Reagents in Organic Synthesis
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Lecture 29
Nickel, Platinum and Iridium based reagents in organic synthesis

Welcome again today we will discuss nickel, platinum and iridium based reagents in organic synthesis.

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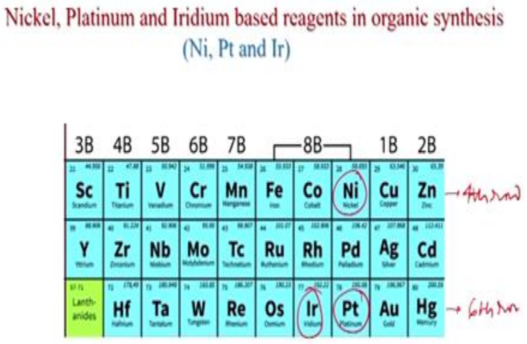

Nickel, Platinum and Iridium based reagents in organic synthesis

(Ni, Pt and Ir)

3B	4B	5B	6B	7B	8B			1B	2B
Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn
Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd
Lanthanides	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg

→ 4th row

→ 6th row

So, if you see the periodic table nickel is here, this is 4th row and iridium and platinum they are side by side, they are in the 6th row.

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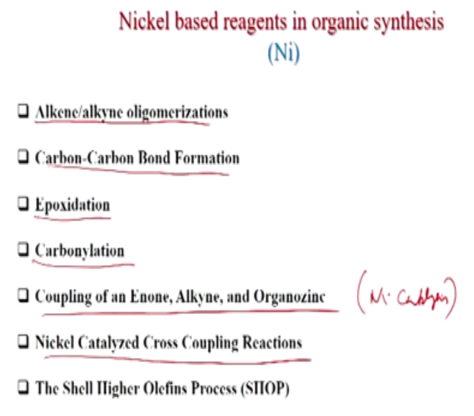

Nickel based reagents in organic synthesis
(Ni)

☐ Alkene/alkyne oligomerizations
☐ Carbon-Carbon Bond Formation
☐ Epoxidation
☐ Carbonylation
☐ Coupling of an Enone, Alkyne, and Organozinc (Ni. Catalysis)
☐ Nickel Catalyzed Cross Coupling Reactions
☐ The Shell Higher Olefins Process (SHOP)

So, first we will discuss nickel based reagents in organic synthesis so we will discuss alkene alkyne oligomerization, carbon-carbon bond formation, epoxidation, then carbononylation, coupling of an enone, alkyne and organozinc we will discuss. This is nickel catalysis and nickel catalyzed cross coupling reactions also we will discuss and shell higher olefins process, that is industry process also we will discuss.

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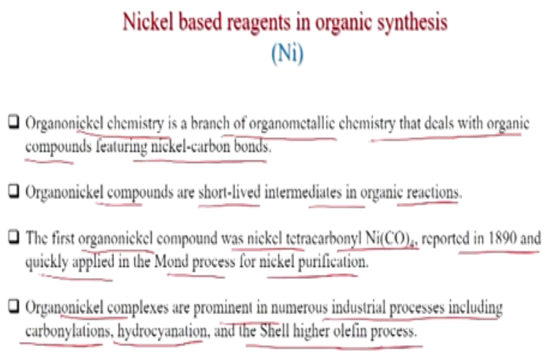

Nickel based reagents in organic synthesis
(Ni)

☐ Organonickel chemistry is a branch of organometallic chemistry that deals with organic compounds featuring nickel-carbon bonds.
☐ Organonickel compounds are short-lived intermediates in organic reactions.
☐ The first organonickel compound was nickel tetracarbonyl $Ni(CO)_4$, reported in 1890 and quickly applied in the Mond process for nickel purification.
☐ Organonickel complexes are prominent in numerous industrial processes including carbonylations, hydrocyanation, and the Shell higher olefin process.

So, organonickel chemistry is a branch of organometallic chemistry that deals with organic compounds featuring nickel carbon bonds. Organonickel compounds are short lived intermediates in organic reactions. And the first organonickel compound was nickel tetracarbonyl NiCO4, reported in 1890 and quickly applied in the Mond process for nickel purification. Organonickel complexes are a prominent in numerous industrial processes including carbonylation that we will discuss hydrocyanation and the shell higher olefin process that also we will discuss.

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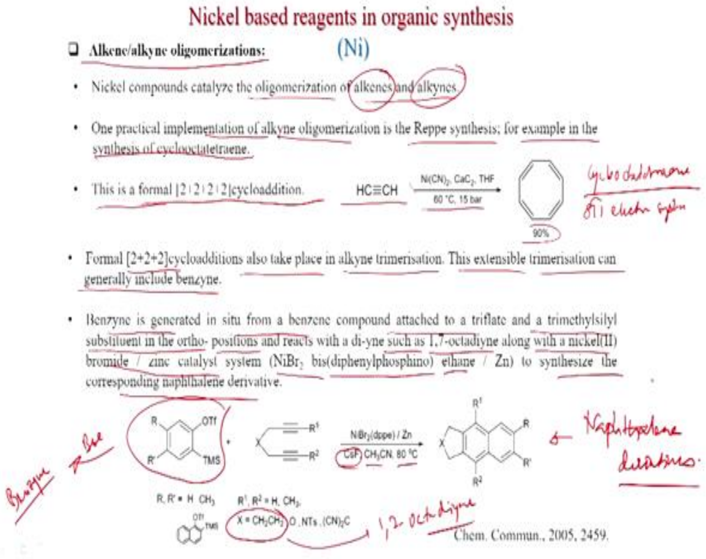

Nickel based reagents in organic synthesis

❑ **Alkene/alkyne oligomerizations:** (Ni)

- Nickel compounds catalyze the oligomerization of alkenes and alkynes.
- One practical implementation of alkyne oligomerization is the Reppe synthesis; for example in the synthesis of cyclooctatetraene.
- This is a formal [2+2+2+2]cycloaddition.
- Formal [2+2+2]cycloadditions also take place in alkyne trimerisation. This extensible trimerisation can generally include benzyne.
- Benzyne is generated in situ from a benzene compound attached to a triflate and a trimethylsilyl substituent in the ortho- positions and reacts with a di-yne such as 1,7-octadiyne along with a nickel(II) bromide / zinc catalyst system (NiBr$_2$ bis(diphenylphosphino) ethane / Zn) to synthesize the corresponding naphthalene derivative.

Chem. Commun., 2005, 2459.

So first we will discuss alkene alkyne oligomerization. So, nickel compounds catalyze the oligomerization of alkenes and alkynes. So, this is important both alkenes and alkynes. 1 practical implementation of alkyne oligomerization is the Reppe synthesis, for example in the synthesis of cyclooctatetraene and this is a formal 2 plus 2 plus 2 cycloadditions. So, this kind of cycloaddition is only possible with metal catalysis like here acetylene if you put with nickel CN whole 2 calcium carbide THF in 60 degree centigrade you get cyclooctatetraene, cyclooctatetraene. This is 8 pi electron system. So this is not an aromatic. Formal 2 plus 2 plus 2 cyclo addition also take place in alkyne trimerization and this extensible trimerization can generally include benzyne.

