Advanced Transition Metal Chemistry – Periodic Table
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Lecture – 5
Introduction to Transition Elements

Welcome to MSB lecture series on advanced transition metal chemistry. In my previous lecture, I had initiated discussion on physical and chemical properties of transition elements. Let me continue from where I had stopped. If you consider metals such as titanium, zirconium, iron, nickel, copper, silver, gold and platinum, they are used in ~~in~~ many ways in everyday life.

However, molecular complexes, organometallic compounds, transition metal chalcogenides, I mean solid state compounds and halides are extensively used in inorganic and bio-inorganic areas of research besides their utility in homogeneous as well as heterogeneous catalysis for a variety of organic transformations.

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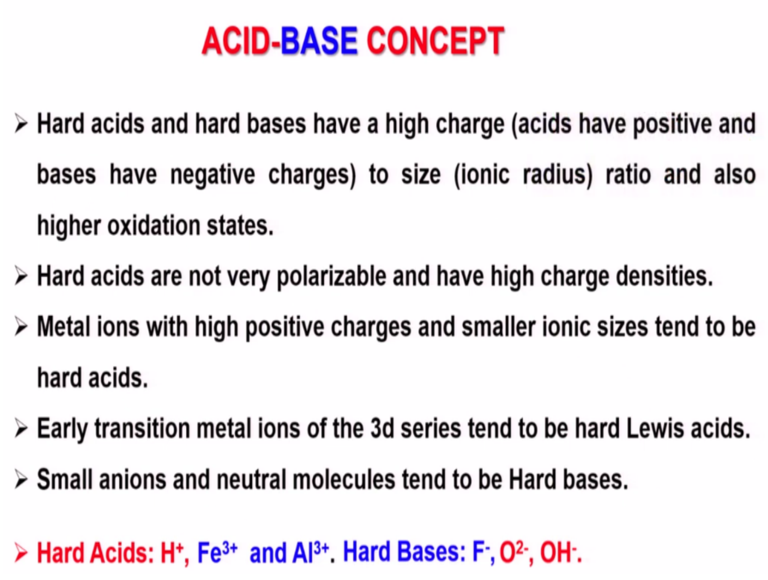

ACID-BASE CONCEPT

- Hard acids and hard bases have a high charge (acids have positive and bases have negative charges) to size (ionic radius) ratio and also higher oxidation states.
- Hard acids are not very polarizable and have high charge densities.
- Metal ions with high positive charges and smaller ionic sizes tend to be hard acids.
- Early transition metal ions of the 3d series tend to be hard Lewis acids.
- Small anions and neutral molecules tend to be Hard bases.
- Hard Acids: H^+, Fe^{3+} and Al^{3+}. Hard Bases: F^-, O^{2-}, OH^-.

Before we dig little deep into coordination compounds, let us try to understand acid-base concept. Hard acids and hard bases have high charge. That means acids have positive and bases have negative charges-to-size ratio, that means, they have high charge-to-size ratio, and also metals are always in their higher oxygen states. Hard acids are not very polarizable and have high charge densities.

Metal ions with high positive charges and smaller ionic sizes tend to be hard ~~assets~~ acids, that is the reason, early metals when you strip off all valence electrons, they always try to be hard acids and hence they are oxophilic and halophilic. Early transition metal ions of $3d$ series tend to be always hard Lewis acids. Small anions ~~are~~ OR neutral molecules tend to be hard ~~to~~ bases. If you want to consider examples for hard acids: H^+, Fe^{3+} and ~~aluminum~~ Al^{3+}, are examples of a hard acids as far as main group acids and bases are concerned.

And in case of hard bases:~~;~~ F^-, O^{2-}, OH^- (hydroxide). Let us try to understand what are soft acids or soft bases. Soft acids or soft bases have a low charge-to-radius ratio; with metals in their low oxidation state. This is exactly opposite to hard acids and hard bases. They are normally larger ions and are polarizable. For example, I^- iodide and S^{2-} sulphide are soft bases. And low valent transition metals are metal ions such as silver plus or copper plus are soft acids.

Also, $4d$ and $5d$ metals in their +1 and +2 oxidation states as well as late transition metals with filled or almost completely filled d-orbitals are soft acids. Acids such as ~~trimethyl boron~~ BMe_3, Fe^{2+}, Pb^{2+} are intermediate acids, whereas pyridine and ~~amylene~~ aniline are intermediate bases. An element can also change its hard and soft character depending on its oxidation state. For example let us consider hydrogen, H^+ is a hard acid, whereas H^- is a soft base.

Similarly, ~~nickel~~ Ni^{3+} is a hard acid whereas ~~nickel~~ Ni^0 in nickel tetracarbonyl, for example, is a soft acid. So, the figures that; I am going to show hard soft trends for acids and bases in the periodic table. For bases the major hard-soft discontinuity is between second row, that is, for nitrogen, oxygen, fluorine and the rows below.

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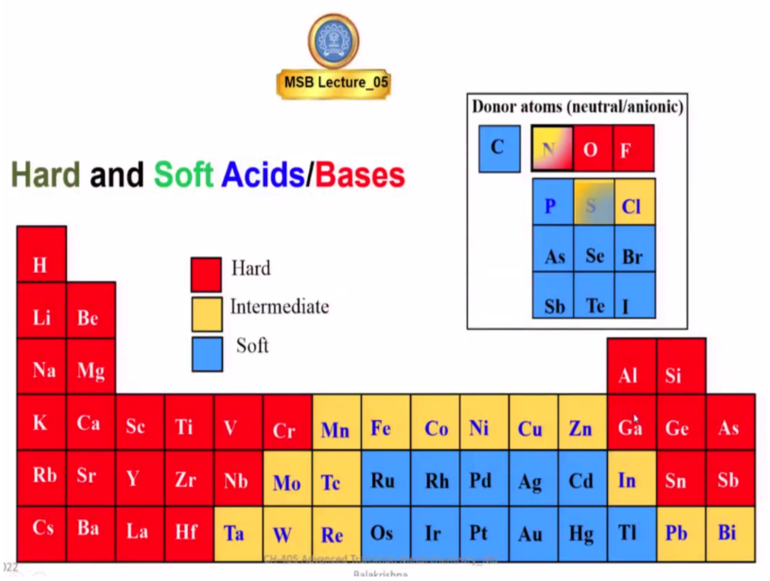

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Hard and Soft Acids/Bases

🟥 Hard
🟨 Intermediate
🟦 Soft

Donor atoms (neutral/anionic)

C	N	O	F
	P	S	Cl
	As	Se	Br
	Sb	Te	I

H														
Li	Be													
Na	Mg											Al	Si	
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi

You can see here, hard and soft acids and bases, I have given here. And if you see the left side of the periodic table ~~and~~ covering ~~almost~~ all alkali metals and alkaline earth metals and partly 3d and 4d and 5d metals, they are all hard acids, and they have less number of electrons in the valence shell and they exist in their highest possible ~~orbital~~ oxidation states and are hard acids. And if you just look into elements put in blue colour, they are all soft acids, you can consider here.

