordination; then you can see that kind of a thing is one ligand another ligand in the metal center trigonal with the metal with a 3 ligands and the square planar with the

ligand, with the 4 with the metal ion with the 4 ligands and tetrahedral metal ion with the 4 ligands, but they are arranged in nor in a planar in a non planar and which is very close to the tetrahedral kind of a structure.

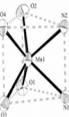
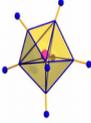
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Inorganic Chemistry of Life			
Geometries (Coordination Number- 5)			
Number	Geometry	Polyhedron	Examples
Square pyramid (5)			$[\text{Ni}(\text{CN})_5]^{3-}$
Trigonal bipyramid (5)			$[\text{Cu}(\text{Cl})_5]^{3-}$

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Then you have a 5 coordinated this is the this 4 are square and the one is like a pyramid it is called. So, it is called the square pyramid then you can see the example of a trigonal bipyramid; yes this is trigonal and this is the bipyramid. So, 3 in the row and 2; one above and one below so, therefore, you have a.

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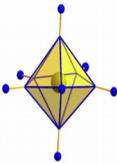
Inorganic Chemistry of Life			
Geometries (Coordination number- 6,7)			
Number	Geometry	Polyhedron	Examples
Octahedral (6)			$[\text{Mo}(\text{CO})_6]$
Trigonal prism (6)			$[\text{Mo}(\text{SCHCHS})_3]$
Singly capped octahedron (7)			$[\text{Mo}(\text{CN})_7]^{2-}$

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So, you have by looking at the previous one and this let us continue with the 6 and 7 as well 6 coordinated, as I said, we have octahedral geometry. So, the kind of a polyhedron structure is also shown we have and yeah trigonal prism is also shown this example is shown over here and this will come as a anti prism. So, a regular octahedral will be a trigonal anti prism and this is an trigonal prism, both are 6 coordinated. So, one is Mo CO 6 other is Mo SCH 2 SCHS.

This is a dithiolate stress. So, therefore, 6 coordinations totally, then you have a 7 coordinated system this is singly capped octahedron. So, you basically have an octahedron and to this octahedron one extra is added to a face.

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Inorganic Chemistry of Life			
Geometries			
Number	Geometry	Polyhedron	Examples
Pentagonal bipyramidal (7)			$[\text{Re}(\text{CN})_7]^{2-}$

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So, Mo CN 7 and continuation of this is pentagonal. So, 1, 2, 3, 4, 5; these 5 ligands are in one plane and you have one above and one below and that is the pentagonal bipyramid. So, the polyhedron will look like this premium CN 7. So, what did I talk to you now? Different geometries up to coordination number 7; coordination number 2 coordination number 1 has no meaning, coordination number 2, coordination number 3, 4, 5, 6 and 7; for 1 and 2 and 3, there are most of the often there found as a linear and the trigonal planar, when it comes to the 4 you have a tetrahedral and square planar and when it comes to the 5 you have a trigonal bipyramid as well as square pyramid, when you come to the 6, you have a octahedron you have a prismatic or trigonal prismatic

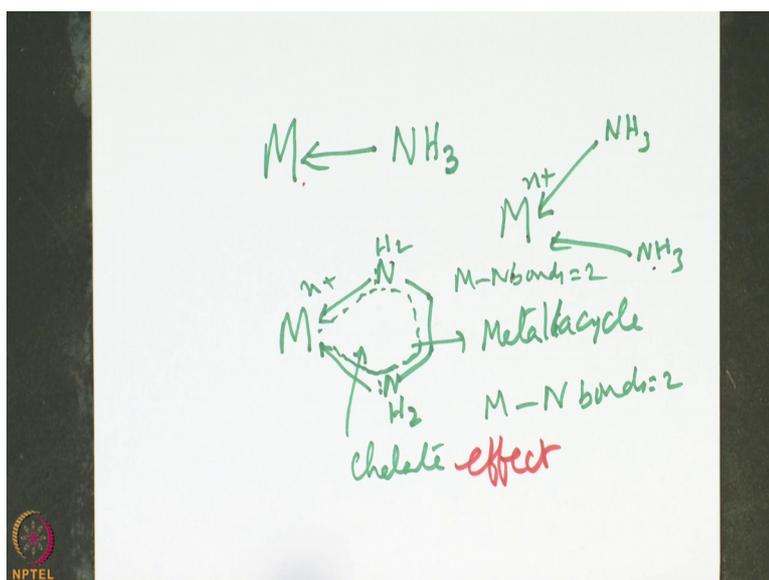
when you come to the 7, you have a pentagonal bipyramid and you also have cap kind of a octahedron all these kinds of a things are there.