So, this mechanism we will discuss in next slide. So, benzyne is generated in situ from a benzene compound attached to triflate and trimethylsilyl substituted and in the ortho positions. Here you can see, this OTf and TMS is present and with base, if you put base here then you will get benzyne. So, this is benzyne precursor and reacts with the di-yne such as 1, 7 octadiyne along with a nickel II bromide zinc catalyst system, NiBr2 bis diphenylphosphino ethane zinc to synthesize the corresponding naphthalene derivatives. So, these are naphthalene derivatives and when x is equal to CH2CH2 then it is 1, 7 octadiyne and this is the catalyst NiBr2 dppe zinc and this is the base solvent 80 degrees centigrade you get this. This was published in Chem Commun., 2005 this mechanism also we will discuss.

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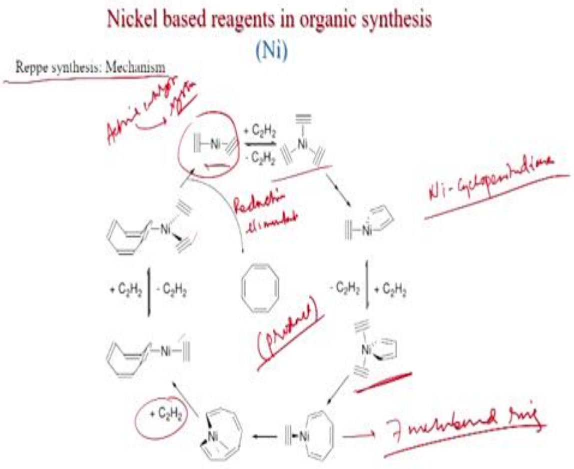

Nickel based reagents in organic synthesis

(Ni)

Reppe synthesis: Mechanism

So, first we will discuss Reppe synthesis mechanism and Reppe synthesis we have already told that 4 molecules of acetylene will give cyclooctatetraene and this is completely atomic economic forces. So, first step is that, 2 acetylene moiety bind to this and then another acetylene can bind and then this kind of cyclopentadiene nickel system. So, nickel cyclopentadiene will form this kind of system we have seen with titanium. So, nickel can also do this, nickel cyclopentadiene and then another molecule of acetylene can come. So, this kind of species will form. Then this alkyne inserts here to join the 7 member rings.

This is a nickel cyclooctatetraene and this acetylene moiety will again insert to generate this and now nickel coordinate to impart. This is the double bond part and then again another acetylene will come so nickel will coordinate with double bond of a cyclooctadiene, cyclooctatetraene and it will coordinate with an external acetylene group and now again another acetylene will coordinate it will and then it can reductively eliminate, so, this is reductive elimination. And this is the product, cyclooctatetraene and you get this, this is the active catalyst system. So, this is the Reppe synthesis that from an acetylene you can get cyclooctatetraene.

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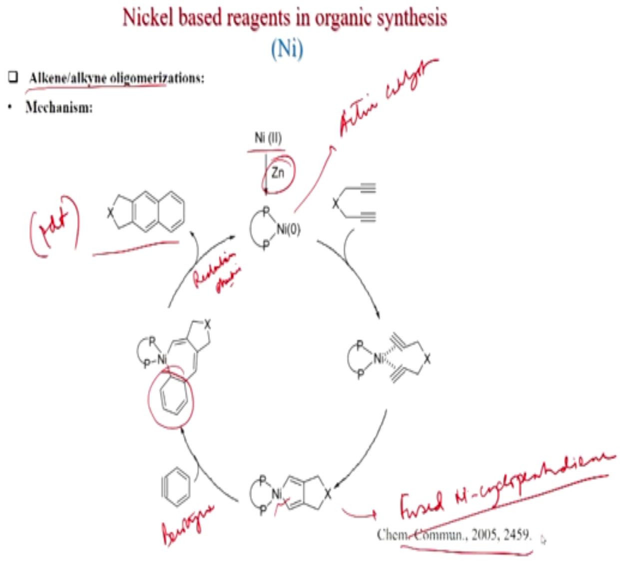

Nickel based reagents in organic synthesis

(Ni)

❑ Alkene/alkyne oligomerizations:

- Mechanism:

Chem. Commun., 2005, 2459.

Alkyne alkene oligomerization so that we will discuss the benzyne 1, here. So, with nickel 2 will first react with zinc to generate the nickel 0. Alkyne will coordinate with the nickel, like this. We have already seen with acetylene so this kind of coordination will happen. And then fused nickel cyclopentadiene. So, earlier we have seen nickel cyclopentadiene here, fused nickel cyclopentadiene is formed and now the benzyne will come. So this is benzyne and benzyne will come and then this, it inserts here you can see this is the benzyne component, and it inserts here, this bond, nickel carbon bond and you get this is the 7-member ring is formed and now the reductive elimination happens. So, now the reductive elimination will give this naphthalene derivative. So, this is the product and you get this, this is the active catalyst here. So, 2 plus 2 plus 2 cycloadditions here is happening and you get the naphthalene derivatives and these products are very useful and this was published in Chem Commun 2005.

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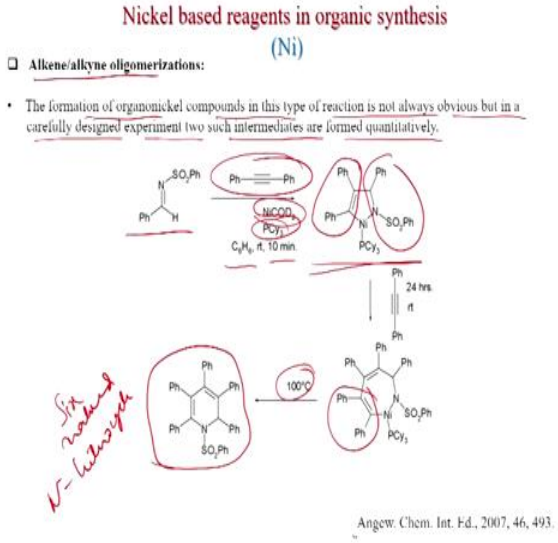

Nickel based reagents in organic synthesis

(Ni)

❑ **Alkene/alkyne oligomerizations:**

- The formation of organonickel compounds in this type of reaction is not always obvious but in a carefully designed experiment two such intermediates are formed quantitatively.

Angew. Chem. Int. Ed., 2007, 46, 493.

Some more alkene alkyne oligomerization. Now the formation of organonickel compounds in this type of reaction is not always obvious but in a carefully designed experiment 2 such intermediates are formed quantitatively. So, you can form the intermediate also that this kind of mechanism is operating like this one with imine. And this internal alkyne with nickel COD, tricyclohexylphosphine and benzene room temperature, 10 minutes you get this, 5-member ring and here you can see this is the alkyne component, this is the imine component and this is the nickel. So, this tells that this 5-member ring with nickel is forming also with alkyne, then the 7 membered will form that another alkyne we will insert. And after heating at 100 degree centigrade reductive elimination happens and you get this compound, 6 membered heterocycle, N-hetero cycle is forming here. This was published in Angew Chem 2007.