~~And w~~Whereas in case of donor atoms, ~~it is~~ blue in colour are soft bases, that means soft Lewis acids, I would say. Carbon, phosphorus, arsenic, antimony, selenium, tellurium, bromine and iodine whereas nitrogen, sulfur have partial or intermediate character. Chlorine is also intermediate in nature, whereas oxygen and fluorine are hard bases. And here aluminum, silicon, gallium, germanium and tin, when it comes to metallic properties, there are soft hard acids.

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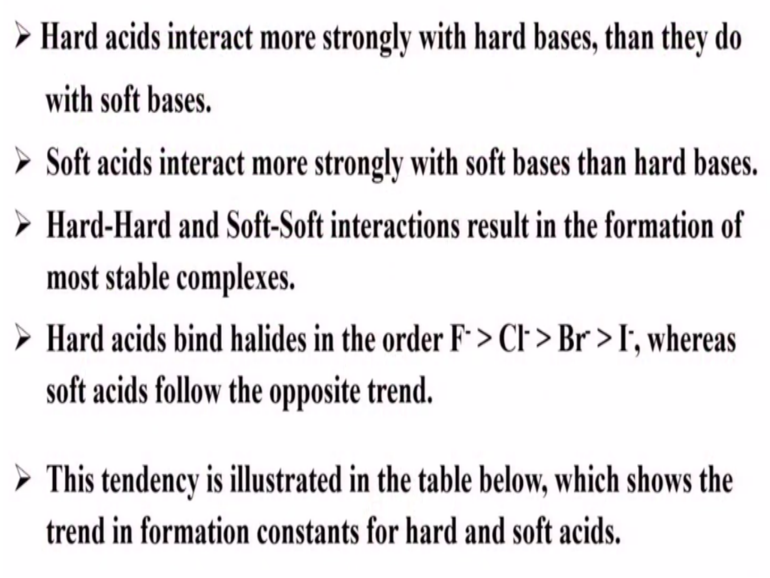

- Hard acids interact more strongly with hard bases, than they do with soft bases.
- Soft acids interact more strongly with soft bases than hard bases.
- Hard-Hard and Soft-Soft interactions result in the formation of most stable complexes.
- Hard acids bind halides in the order $F^- > Cl^- > Br^- > I^-$, whereas soft acids follow the opposite trend.
- This tendency is illustrated in the table below, which shows the trend in formation constants for hard and soft acids.

Hard acids interact more strongly with hard bases than they do with soft bases, that is, the reason the combination of hard~~-~~acid and hard~~-~~base is more stable. And similarly, a combination of soft~~-~~acid and soft~~-~~base is very stable. But other way around ~~is~~, considering hard acid and soft base or soft acid and hard base, they are relatively less stable. So, soft acids interact more strongly with the soft bases than hard bases.

Hard-hard and soft-soft interactions result~~s~~ in the formation of most stable complexes, and hard acid bind halides in this order; you can see the order shown, whereas soft acids follow the opposite trend. For example, if you consider early metal fluorides are more stable, whereas late metal iodides are more stable.

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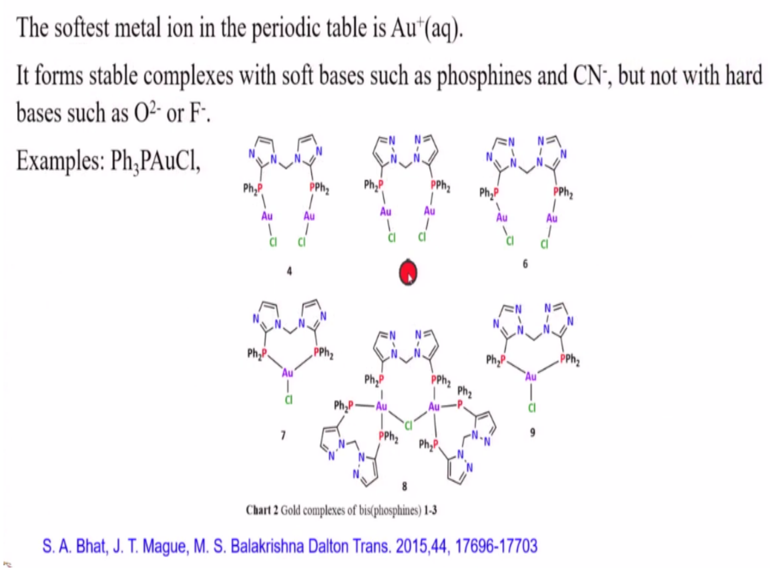

The softest metal ion in the periodic table is $Au^+(aq)$.

It forms stable complexes with soft bases such as phosphines and CN^-, but not with hard bases such as O^{2-} or F^-.

Examples: Ph_3PAuCl,

Chart 2 Gold complexes of bis(phosphines) 1-3

S. A. Bhat, J. T. Mague, M. S. Balakrishna Dalton Trans. 2015,44, 17696-17703

The softest metal ion in the periodic table is ~~Gold plus~~Au^+ in aqueous solution. It forms stable complexes with the soft bases such as phosphines and cyanide but not with hard bases such as oxide and fluoride. And here I have shown some examples of Gold +1 complexes, here it is linear, and of course we have extensively studied gold chemistry in our laboratory and we have examples for different geometries of gold.