So, that means, when a metal ions is present in these metalloproteins, it would be stabilized to into any of these geometries. So, the geometry is dictated both by the metal ion, its oxidation state as well as the protein surrounding both of these. So, please keep in mind that the geometries have an influence both from the ligand in case of the biological inorganic chemistry it is a protein and the metal ion means it is oxidation state both of these are very important.

So, whenever we explain in future we refer back to these basics and at the time these basics will be of great use to you. So, that is why a teaching you this basic concepts though you are aware in your 12th and you know BSC, etcetera, still I am trying to bring a kind of recapitulation as for as the coordination chemistry is concerned, since, we assume or we consider that the a metalloenzyme the metal portion is like a coordination complex. Now, let us get into another aspect of it we talked about a ligand can act as monodentate.

We also talked about a ligand can acts as a bidentate or multidentate. Now when the when the ligand can act as a bidentate and both the centers are bound together what it forms it forms a kind of a chelate, let me let me show you what I mean by that.

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So, when you have a metal ion and you have a let us say mono dentate ligand. So, you have only this, now let us we take a metal ion with 2 binding centers and let us say, you have the nitrogen here binding. So, you form a n h cycle. So, this is also called metallacycle and these also referred as the chelate, this organometallic chemists will call this is a metallacycle and coordination chemist called is a chelate and when you have. So, now, if I take another case where I have 2 ammonias and I have ethylene diamine.

So, do you expect any change in it is in its stability? See the metal ion same metal ion let us say same n plus is bonded to 2 ammonias here and 2 amine moieties over here. So, the number of bonds from the metal to the nitrogen bonds M N bonds here are 2. So, here also MN bonds are 2. So, do you expect any difference in the enthalpy of these 2 systems? So, I am sure when I ask this in the regular class some people said no, we do not expect much different some people said, yes, that this will make a difference in this. Let me tell you when you look at directly and compare there are 2 bonds of the ammonia 2 bonds with the amine it should not expect much as far as the bonds trying is concerned, but that is not true because it is forming a kind of a closed cycle so, which is a chelate and this gives a bit more stability then this molecule.

If I have a metal this 2 ammonia versus, I have a same metal ion with one ethylene diamine both the nitrogens amines are binding; I would have greater stability in found in case of the ethylene diamine complex. How? I will explain just in a while. So, let us in the meanwhile look at this you have copper with a tetra amine complex.

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Chelate effect

- By comparing the coordination of chelating ligand vs comparable monodentate ligand with central metal atom/ion.

$$\text{Cu}^{2+} + 4\text{NH}_3 \rightleftharpoons [\text{Cu}(\text{NH}_3)_4]^{2+}$$
$$\text{Cu}^{2+} + 2\text{en} \rightleftharpoons [\text{Cu}(\text{en})_2]^{2+}$$
$$[\text{Cu}(\text{NH}_3)_4]^{2+} + 2\text{en} \rightleftharpoons [\text{Cu}(\text{en})_2]^{2+} + 4\text{NH}_3$$
$$\Delta G^\circ = -RT\ln(\beta) = \Delta H^\circ - T\Delta S^\circ$$

Ligand	ΔG° KJ/mol	ΔH° KJ/mol	ΔS° J/mol	$\log\beta$
4NH ₃	-42.51	-53.14	-35.50	7.44
2 en	-60.67	-56.48	+13.75	10.62

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So, 4 ligands over there, you can see and instead you can have a copper with 2 ethylene diamines, it also beginning that. Now if I take a copper ammonia complex and in react with 2 equivalents ethylene diamine; what I would get copper ethylene diamine this that is 2 and 2 plus 4 ammonia.

Now, let us look at bit more carefully. Here what do you have? On this side the left side of this you have one ion and you have 2 ethylene diamine molecules; total particles are 1 plus 2; 3 particles here and on this side, you have 1 and then plus 4; 5 particles. So, 3 particles have turn to be 5 particles. What has happened?

So, it is like a class having 20 people versus a class having a 40 students. So, it is a teachers control on a 40 students would be; obviously, much less than the his own control on a 20 students. So, therefore, more number of ions, more number of the disturbance. So, it is basically called entropy. So, therefore, this particular reaction is guided by the entropy positive; what happens? In the product side more entropy and the reactor side less entropy.

So, entropy is changed, but enthalpy is not changed. So, because there are 2 bonds of the M-N here as well as M-N here, therefore, you do not have any difference in the or no significant difference in the delta H, but significant difference in the delta G because of the difference in the delta S. So, therefore you going from 3 particles to a 5 particles. If you look at the particle kind of a statistical thermodynamics then you will understand if

you study some physical chemistry there. But anyhow, right now, you take it is granted that there are 5 particles generated out of the 3 particles which means 2 particles are extra; that means, they are in random motion. So, therefore, they will contribute to the entropy positive.