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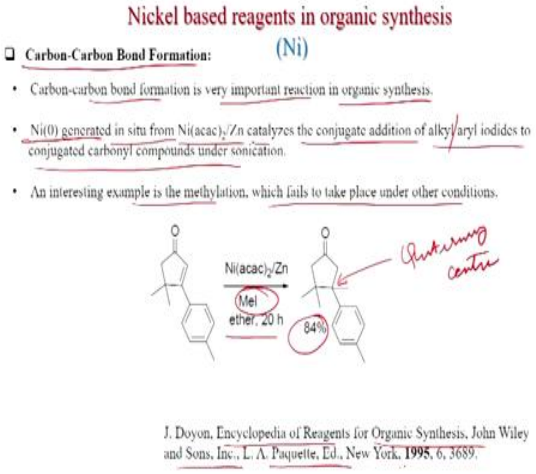

Nickel based reagents in organic synthesis

(Ni)

- **Carbon-Carbon Bond Formation:**
  - Carbon-carbon bond formation is very important reaction in organic synthesis.
  - Ni(0) generated in situ from Ni(acac)$_2$/Zn catalyzes the conjugate addition of alkyl/aryl iodides to conjugated carbonyl compounds under sonication.
  - An interesting example is the methylation, which fails to take place under other conditions.

J. Doyon, Encyclopedia of Reagents for Organic Synthesis, John Wiley and Sons, Inc., L. A. Paquette, Ed., New York, **1995**, 6, 3689.

Now, we will discuss other carbon-carbon bond formations. So, carbon-carbon bond formation is very important reaction in organic synthesis and nickel 0. So, earlier also you have seen nickel 0 is the active catalyst, it can in situ generated from nickel acetylacetonate zinc catalyze the conjugate addition, alkyl or aryl iodides to conjugated carbonyl compounds under sonication. An interesting example is the methylation which fails to take place under other conditions. So, this is the reaction. This is cyclopentene 3 substituted at with nickel acetylacetonate zinc with methyl iodide ether, 20 hours you will get 84 percent yield. So, this conjugate addition happens and you get this quaternary center. So, this kind of reaction is difficult by other ways because you generated quaternary center that methyl group is adding in a conjugate fashion. This was reviewed in Encyclopedia of Reagents for Organic Synthesis, John Wiley and Sons by Leo Paquette in 1995.

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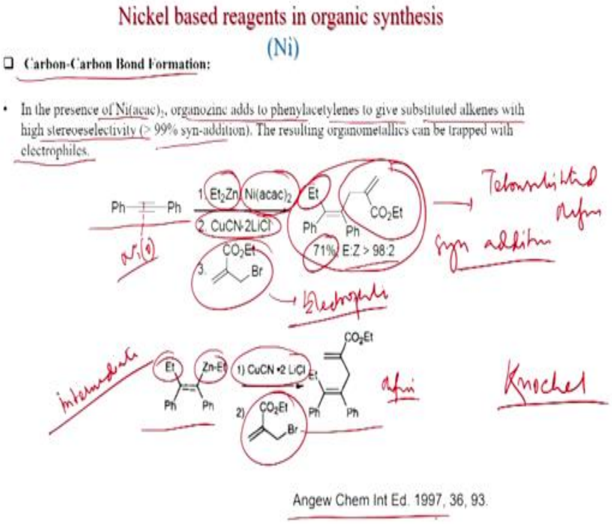

Nickel based reagents in organic synthesis

(Ni)

- ☐ **Carbon-Carbon Bond Formation:**

- In the presence of Ni(acac)$_2$, organozinc adds to phenylacetylenes to give substituted alkenes with high stereoeselectivity (> 99% syn-addition). The resulting organometallics can be trapped with electrophiles.

Angew Chem Int Ed. 1997, 36, 93.

In the presence of nickel acetylacetonate, organozinc adds to phenylacetylenes to give substituted alkenes with high stereoselectivity, greater than 99 percent syn-addition. The resulting organometallics can be trapped with electrophiles. So, this is an important reaction. This is Negishi kind of reaction so this is internal alkyne, diethyl zinc acetylacetonate, CuCN lithium chloride and then this is the electrophile. So, this is electrophile and you get these compounds are very important. So, this compound is tetra-substituted olefin, substituted olefin. So, one ethyl group is coming from di-ethyl zinc and this is the electrophilic component and this is syn addition; this is also important, syn addition and 71 percent is forming and this is the ratio here E/Z 98:2.

So, the possible mechanism that this intermediate is formed, intermediate, this intermediate is formed that this is the di-ethyl zinc that 1 ethyl group adds here and ZnEt adds here and also this alkyne will be coordinated with nickel 0. Because alkynes always like to coordinate with nickel and then only this syn addition will take place and after that this intermediate reacts with copper cyanide lithium chloride and this allylic bromide and then this product, olefin product is forming. This was developed by Paul Knochel, German scientist and the paper was published in Angew Chemie International Edition 1997.

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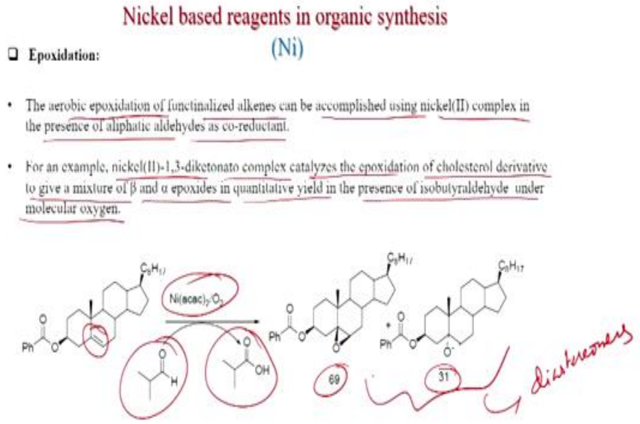

Nickel based reagents in organic synthesis

(Ni)

❑ **Epoxidation:**

- The aerobic epoxidation of functionalized alkenes can be accomplished using nickel(II) complex in the presence of aliphatic aldehydes as co-reductant.
- For an example, nickel(II)-1,3-diketonato complex catalyzes the epoxidation of cholesterol derivative to give a mixture of β and α epoxides in quantitative yield in the presence of isobutyraldehyde under molecular oxygen.