For example, in these examples it is linear, in this one it is trigonal planar, whereas in this case Gold +1 state being tetrahedral, and again it is trigonal planar.

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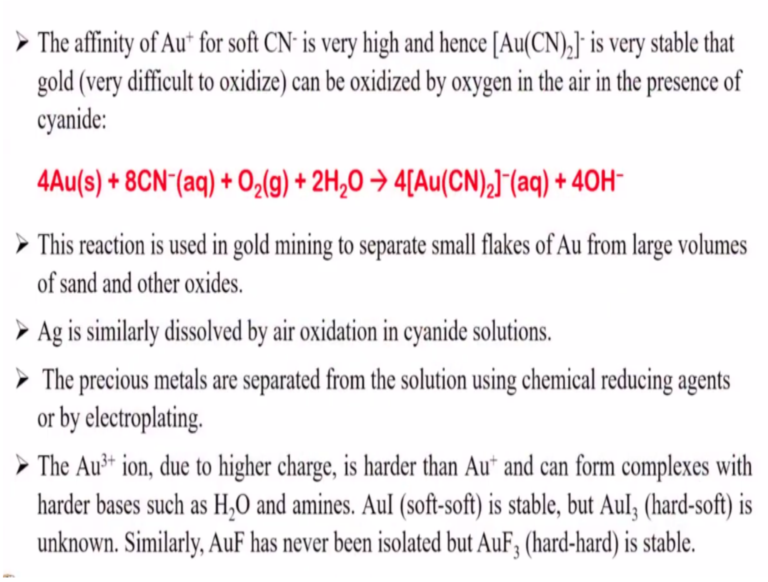

- The affinity of Au^+ for soft CN^- is very high and hence $[Au(CN)_2]^-$ is very stable that gold (very difficult to oxidize) can be oxidized by oxygen in the air in the presence of cyanide:

$$4Au(s) + 8CN^-(aq) + O_2(g) + 2H_2O \rightarrow 4[Au(CN)_2]^-(aq) + 4OH^-$$

- This reaction is used in gold mining to separate small flakes of Au from large volumes of sand and other oxides.
- Ag is similarly dissolved by air oxidation in cyanide solutions.
- The precious metals are separated from the solution using chemical reducing agents or by electroplating.
- The Au^{3+} ion, due to higher charge, is harder than Au^+ and can form complexes with harder bases such as H_2O and amines. AuI (soft-soft) is stable, but AuI_3 (hard-soft) is unknown. Similarly, AuF has never been isolated but AuF_3 (hard-hard) is stable.

The affinity of ~~oxygen~~ gold plus (Au^+) for soft cyanide minus is very high and hence $[Au(CN)_2]$~~twice~~$^{2-}$ is very stable. That means the gold can be oxidized by oxygen in the, air in the presence of cyanide. The affinity of Gold plus for soft cyanide is very high and hence $[Au(CN)_2]^{2-}$ ~~Au CN twice anion~~ is very stable that gold can be oxidized by oxygen in the air in the presence of cyanide. So, this property is exploited in separating gold from sand and other oxides.

For example, you can see when gold is reacted with cyanide that means basically we are taking sodium or potassium cyanide with water, dissolved oxygen is good enough, it forms this dicyanoaurate anion. This reaction is used in gold mining to separate small flakes of gold from large volumes of sand and other oxides. Silver is similarly dissolved by air oxidation in cyanide solutions and this is called cyanide process.

The precious metals are separated from the solution using chemical reducing agents or by electroplating. The Au^{3+} ion; (gold^{3+}) ion due to its higher charge is harder than Gold(+) ~~plus~~ and can form complexes with harder bases such as water and amines and auric iodide or aurous iodide that is Au-I, a combination of soft-acid and soft-base is stable, but Au-I$_{3}$ is a combination of hard-acid and soft-base, is unknown.

That means one hard acid and the other one soft base, extreme ones, is unknown similar to Pb-I$_4$. Similarly, Au-F has never been isolated but Au-F$_3$ is stable. Au-F$_3$ is stable because Au^{3+} is hard acid.

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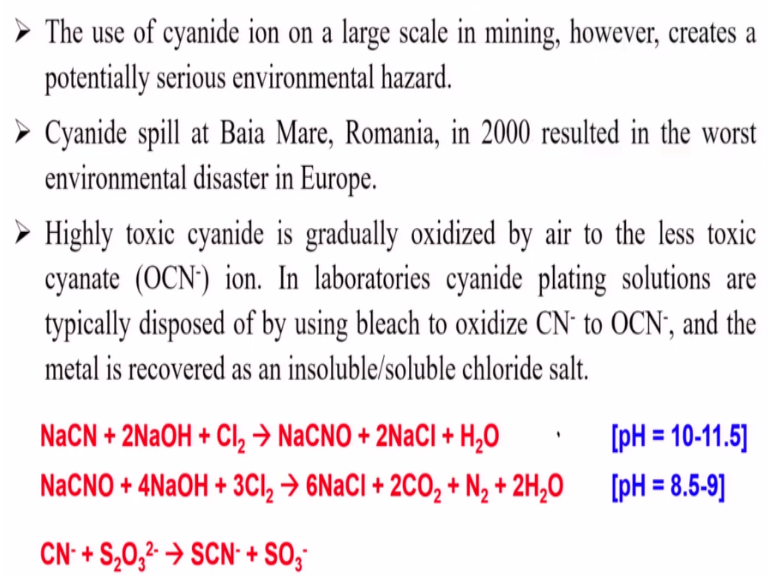

- The use of cyanide ion on a large scale in mining, however, creates a potentially serious environmental hazard.
- Cyanide spill at Baia Mare, Romania, in 2000 resulted in the worst environmental disaster in Europe.
- Highly toxic cyanide is gradually oxidized by air to the less toxic cyanate (OCN^-) ion. In laboratories cyanide plating solutions are typically disposed of by using bleach to oxidize CN^- to OCN^-, and the metal is recovered as an insoluble/soluble chloride salt.