Now, the same thing you can look at here you see that ΔH value for the 4 ammonias minus 53 for the 2 ethylene diamines minus 56; not much difference here, but whereas, if you look at the ΔG is minus 42.5 and minus 60 point, let us say 5. So, 20 almost 18 kilo calories difference there is about 18 kilo calories difference in the ΔG between a copper tetra amine complex versus a copper this ethylene diamine complex.

But both these have got 4 copper nitrogen bonds, there should not be any difference if it is only thermal, if it is only the enthalpy which is playing a role there should not be difference; that means, some other factor other than enthalpies the other than enthalpy is playing a role and that is called the entropy.

Now, you look at the entropy term. So, entropy term is minus 35 joules per mole and plus 13, it is going all the way from minus to plus. So, plus means more disturbance more entropy minus means less disturbance and less entropy greater thing. So, therefore, the chelate effect is not really from a thermodynamically not really from the enthalpy driven 1, it is an entropy driven 1. So, it is an entropy driven 1. So, though we do not expect when we look at the 2 ammonia bonded to the same metal ion versus the an ethylene diamine molecule bonded to the same metal ion; though, we do not expect much enthalpy is change there is a huge entropy change, therefore, is more favourable and such say favourable effect is called chelate effect.

So, on that is what is the chelate effect basically means so; that means, when a ligand is bound through 2 of its 3 of its 4 of it is like getting centers you can expect such a kind of a thing to happen ok.

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Spectrochemical Series

$I^- < Br^- < S^{2-} < SCN^- < Cl^- < N_3^-; F^- < \text{urea} < OH^- < \text{oxo}, O^{2-} < H_2O < NCS^- < py, NH_3 < en < bpy, phen < NO_2^- < CH_3^-$
 $, C_6H_5^- < CN^- < CO.$

Weaker Field

Stronger Field

Less 10Dq value

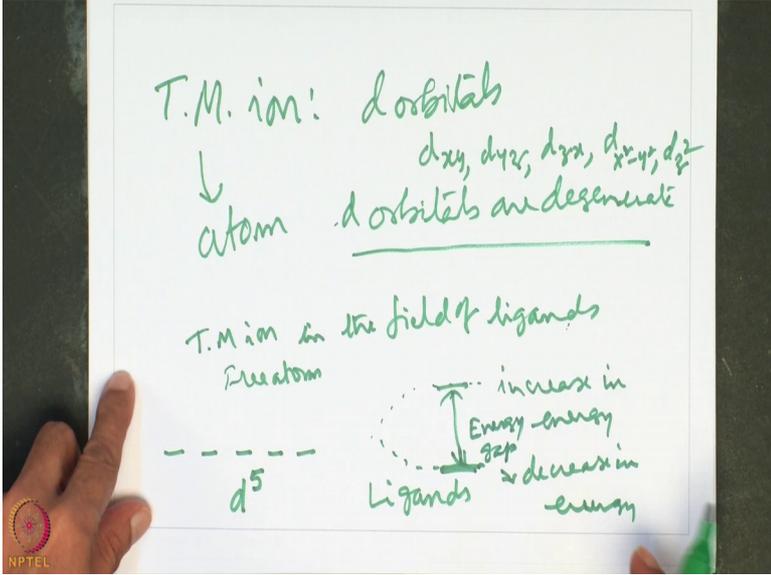
More 10Dq value



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One another very important aspect that I need you to see in these ones is the is as follows ok, we have looked at the different geometries in this, you know the different geometries will split the energy levels of the transition metal ion to differently. So, any transition metal ion ok.

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T.M. ion: d orbitals
 $d_{xy}, d_{yz}, d_{zx}, d_{x^2-y^2}, d_{z^2}$
↓
atom: d orbitals are degenerate