So, some more reaction like epoxidation we will discuss now. The aerobic epoxidation of functionalized alkenes can be accomplished using nickel (II) complex in the presence of aliphatic aldehydes as co-reductant. For an example, nickel (II) 1, 3-diketonato complex catalyzes the epoxidation of cholesterol derivative to give a mixture of beta and alpha epoxides in the quantitative yield in the presence of isobutyraldehyde under molecular oxygen. So, this is the reaction, you can see this is a double bond here that will be epoxidized. And this is the catalytic system nickel acetylacetonate oxygen and isobutyraldehyde is converting to the isobutyric acid and in this process you get the epoxidation of the double bond and two diastereomers are forming so they are diastereomers. And this product is forming major up epoxide 69 percent and down is 31 percent.

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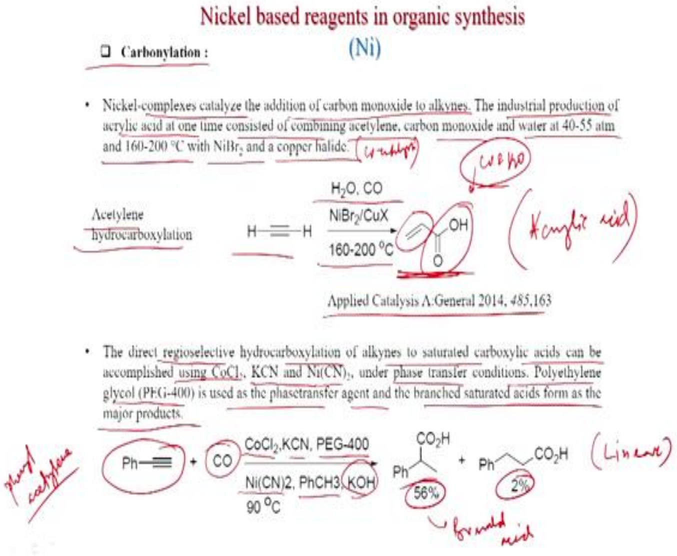

Nickel based reagents in organic synthesis

(Ni)

☐ **Carbonylation :**

- Nickel-complexes catalyze the addition of carbon monoxide to alkynes. The industrial production of acrylic acid at one time consisted of combining acetylene, carbon monoxide and water at 40-55 atm and 160-200 °C with $NiBr_2$ and a copper halide. (co-catalyst)

Acetylene hydrocarboxylation

Applied Catalysis A:General 2014, 485,163

- The direct regioselective hydrocarboxylation of alkynes to saturated carboxylic acids can be accomplished using $CoCl_2$, KCN and $Ni(CN)_2$, under phase transfer conditions. Polyethylene glycol (PEG-400) is used as the phasetransfer agent and the branched saturated acids form as the major products.

Now, we will discuss carbonylation that is also an important reaction carried out by nickel. Nickel-complexes catalyze the addition of carbon monoxide to alkynes. The industrial production of acrylic acid at one time consisted of combining acetylene, carbon monoxide and water at 40 to 55 atmosphere and 160 to 200 degree centigrade with nickel bromide and copper halide. So, copper halide is the co-catalyst here and example is acetylene hydrocarboxylation, this is acetylene and water, carbon monoxide, nickel bromide, copper X, 160 to 200 degrees centigrade you get this. So, this is acrylic acid. So, this part you can see this is coming from carbon monoxide and water part. This was published in many journals, one of the paper is Applied Catalysis A: General 2014.

Also the regioselective hydrocarboxylation of alkynes to saturated carboxylic acid can be accomplished using cobalt chloride, potassium cyanide and nickel cyanide, under phase transfer conditions. Polyethylene glycol PEG-4 is used as the phase transfer agent and the branched saturated acids form as the major products. So, here earlier we have seen that the double bond is there but here we will see that complete saturation. So, with phenylacetylene, phenylacetylene reacting carbon monoxide with cobalt chloride, potassium cyanide, PEG-400 and nickel cyanide, toluene solvent, potassium hydroxide base, you get this, this is a branch acid, branch acid is more 56 percent yield and this is linear acid, this is forming only 2 percent yield.

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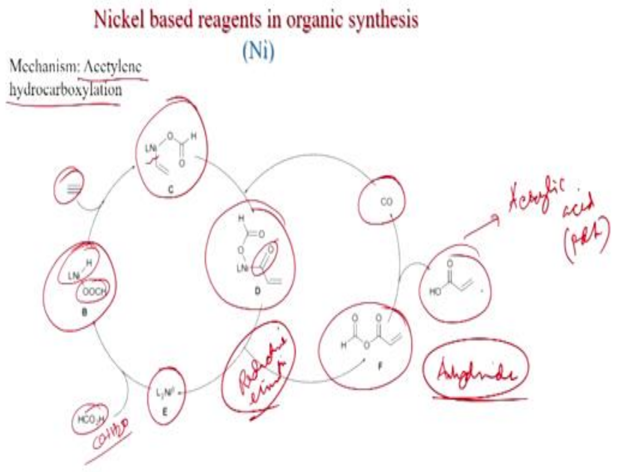

Nickel based reagents in organic synthesis

(Ni)

Mechanism: Acetylene hydrocarboxylation

So, first we will discuss the mechanism of the acetylene hydrocarboxylation. So, most likely nickel 0 is there as the active catalyst and this mechanism has been shown with formic acid, where this can be considered as carbon monoxide plus H2O also. So, this active intermediate is formed and here you can see there is a nickel hydride species is there. So, this nickel hydride that is actually reducing the acetylene and now this olefin is co-ordinated with the nickel. So, this nickel hydride species that is reducing the acetylene and you get a vinyl species now, and these vinyl species will react with carbon monoxide.

So, the carbon monoxide insertion will happen and this species will form that is D and in the D you can see the carbon monoxide insertion happens and D then the reductive elimination will happen. So, these reductive eliminations will give this, this is actually anhydride kind. And after elimination of carbon monoxide you get this acrylic acid. This is the product acrylic acid. So, main thing is that H2O, carbon monoxide reacts with nickel 0 to generate this nickel hydride species along with this and that hydride when acetylene is coordinating then it is converted into the vinyl species and then carbon monoxide comes. So, carbon monoxide inserts into this bond, after reductive elimination you get this anhydride and after anhydride the you get the carbon monoxide as well as the acrylic acid.

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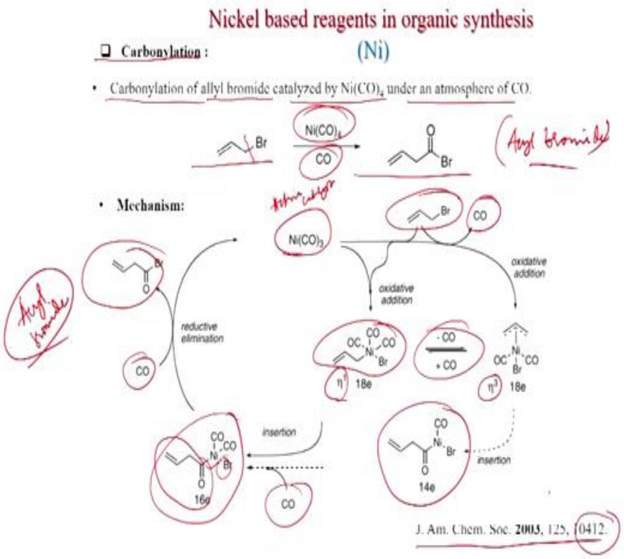

Nickel based reagents in organic synthesis

- ☐ **Carbonylation :** (Ni)

- Carbonylation of allyl bromide catalyzed by $Ni(CO)_4$ under an atmosphere of CO.