$NaCN + 2NaOH + Cl_2 \rightarrow NaCNO + 2NaCl + H_2O$ [pH = 10-11.5]

$NaCNO + 4NaOH + 3Cl_2 \rightarrow 6NaCl + 2CO_2 + N_2 + 2H_2O$ [pH = 8.5-9]

$CN^- + S_2O_3^{2-} \rightarrow SCN^- + SO_3^-$

The use of cyanide ion on a large scale in mining, however, creates a potentially serious environmental hazard. Cyanide spill at Baia Mare in Romania in 2000 resulted in the worst environmental disaster in Europe. Highly toxic cyanide is gradually oxidized by air to the less toxic cyanide ion. In laboratories, cyanide plating solutions are typically disposed off by using bleach to oxidize cyanate to cyanide it and the metal is recovered as an insoluble or soluble chloride salt.

For example, sodium cyanide on treatment with the sodium hydroxide in presence of chlorine gives: Na-CNO + 2 Na-Cl + H$_2$O. So, this reaction takes place in the pH range of 10 to 11.5 and sodium cyanide on further reaction with sodium hydroxide or bleach, say sodium hydroxide, + 3Cl$_2$ gives 6 Na-Cl + 2 CO$_2$ + N$_2$ + 2H$_2$O. So, this takes place in the pH range of 8.5 to 9 and similarly cyanide can also be neutralized by using thiosulfate.

And this process is used in cyanide poisoning in the living beings, and using base should not be considered. And if very small quantity of cyanide poisoning is there, sodium thiosulfate can be used. So on January 30th 2000, the dam containing toxic waste material from the Baia Mare Aurul Goldmine in North Western Romania burst and released 100 thousand cubic meters of waste water that was heavily contaminated with cyanide into the Lapus and some tributaries of the river Tisza, one of the biggest river in Hungary.

And because of this disaster wildlife was severely impacted by the Baia Mare cyanide leak and all living things around that riverbank were killed. And in Serbia, 200 tons of fish in the rivers were killed and 80% of all aquatic life was totally destroyed. The cyanide leak affected at least 32 fish species in that river. So, you can imagine the kind of disaster we had because of cyanide process and letting cyanide to contaminate river.

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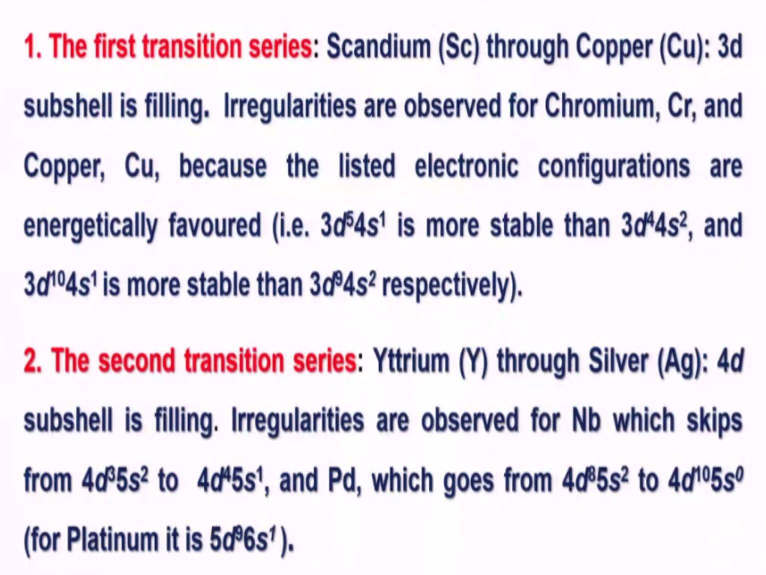

1. **The first transition series**: Scandium (Sc) through Copper (Cu): 3d subshell is filling. Irregularities are observed for Chromium, Cr, and Copper, Cu, because the listed electronic configurations are energetically favoured (i.e. $3d^5 4s^1$ is more stable than $3d^4 4s^2$, and $3d^{10} 4s^1$ is more stable than $3d^9 4s^2$ respectively).

2. **The second transition series**: Yttrium (Y) through Silver (Ag): 4*d* subshell is filling. Irregularities are observed for Nb which skips from $4d^3 5s^2$ to $4d^4 5s^1$, and Pd, which goes from $4d^8 5s^2$ to $4d^{10} 5s^0$ (for Platinum it is $5d^9 6s^1$).

Let us come back to transition element series. If we look into the first transition series scandium through copper $3d$ subshell is failing starting from $3d^1$ to $3d^9$ and you can see irregularities when you go to chromium. So, chromium is supposed to have $3d^4 4s^2$ and similarly copper should have $3d^9 4s^2$ because the electronic configuration listed is slightly different. The reason is we know the fact that half-filled and completely different electronic configuration gives the stability.

As a result, what happens one electron from $4s^2$ is added to have $3d^5$ and $4s^1$ electronic configuration for chromium and similarly copper assume an electronic configuration of $3d^{10}$ and $4s^1$. So, this is because of extra stability and of course this anomaly we also see with nickel group where we have d^{8} and s^{2} electronic configuration. If you look into nickel it is perfect, no issues. It shows d^{8} and s^{2}~~d8 and s2~~ electronic configuration.

But if you go to 4*d*, palladium just below nickel, it has instead of $4d^{8}5s^{2}$ electronic configuration it has $4d^{10}5s^{0}$~~4d 10 and 5s 0~~ electronic configuration. And again, there is a difference in the electronic configuration of platinum as well. Platinum instead of having $5d^{8}6s^{2}$~~d 8s 2~~ electronic configuration, it has $5d^{9}6s^{1}$~~d 9s 1~~ electronic configuration. That means the electronic configuration of platinum is $5d^{9}6s^{1}$~~5d 9 and 6s 1~~.

When we look into second transition series, we go through yttrium to silver and again 4d subshell is filling. Irregularities are observed for niobium which skips from $4d^{3}5s^{2}$ to $4d^{4}5s^{1}$ and palladium which goes from 4d-8-5s-2 to 4d-10-5s-0 that is what I did mention. And irregularities are observed for 4d-3-5s-2, if you just look into it that also but in this case, there is as such no benefit for the stability.