T.M. ion in the field of ligands
Free atom

 d^5

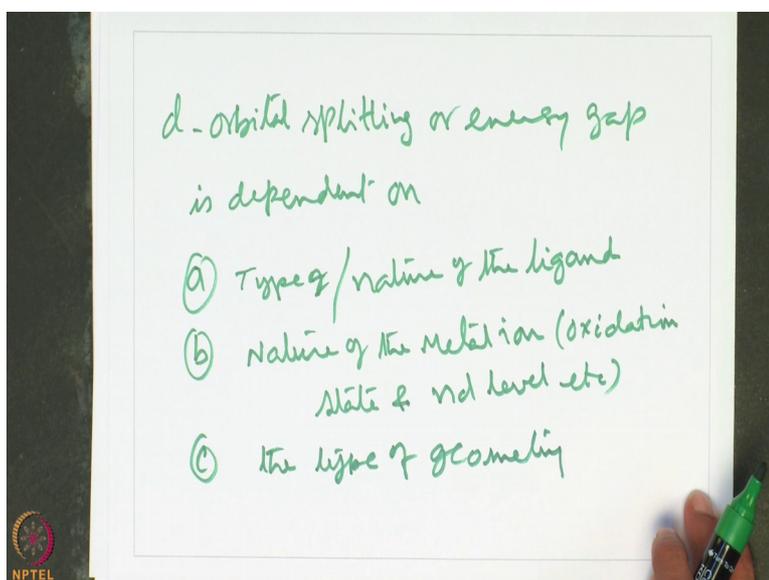
↑ increase in Energy-energy
↓ decrease in energy
Ligands

The transition metal ion has d orbitals. So, we need to consider mainly the d orbitals primarily. So the d orbitals when you put in the in a in a field versus in an in an atom. So, in an atom the d orbitals or degenerate or degenerate ok, but when you put this d orbital d

d d transition metal ion in the field of ligands, then the field of ligands will influence on the transition metal ion and that will split the d orbital energy levels which are having equal energy, there are 5 d orbitals are there and these 5 d orbitals are degenerate and these are called d_{xy} d_{yz} d_{zx} $d_{x^2-y^2}$ d_{z^2} .

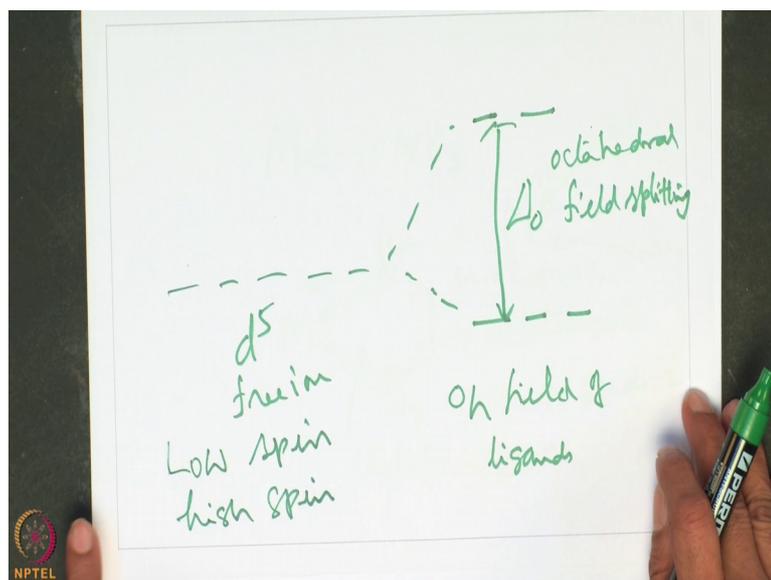
Now, this you can see from a any text book and you will understand that all of these in a free atom and they are having the same energy, but if I put some ligands. So, some of them will go up and some of them will go down some in decrease in energy and increase in energy. So, this is the energy gap. So, this energy gap is dependent on this energy gap is dependent on various factors.

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So, the d orbital splitting or energy gap is dependent on or a; the type of ligand or type or nature of the ligand and b; nature of the metal ion in terms of oxidation state and n d level, etcetera and c; depends on the nature of the geometry the type of geometry the type of geometry. So, the main his things are there.

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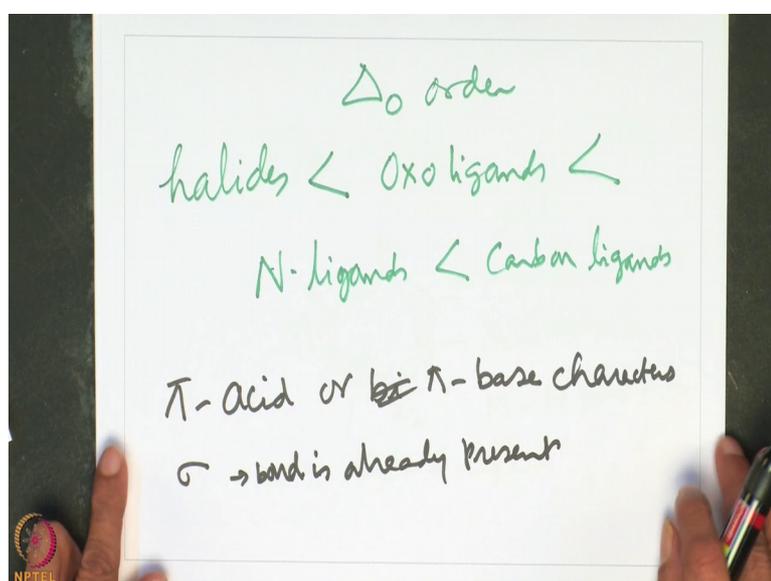
So, therefore, the d orbital splitting is dependent on from let us say one if you put in octahedral field ok.