- **Mechanism:**

J. Am. Chem. Soc. **2003**, 125, 10412.

Now, we will discuss carbonylation. So, this mechanism we have already seen carbonylation. So carbonyl compound also you can generate, carbonylation of allyl bromide catalyzed by nickel tetracarbonyl under atmosphere of carbon monoxide. Like allyl bromide with nickel tetra carbonyl also carbon monoxide external and you get this acyl bromide. So, what is happening here, here one carbon monoxide has inserted and it then only get this acyl bromide. So, this is very useful reaction from allyl bromide you can get this acyl bromide. So, what could be the mechanism?

So, here nickel tetra carbonyl will convert to nickel tricarbonyl, this is the active catalyst actually, active catalyst and after reacting with allyl bromide this carbon nickel bond will form either, eta 1 or with 1 elimination of carbon monoxide the eta 3 species can form. This is the eta3. Because here this 1 carbon is attached here this whole allyl system is coordinated with the nickel, so, this eta 3 and they can equilibrate also after 1 molecule of carbon monoxide with here 3 carbon monoxide is there, here 2 carbon monoxide so, 1 elimination carbon monoxide will give this, alternatively addition will give this.

Now, this insertion will happen. So, this insertion possible to give these 14 electrons species, alternatively here also the insertion can happen from this intermediate also 1 carbon monoxide goes this and you get this. And for this to this unit 1 molecule of carbon monoxide that is also possible. Carbon monoxide comes and after reductive elimination the, you get this acyl bromide and you get this nickel tricarbonyl you get back. So, this is the reductive elimination happened at this component and this component bromide is giving the acyl bromide. This was published in JACS 2003, page number is 10412.

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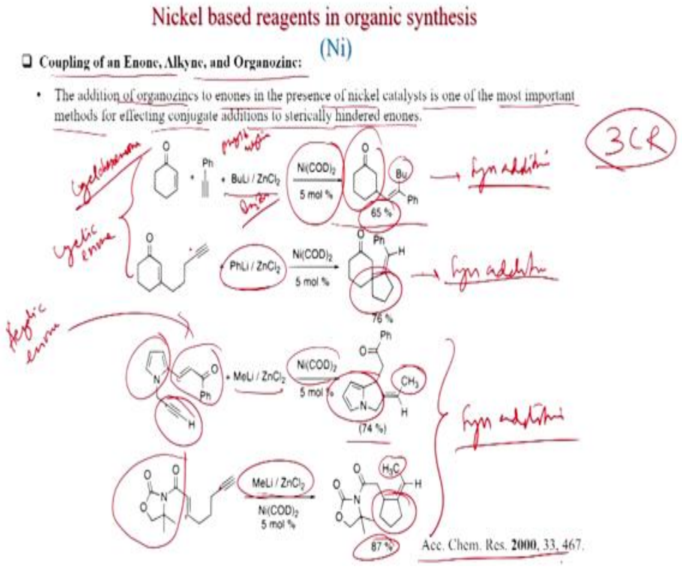

Nickel based reagents in organic synthesis

(Ni)

- **Coupling of an Enone, Alkyne, and Organozinc:**
  - The addition of organozincs to enones in the presence of nickel catalysts is one of the most important methods for effecting conjugate additions to sterically hindered enones.

Acc. Chem. Res. **2000**, 33, 467.

Another important reaction carried out by nickel is coupling of an enone, alkyne and organozinc. This is very important reaction, 3 components reaction, the addition of organozinc to enones in the presence of nickel catalyst is one of the most important methods for effecting conjugate additions to sterically hindered enones. Like here, this is cyclohexenone, this is phenyl acetylene, and butyl lithium zinc chloride so in situ you will get buttyl-zinc and with nickel COD 5 mol percent catalyst you get this. So, this is very important that the conjugate addition of alkyne to the enone is happening followed by the addition of the zinc species to the triple bond, this group and this group on the syn.

So, they are syn addition and this product you get 65 percent yield so, this is very important, 3 component reaction is called 3CR. Also, if you have an alkyne with the enone itself, then also this kind of reaction will happen and here if you see this carbon is adding to this carbon so that 1 2 3 4 5 so, that 5-member ring is forming. And after that this terminal carbon atom of the alkyne, your zinc species that is the diphenylzinc will add and you get these products. So, here also syn addition. So, that means some cyclic intermediate is there that we will discuss that is why you are getting this syn geometry and this product is formed in 76 percent yield.

Also if you see this one, here is a heterocyclic moiety and this is the alpha beta unsaturated ketone. So, this is acyclic enone, acyclic, cyclic enone and these 2 are cyclic enone. So, acyclic enone also it can do the reaction with this alkyne, here dimethyl zinc will form in situ nickel COD, 5 mol percent yield you get this. So, here also this carbon is attacking here 1 2 3 4 5 so, this 5 member is forming and this terminal carbon atom there is methyl group is adding and you get this product in 74 percent yield.

Also this one you can see the oxazolidinone moiety is there, here also so, these are all ketone, this oxazolidinone. So, this carbon will attack will react with this carbon so, 1 2 3 4 5, 5 member ring is forming and this terminal carbon where this dimethlyzinc will add and we will this methyl and here also the syn addition and this product is forming in 87 percent yield. So, all cases the syn addition is happening, this is in gel. So, different, enone not only cyclic enone, acyclic enone can also be used in this 3 component reaction and you get, can get this cyclic product sometimes, if you have the alkyne and the enone in the same molecule then you get the cyclic compound. This has reviewed in Account Chemical Research 2000, page number is 467.

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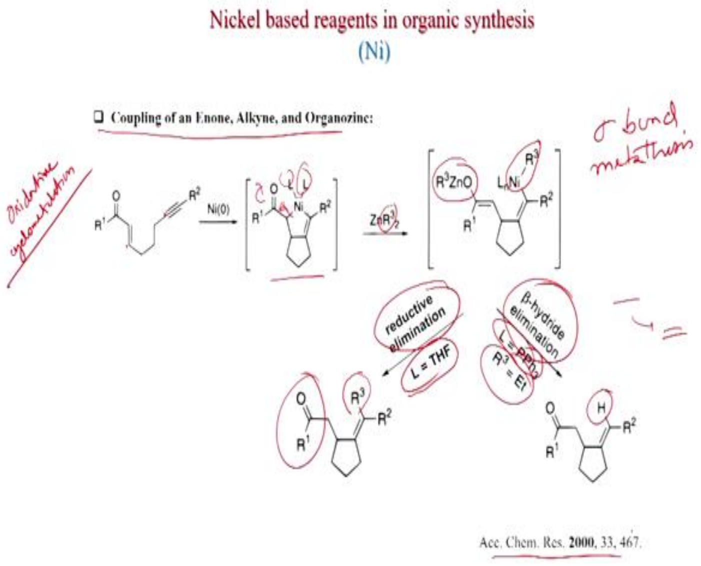
Nickel based reagents in organic synthesis

(Ni)

❑ Coupling of an Enone, Alkyne, and Organozinc:

Acc. Chem. Res. 2000, 33, 467.