But the reason is not clear why niobium instead of having 4d-3-5s-2 electronic configuration it has 4d-4-5s-1, probably to facilitate more metal-metal bonding. And also, when you go for higher orbitals, the energy difference will be smaller and the size is bigger, as a result these orbitals can diffuse into each other and hence probably this kind of promotion of electron either way should not take much energy and that is the reason probably the electrons can be moving or dissociating or associating easily between the neighbouring orbitals.

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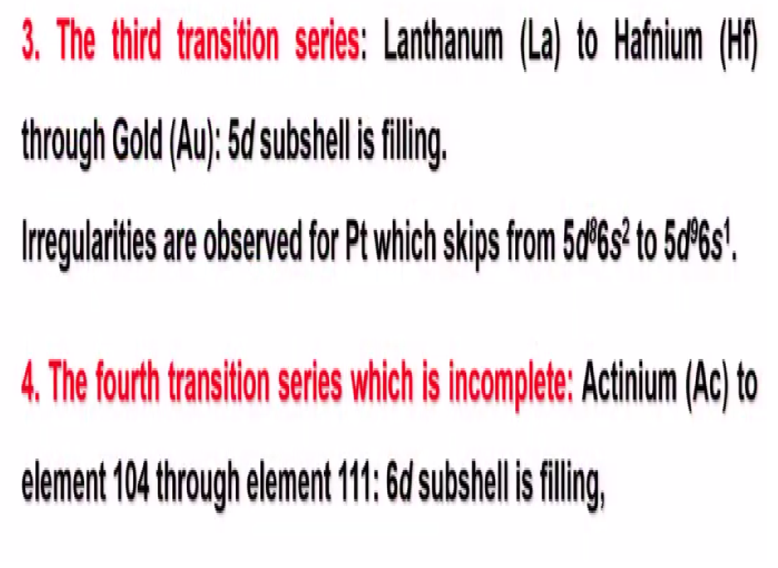

3. The third transition series: Lanthanum (La) to Hafnium (Hf) through Gold (Au): 5*d* subshell is filling.

Irregularities are observed for Pt which skips from $5d^{8}6s^{2}$ to $5d^{9}6s^{1}$.

4. The fourth transition series which is incomplete: Actinium (Ac) to element 104 through element 111: 6*d* subshell is filling,

When you look into third transition series Lanthanum to Hafnium through Gold, 5d subshell is filling, again irregularities are observed only in case of platinum that I have already mentioned. The fourth transition series which is incomplete, Actinium to element 104 through element 111 and here 6d subshell is filling and of course now we have completed the series.

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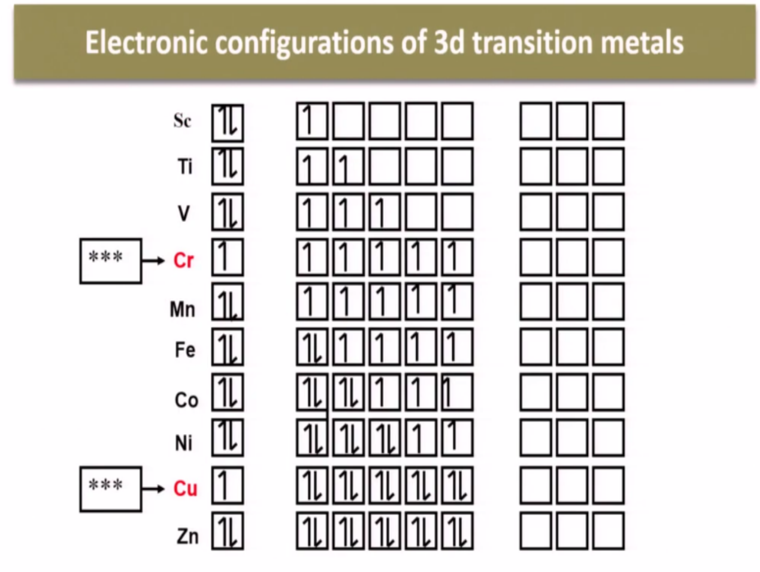

Electronic configurations of 3d transition metals

This slide shows the electronic configuration of 3d series starting from scandium to zinc. We have d–1 system here and we have the d–10 system. Since all the valence orbitals are completely filled here and zinc do not really follow the trends that are observed among transition elements. And in contrast the chemical and physical properties of zinc, cadmium and mercury are much more related to main group elements.

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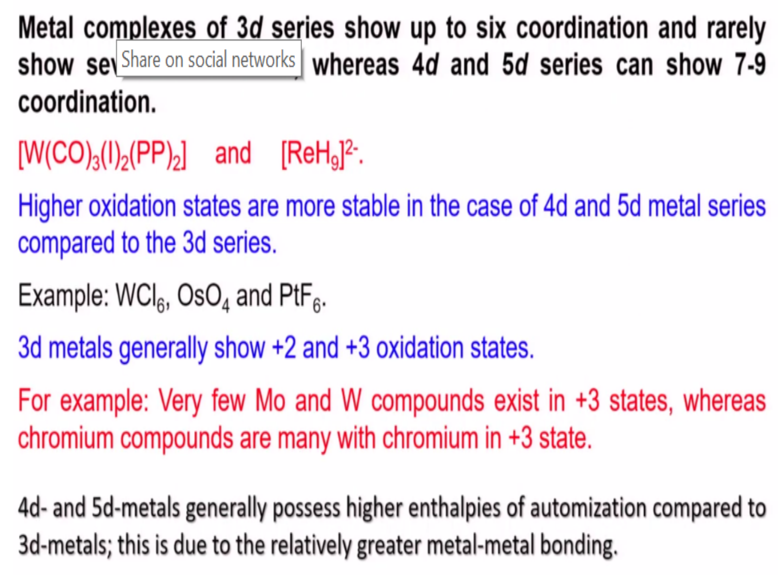

Metal complexes of 3*d* series show up to six coordination and rarely show se[illegible] whereas 4*d* and 5*d* series can show 7-9 coordination.

$[W(CO)_3(I)_2(PP)_2]$ and $[ReH_9]^{2-}$.

Higher oxidation states are more stable in the case of 4d and 5d metal series compared to the 3d series.

Example: WCl_6, OsO_4 and PtF_6.