So, this will split into ok. So, d^5 a free ion d^5 and octahedral field of ligands and this is referred as octahedral splitting octahedral field splitting octahedral field splitting ok. So, this octahedral field splitting; obviously, is dependent on is dependent on the type and nature the ligand nature the metal ion oxidation state and which n level n is equal to 3 n is equal to 4 n is equal to 5, etcetera n is equal to 3 d n is equal to 4 d n is equal to 5 d or the type of the geometry and all of these aspects are involved.

So, therefore, so, how does it matter? This matters because the electrons either may pair up into the lower energy level or may occupy these 2 and as a result of that; you get a situation of either a low spin kind of a situation or a high spin kind of a situation. Both of these important in the biological inorganic chemistry because the metal ions will have either a low spin or a high spin configuration depending upon what kind of ligands are bound there, what kind of a field being created by the protein what kind of a charge that we have on the metal ion what is the oxidation state; all these kinds of things are very important and that will reflect on the magnetic properties of this now. So, in an octahedral case; let us look at and try to compare these things, let us look for a while the kind of a ligands will effect effecting this field is given over there.

So, this is referred as a spectro chemical series. So, the way that these Δ_o splitting occurs is dependent on the as I said nature the one of the thing is nature the ligands. Now you see this is i minus b r minus CL minus f minus; that means, in the initial thing you have almost halides in the next one you have hydroxo oxo, water, etcetera, oxo ligands, then you have a period in ammonia ethylene diamine bipyramid, these are all nitrogen kind of ligands phenanthroline, then you have N_2 , C_2H_4 , C_6H_6 , etcetera which has a carbon base ligands sign c n minus c o. So, this Δ_o splitting is very least for the all the for the halides and the most for the cyanide and carbonyl ligands. So, this is very much influential on this ones.

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So, the halides; so, Δ_o order, the Δ_o order is the halides will split less than the oxo ligands than the nitrogen ligands and than the carbon ligands. So, how do we explain this can we have explain this based on the electronegativity principle.

So, several other students in the class, I have agreed on this in when I ask question in the class and several I have very few have disagreed with this so. In fact, it is those few will disagree with this organ, right. So, you can explain this using the electronegativity only to a partial extent not to your complete extent, but you have to invoke something called the π acid or π , sorry, base characters of this note the sigma bond is already there bond is already present.

So, what we are looking at is only the pi characteristic. So, I will be explaining in the next class, what is how an acid, how a base, we are looking at the Lewis acid and Lewis base. Lewis acid is the one which has got a low lying orbital which is ready to accept low electron pair and the Lewis base is the one where you have a pair of electrons and the pair electrons we can be easily denotable. So, this can be explained based on the pi bond or pi acidic kind of a character or pi basic kind of character. So, therefore, pi bonding characteristics are important as compared to the sigma bonding rather than just using the electronegativity; think. So, you can see that very clearly that you have a weaker field on this side and stronger field on this end ok. So, you will have with these with these ligands like halide will have a less Δ_o value.

And with these ligands carbon base ligands; we will have greater Δ_o value in this going to 2. So, I think in this particular lecture what I have talked to you is about the basic characteristics of the coordination complexes what how one define a coordination complex; what is a ligand? What is the charge? What is the oxidation state or kind of ligands favor? The kind of a binding geometry is that we have and then we have looked at the crystal field splitting which I talk to you just now for case of the octahedral and the octahedral Δ_o splitting, it depended upon the nature of the ligands.

It also depends upon the nature of the metal ion oxidation state at the metal ion and whether it is in the 3 d series, 4 d series, 5 d series, all of these will influence, if we go from 3 d to 4 d to 5 d keeping the ligand same, we have a large split of the energy is also there, if you go from 2 plus to 3 plus to 4 plus, again, the Δ_o will increase and going from halides to the oxo ligands to nitrogen ligands carbon ligands also the Δ_o increases.

So, all of these are important in understanding the magnetic characteristics and electronic characteristics of the metal ion present in a metalloenzymes, they can form low spin or high spin they can become diamagnetic or paramagnetic.

Thank you very much.