So, what can be the mechanism of an enone, alkyne and organozinc. If we have a enone, this is actually enone and alkyne are in the same molecule we have syn also earlier where they can be the same molecule and with nickel 0 this kind of thing is happening. So, this carbon is adding to this carbon so, that 5-member ring is forming, this one and this carbon is coordinated with the nickel and nickel is there so 5 membered cycle is formed and this process is called oxidative cyclometalation. So, oxidative cyclometalation is happening, here, because nickel is going to nickel plus II and now, zinc will come here, here the zinc, that R3 group is coming to the nickel and this is bondage breaking and you get an enolate here, there the R3 Zn group is coming and this process is called sigma bond metathesis.

And now the reductive elimination happens so, after reductive elimination what will happen? This of course with this will go to the enol and enol will go to the carbonyl and here this reductive elimination happens nickel eliminates and R3 adds here. So, what happens the R3 because nickel is adding to this side R3 can come through only this side, and that is why the selectivity is coming. So, R3 can only come from the side of nickel and this kind of reductive elimination happens when L is equal to THF.

So, ligand, this ligand if it is THF that means THF solvent, this kind of product is forming. Alternatively, if you use the external ligand like triphenylphosphine and R3 is equal to ethyl, so ethyl if you see this can convert to ethylene also. So, ethylene that is the beta hydride elimination, after beta hydride elimination the hydrogen will come here that is also coming from the nickel side. So, when THF is there then the reductive elimination will give the component with the alkyl zinc. On the other hand, if ligand is triphenylphosphine and R3 is equal to ethyl, that is diethyl zinc then the beta hydride elimination can happen and you get this hydrogen here. So, here, all substituted olefin, here tri substituted olefin is forming. And this was also the reviewed in Account of Chemical Research 2000, page number is 467.

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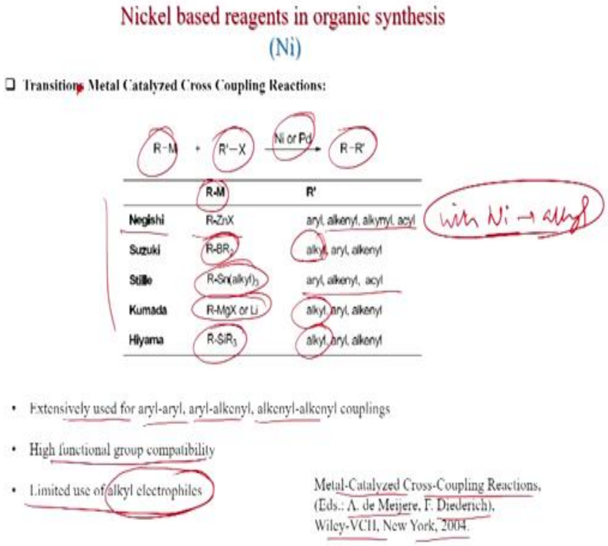

Nickel based reagents in organic synthesis

(Ni)

☐ **Transitions Metal Catalyzed Cross Coupling Reactions:**

$$R{-}M + R'{-}X \xrightarrow{\text{Ni or Pd}} R{-}R'$$

	R-M	R'
Negishi	R-ZnX	aryl, alkenyl, alkynyl, acyl
Suzuki	$R\text{-}BR_2$	alkyl, aryl, alkenyl
Stille	$R\text{-}Sn(alkyl)_3$	aryl, alkenyl, acyl
Kumada	R-MgX or Li	alkyl, aryl, alkenyl
Hiyama	$R\text{-}SiR_3$	alkyl, aryl, alkenyl

with Ni → alkyl

- Extensively used for aryl-aryl, aryl-alkenyl, alkenyl-alkenyl couplings
- High functional group compatibility
- Limited use of alkyl electrophiles

Metal-Catalyzed Cross-Coupling Reactions,
(Eds.: A. de Meijere, F. Diederich),
Wiley-VCH, New York, 2004.

So, now we will discuss transition metal catalyzed cross coupling reactions. So, these are the overall cross coupling reactions. R-M, R dash X, nickel or palladium you get this cross coupled product. So, Negishi, RZnX is the component RM is R-ZnX, Suzuki R-BR2, Stille R-Sn alkyl whole 3, Kumada R-MgX or R-Li, Hiyama R-SiR3 and some cases alkyl like boronic acid, you already discussed alkyl can be used, Stille we have discussed, aryl mainly but Kumada alkyl can be also employed and Negishi we did not discuss any alkyl. So, here with nickel we will discuss, with nickel you can use the alkyl.

So, that is an important discovery in Negishi coupling. So, these methods have been extensively used for aryl allyl, aryl alkenyl, alkenyl alkenyl couplings, high functional group compatibility and limited use of alkyl electrophiles so, this is important. So, nickel chemistry can solve this problem that alkyl electrophiles can be used and this was reviewed in Metal-Catalyzed Cross Coupling Reaction, A. de Meijere and Diederich, Wiley VCH New York 2004, this is a book.

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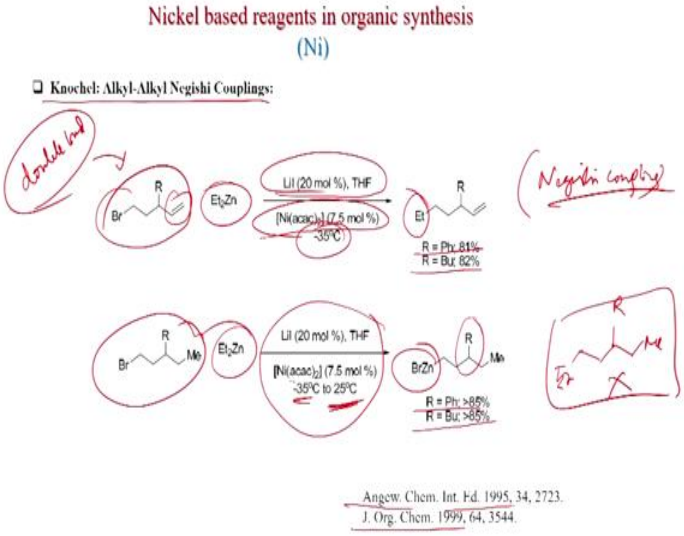

Nickel based reagents in organic synthesis

(Ni)

❑ Knochel: Alkyl-Alkyl Negishi Couplings:

Angew. Chem. Int. Ed. 1995, 34, 2723.
J. Org. Chem. 1999, 64, 3544.