3d metals generally show +2 and +3 oxidation states.

For example: Very few Mo and W compounds exist in +3 states, whereas chromium compounds are many with chromium in +3 state.

4d- and 5d-metals generally possess higher enthalpies of automization compared to 3d-metals; this is due to the relatively greater metal-metal bonding.

So, metal complexes of 3d series show up to six coordination and rarely show seven coordination. The 3d series metals or elements are relatively smaller in size and as a result they cannot go beyond six-coordination, whereas 4d and 5d series can show up to nine coordination. For example, there is a tungsten-2+ complex shown here, this can have either ~~captured~~ capped-octahedral geometry or pentagonal bipyramidal geometry and here coordination number is 7.

And in case of this hydride, homolytic hydride, ~~rhenium~~ $[ReH_9]^{2-}$, rhenium is in +9 state having tricapped trigonal prismatic geometry and higher oxidation states are more stable in the case of 4d and 5d metal series compared to 3d series. So, 3d series prefer to have lower oxidation states, whereas metals in 4d and 5d tend to stabilize with higher oxidation states. And of course, here the reason is very simple.

The size is little larger compared to 3d, as a result valence electrons are a little away from the nucleus and as a result it is very easy to ionize electrons in 4d and 5d series. For example, hexachlorotungsten, osmium tetroxide and PtF_6. And here tungsten exists in +6 oxidation state, whereas in this one Osmium exists in +8 oxidation state and, whereas in this case platinum is in +6 state. So, 3d metals generally show +2 and +3 oxidation states.

For example, very few m~~M~~olybdenum and tungsten compounds exist in +3 states, whereas chromium compounds are many, with chromium in +3 oxidation state. And 4d and 5d metals generally possess higher enthalpies of atomization compared to 3d metals, this is due to the relatively greater metal-metal bonding. So, while explaining the radius and also melting point, I did discuss about these aspects.

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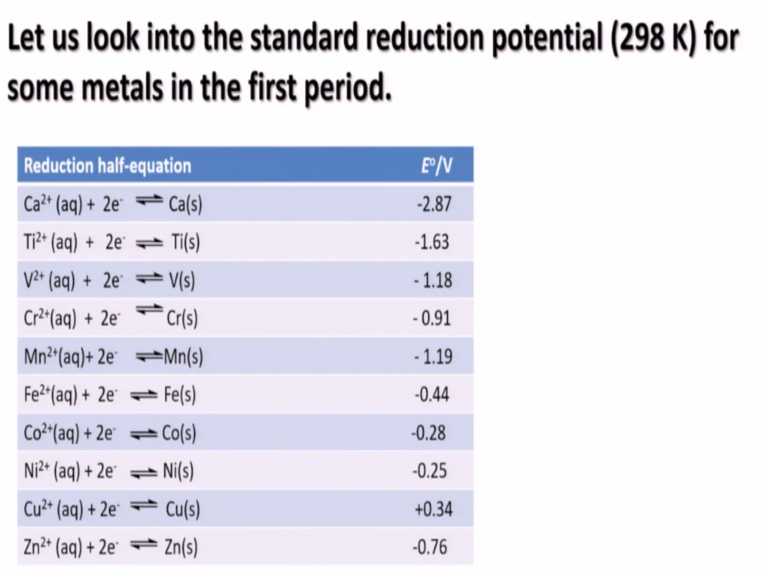

Let us look into the standard reduction potential (298 K) for some metals in the first period.

Reduction half-equation	E^o/V
$Ca^{2+}(aq) + 2e^- \rightleftharpoons Ca(s)$	-2.87
$Ti^{2+}(aq) + 2e^- \rightleftharpoons Ti(s)$	-1.63
$V^{2+}(aq) + 2e^- \rightleftharpoons V(s)$	- 1.18
$Cr^{2+}(aq) + 2e^- \rightleftharpoons Cr(s)$	- 0.91
$Mn^{2+}(aq) + 2e^- \rightleftharpoons Mn(s)$	- 1.19
$Fe^{2+}(aq) + 2e^- \rightleftharpoons Fe(s)$	-0.44
$Co^{2+}(aq) + 2e^- \rightleftharpoons Co(s)$	-0.28
$Ni^{2+}(aq) + 2e^- \rightleftharpoons Ni(s)$	-0.25
$Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s)$	+0.34
$Zn^{2+}(aq) + 2e^- \rightleftharpoons Zn(s)$	-0.76

Let us look into the standard reduction potential for some metals in the first period. So, values are given here, and here if you just see, I have included calcium also, and starts with calcium and ~~the~~ end with zinc here. As you see, the values of alkaline earth metal is negative that means it can be readily oxidized, and as the value decreases, they tend to be more and more reducible in character.

That means copper-2+ can be readily reduced to copper compared, to calcium-2+ getting reduced to calcium in its zero valence state. And this redox potential is very important when we want to use these metal complexes in various applications.

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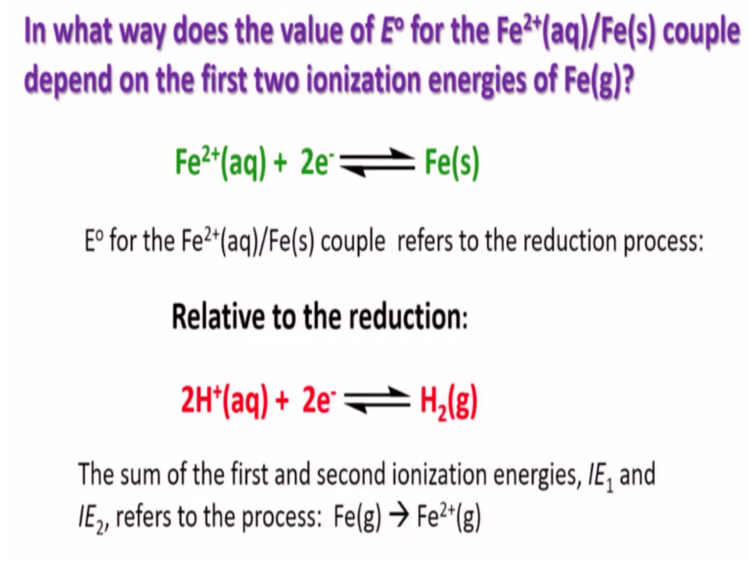