So, Knochel first found this alkyl-alkyl Negishi coupling. This is an important discovery and he found that if you have this alkyl bromide and if a double bond is there so this is very important, if a double bond is there in the substrate, then only with diethyl zinc, lithium iodide 20 mol percent and nickel acetylacetonate 7.5 mol percent at minus 35 degrees centigrade in THF solvent, you get this cross coupled product. So, bromine is displaced by ethyl that is the Negishi coupling is happening here. And with R is equal to Ph you get 81 percent yield, R is equal to butyl you get 82 percent yield. So, this method is quite efficient. Now, whether this olefin is important or not, that's why he performed another experiment, actually this olefin is now saturated. So, this is alkyl group and similar substitution of there, now with diethylzinc and identical conditions, lithium iodide THF minus 35 degree centigrade, even start at room temperature also, you do not get this.

So, this did not happen. This product did not form, there is cross coupling did not happen. What happened? This Br is converted to ZnBr and this product is formed that is the zinc species is formed in 85 percent yield, when R is equal to phenyl and also similar yield when R is equal to butyl. So, that means when there is an olefin then only the cross coupling reaction in happening, without olefin the cross coupling will not happen. And this tells that nickel only can bind with that double bond and that is why it is facilitating this Negishi coupling. We will see the mechanism. So, this was published in Angew. Chem. 1995, also JOC 1999.

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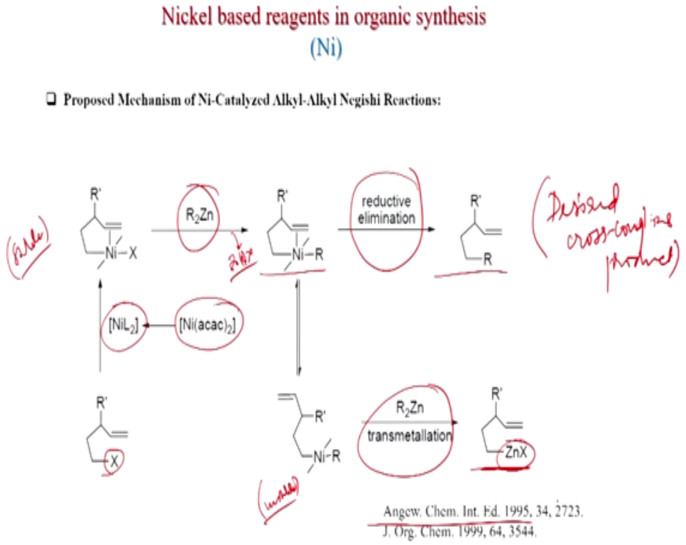

Nickel based reagents in organic synthesis

(Ni)

❑ Proposed Mechanism of Ni-Catalyzed Alkyl-Alkyl Negishi Reactions:

Angew. Chem. Int. Ed. 1995, 34, 2723.

J. Org. Chem. 1999, 64, 3544.

So, what could be the mechanism for this nickel catalyzed alkyl-alkyl Negishi reaction? So, this is the starting material X is equal to bromide but iodide, other things can also be used and now, nickel acetylacetonate is converting to NiL2 that is the nickel 0 and now it can coordinate. So, it can displace the halide and it is coordinated with a double bond. So, this is very stable because when it is coordinated with double bond it is quite stable and now the zinc will come R2Zn. So, this species will form and Zn RX will go out, so, this species is formed this also coordinate with the double bond. Now, this can be in equilibrium with these there is no coordination, but this is unstable. So, when there is no coordination then this is unstable.

And if it is unstable then only the transmetallation will happen with R2Zn and you get this ZnX, so, no cross coupling, because this is unstable and this carbon nickel bond will react with the diethyl zinc to generate this zinc species so, zinc will react here. Alternatively, if this is stable then the reductive elimination will happen and after reductive elimination you get this. So, this is the desired product, desired cross coupling product; Negishi coupling can be performed and these was the papers we already told.

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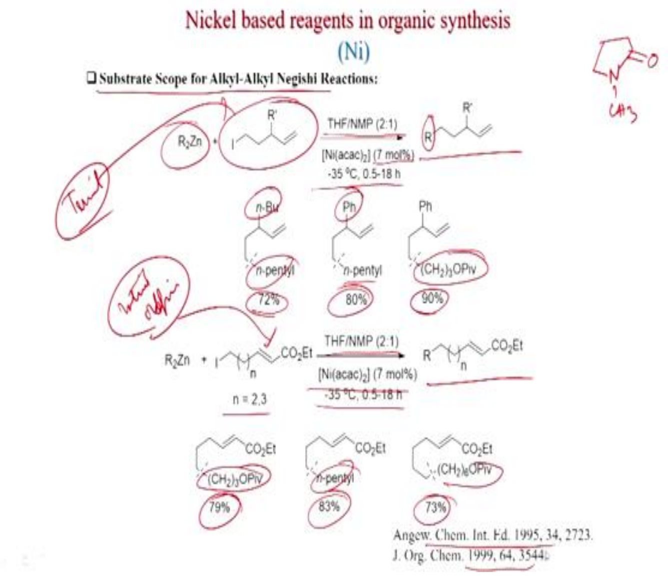

Nickel based reagents in organic synthesis

(Ni)

❑ Substrate Scope for Alkyl-Alkyl Negishi Reactions:

Angew. Chem. Int. Ed. 1995, 34, 2723.
J. Org. Chem. 1999, 64, 3544.

Now, what is the substrate scope for alkyl-alkyl Negishi reaction like here is the iodide now, and R2Zn THF, NMP; this is the NMP N- methyl pyrrolidone and nickel acetylacetonate, 7 mol percent, minus 35 degrees centigrade and you get this cross coupled product. So, R is coming from the zinc and what is the scope here, you can see this R dash is equal to butyl, and R is equal to N-pentyl. So, both are alkyl that is the major thing here and you get this 72 percent here if this is phenyl, this is also N-pentyl 80 percent, here phenyl, this is this O- pivaloyl group is present, also you get high yield 90 percent.

Not only this kind of terminal olefin, internal olefin also can be used. So, this is terminal and this is internal olefin, internal olefin, within CO2 Et group of course conjugated, and here also, this reaction happens and yield can be 2 to 3 with the same condition THF NMP 2 is to 1 nickel acetylacetonate, 7 mol percentage, minus 35 degrees centigrade and you get this cross coupled product. And here also you can see different R group can be used CH2O3, O pivaloyl it giving 79 percent and N-pentyl given 83 percent, (CH2)6-O-pivaloyl giving 73 percent yield and this is the paper Angew. Chem. 1995 and JOC in 1999.