In what way does the value of E^o for the $Fe^{2+}(aq)/Fe(s)$ couple depend on the first two ionization energies of Fe(g)?

$$Fe^{2+}(aq) + 2e^- \rightleftharpoons Fe(s)$$

E^o for the $Fe^{2+}(aq)/Fe(s)$ couple refers to the reduction process:

Relative to the reduction:

$$2H^+(aq) + 2e^- \rightleftharpoons H_2(g)$$

The sum of the first and second ionization energies, IE_1 and IE_2, refers to the process: $Fe(g) \rightarrow Fe^{2+}(g)$

Let us look into this question, here in what way does the value of E^0 for the Fe^{2+}/~~to~~ Fe couple depend on the first two ionization energies of Fe(gaseous)? That means here one should look into the enthalpy heat of formation of Fe^{2+}, is it comparable with the two ionization energies required to remove two electrons from the gaseous iron atom to form Fe^{2+}. So, first consider the Fe^{2+} takes two electrons in a reversible fashion to form Fe, here Fe.

So E^0 for the Fe^{2+} ~~to~~/Fe couple refers to the reduction process. This is the redox potential, I am referring to E_0, redox potential. Relative to the reduction of $2H^+$, it takes 2 electrons in irreversible fashion to form hydrogen molecule. That means the sum of the first and second ionization energies that is IE_1 and IE_2 refers to the process Fe_g giving Fe^{2+}. That means you have to take one electron for using first ionization energy and apply another second ionization energy and takes ~~skip~~ another electron to form di-cation.

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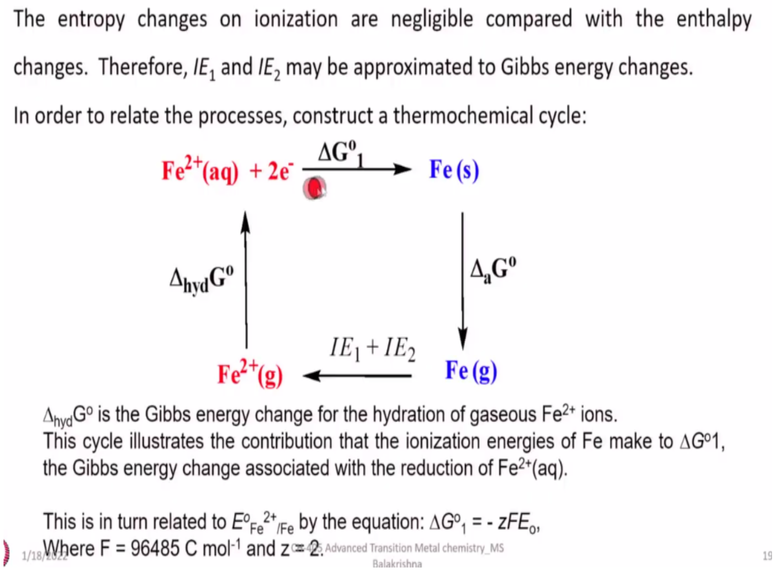

The entropy changes on ionization are negligible compared with the enthalpy changes. Therefore, IE_1 and IE_2 may be approximated to Gibbs energy changes.

In order to relate the processes, construct a thermochemical cycle:

$\Delta_{hyd}G^o$ is the Gibbs energy change for the hydration of gaseous Fe^{2+} ions.
This cycle illustrates the contribution that the ionization energies of Fe make to $\Delta G^o 1$, the Gibbs energy change associated with the reduction of $Fe^{2+}(aq)$.

This is in turn related to $E^o_{Fe^{2+}/Fe}$ by the equation: $\Delta G^o_1 = - zFE_o$,
Where F = 96485 C mol^{-1} and z = 2.

Now to understand this one, this thermochemical cycle, I have shown here, first to consider the Fe^{2+} ~~a~~(aqueous) and when you add two electrons, it forms Fe and then Fe on atomization it forms Fe(gaseous) and then when you apply first ionization energy and second ionization energy so you can remove one electron at a time to eventually form Fe^{2+} and then Fe^{2+} hydration. On hydration it forms aqueous that means hexa aqua iron(2+) $[Fe(OH_2)_6]^{2+}$.

So, here Δ~~delta~~ $_{\text{hydration}}G^0$ is the Gibbs energy change for the hydration of gaseous Fe2+ ion. This cycle illustrates the contribution that ionization energies of Fe makes to ΔG^0~~delta G 0~~$_1$ here. The Gibbs free energy change associated with the reduction of Fe^{2+} to ΔG^0_1 ~~a G that is the one~~. So, this is in turn related to redox potential for this couple, that means you can relate Gibbs free energy to this equation ΔG^0~~delta G 0~~ $= -z F E_0$, where F is 96485 ohms per mole and in this case it is a two electron process z = 2.

So, using this one for any reaction one can find out delta G or any missing component can be found out. Let me discuss a little bit about the reactivity series before I conclude this lecture. The reactivity series is a series of metals in order of reactivity from highest to lowest. It is used to determine the products of single displacement reactions whereby metal A will replace another metal B in a solution, if A is higher in the series. This information also comes from the redox potential table.

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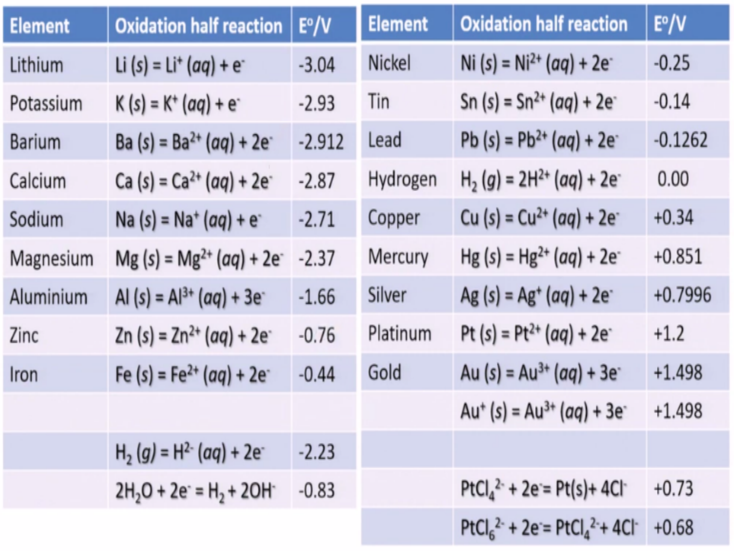

Element	Oxidation half reaction	E°/V
Lithium	$Li\ (s) = Li^+\ (aq) + e^-$	-3.04
Potassium	$K\ (s) = K^+\ (aq) + e^-$	-2.93
Barium	$Ba\ (s) = Ba^{2+}\ (aq) + 2e^-$	-2.912
Calcium	$Ca\ (s) = Ca^{2+}\ (aq) + 2e^-$	-2.87
Sodium	$Na\ (s) = Na^+\ (aq) + e^-$	-2.71
Magnesium	$Mg\ (s) = Mg^{2+}\ (aq) + 2e^-$	-2.37
Aluminium	$Al\ (s) = Al^{3+}\ (aq) + 3e^-$	-1.66
Zinc	$Zn\ (s) = Zn^{2+}\ (aq) + 2e^-$	-0.76
Iron	$Fe\ (s) = Fe^{2+}\ (aq) + 2e^-$	-0.44
	$H_2\ (g) = H^{2-}\ (aq) + 2e^-$	-2.23
	$2H_2O + 2e^- = H_2 + 2OH^-$	-0.83

Element	Oxidation half reaction	E°/V
Nickel	$Ni\ (s) = Ni^{2+}\ (aq) + 2e^-$	-0.25
Tin	$Sn\ (s) = Sn^{2+}\ (aq) + 2e^-$	-0.14
Lead	$Pb\ (s) = Pb^{2+}\ (aq) + 2e^-$	-0.1262
Hydrogen	$H_2\ (g) = 2H^{2+}\ (aq) + 2e^-$	0.00
Copper	$Cu\ (s) = Cu^{2+}\ (aq) + 2e^-$	+0.34
Mercury	$Hg\ (s) = Hg^{2+}\ (aq) + 2e^-$	+0.851
Silver	$Ag\ (s) = Ag^+\ (aq) + 2e^-$	+0.7996
Platinum	$Pt\ (s) = Pt^{2+}\ (aq) + 2e^-$	+1.2
Gold	$Au\ (s) = Au^{3+}\ (aq) + 3e^-$	+1.498
	$Au^+\ (s) = Au^{3+}\ (aq) + 3e^-$	+1.498
	$PtCl_4^{2-} + 2e^- = Pt(s) + 4Cl^-$	+0.73
	$PtCl_6^{2-} + 2e^- = PtCl_4^{2-} + 4Cl^-$	+0.68

So, activity series of some of the more common metals is listed here in the descending order of reactivity, you can see here. And also, of course, this is the oxidation half-reaction, I have given and for comparison, I have also included alkali metals and alkaline earth metals and also main group elements along with some chosen transition elements. And one should give more importance to these signs, this is very important. This will tell you about how easily one can be oxidized or a metal or element can be reduced or oxidized.

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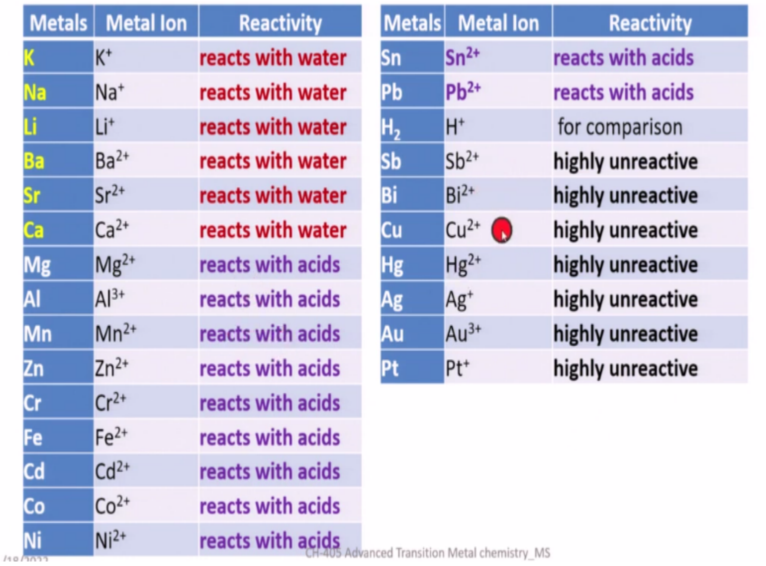

Metals	Metal Ion	Reactivity
K	K^+	reacts with water
Na	Na^+	reacts with water
Li	Li^+	reacts with water
Ba	Ba^{2+}	reacts with water
Sr	Sr^{2+}	reacts with water
Ca	Ca^{2+}	reacts with water
Mg	Mg^{2+}	reacts with acids
Al	Al^{3+}	reacts with acids
Mn	Mn^{2+}	reacts with acids
Zn	Zn^{2+}	reacts with acids
Cr	Cr^{2+}	reacts with acids
Fe	Fe^{2+}	reacts with acids
Cd	Cd^{2+}	reacts with acids
Co	Co^{2+}	reacts with acids
Ni	Ni^{2+}	reacts with acids

Metals	Metal Ion	Reactivity
Sn	Sn^{2+}	reacts with acids
Pb	Pb^{2+}	reacts with acids
H_2	H^+	for comparison
Sb	Sb^{2+}	highly unreactive
Bi	Bi^{2+}	highly unreactive
Cu	Cu^{2+}	highly unreactive
Hg	Hg^{2+}	highly unreactive
Ag	Ag^+	highly unreactive
Au	Au^{3+}	highly unreactive
Pt	Pt^+	highly unreactive

CH-405 Advanced Transition Metal chemistry_MS

And this chart shows the reactivity. For example, whether they react with water, if not they react with acid or they are not at all reactive. So, let me stop here and continue further discussion on transition metal chemistry in my next lecture. Until then have a wonderful time reading chemistry. Thank you.