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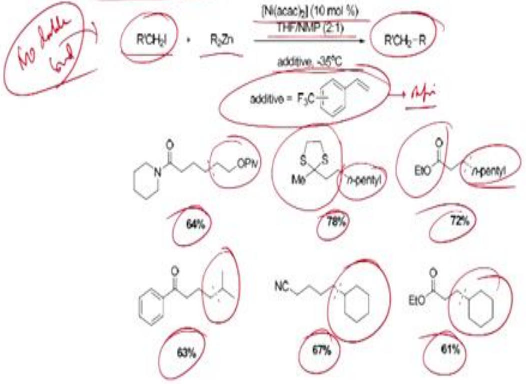
Nickel based reagents in organic synthesis

(Ni)

- Extension of Knochel's Methodology:



Angew. Chem. Int. Ed. 1998, 37, 2387.
J. Org. Chem. 1999, 64, 3544.

So, what we have seen that both terminal as well as internal olefin conjugated with an ester group can be used for this Negishi coupling reaction. So, extension of Knochel's methodology, now it is important that if you do not have the olefin component in the substrate, whether you can use an additive that is important, and he found that this also idea nice to work so suppose this is iodide, this is a zinc of course here no olefin is present, no double bond. And nickel acetylacetonate, 10 mol percent, THF NMP 2 is to 1 additive minus 35 degrees centigrade. Now, this is the additive. So, this is the olefin that of course will coordinate with the nickel and it is not with a substrate but it is additive.

So, you can remove later and you get the desired conversion that is important; the Negishi coupling is happening and you can see here this bond if you break it that this part is coming from the iodide and this part is coming from the zinc you get 64 percent yield, here also the diethyl moiety iodide and N-pentyl zinc you get 78 percent, here the ester group is there and this is the iodide here and N-pentyl zinc you get 72 percent yield. Here also secondary, here also secondary and you get good yields for this product. So, this strategy is very useful, that if you have an olefin additive then also you can perform this Negishi cross coupling reaction and different alkyl groups can be incorporated. This was published in Angew Chem. in 1998 and also JOC 1999.

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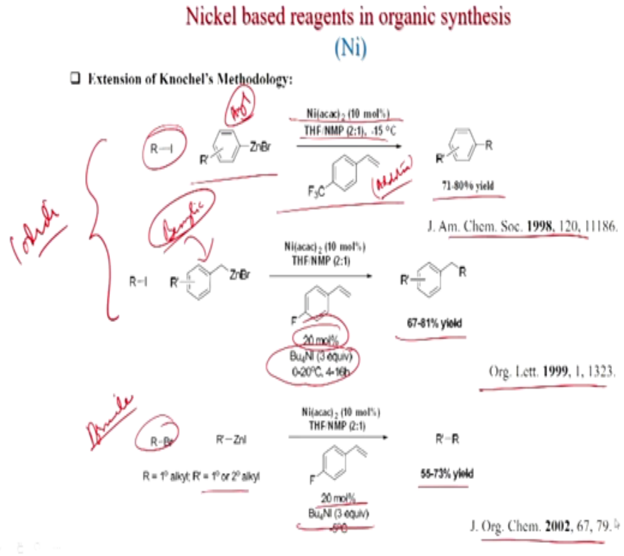

Nickel based reagents in organic synthesis

(Ni)

❑ Extension of Knochel's Methodology:

J. Am. Chem. Soc. **1998**, 120, 11186.

Org. Lett. **1999**, 1, 1323.

J. Org. Chem. **2002**, 67, 79.

Some more extension here, we can see not only the alkyl, so this is aryl. Aryl group can also be used, nickel acetylacetonate, THF NMP and this is additive. So this is additive and you get this cross coupled product in 71 to 80 percent yield, this was published in JACS 1998. Now, benzylic group can be also used, benzylic group that is the benzylic zinc bromide here with aryl iodide and you get this product, under the same condition only additionally you can use tetra butyl ammonium iodide 3 equivalent and this is now in 20 mol percent this olefin. So, it is not 100 mol percent, in this case 20 mol percent then you get this cross coupled product, this was published in Organic Letters, 1999. Also here, bromide is there. So, bromide and these are iodide, here also this reaction happens R dash 1 degree, 2 degree with this 20 mol percent additive then this tetra butyl ammonium iodine use 3 equivalent and you get this products in good yield and this was published in JOC 2002, page number is 79.

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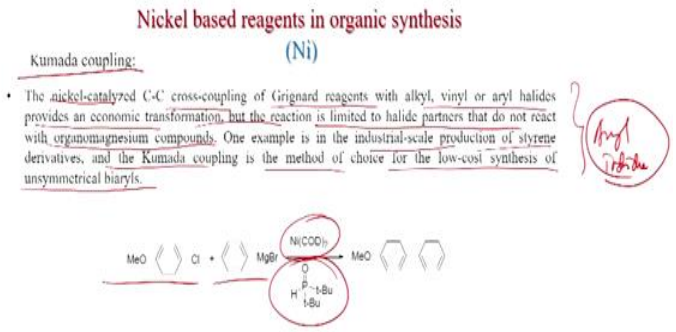

Nickel based reagents in organic synthesis

(Ni)

Kumada coupling:

- The nickel-catalyzed C-C cross-coupling of Grignard reagents with alkyl, vinyl or aryl halides provides an economic transformation, but the reaction is limited to halide partners that do not react with organomagnesium compounds. One example is in the industrial-scale production of styrene derivatives, and the Kumada coupling is the method of choice for the low-cost synthesis of unsymmetrical biaryls.

Aryl Iodide

Kumada coupling now we will discuss. So, nickel catalyzed C-C cross coupling of Grignard reagents with alkyl, vinyl or aryl halides provides an economic transformation, but the reaction is limited to halide partners that do not react with organomagnesium compounds. One example is in the industrial-scale production styrene derivatives, and the Kumada coupling is the method of choice for the low-cost synthesis of unsymmetrical biaryl. So, here in normal Kumada coupling we will use the aryl iodide because the Grignard will not react with the aryl iodide but aliphatic iodide the Grignard will react. So, that is a drawback but with nickel we can solve that problem also. So, this is the aryl halide, aryl magnesium bromide, nickel COD this the phosphine oxide and you get this cross coupled product.

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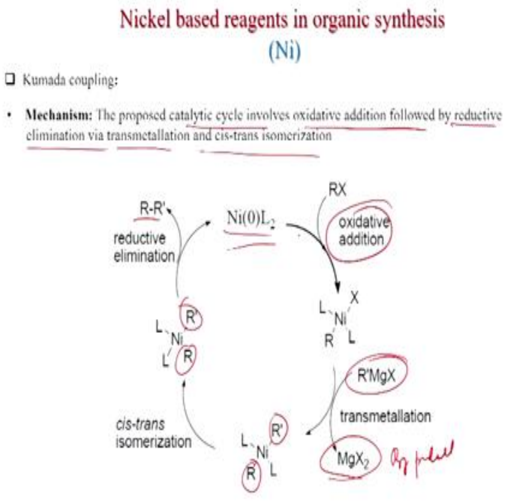

Nickel based reagents in organic synthesis

(Ni)

☐ Kumada coupling:

- **Mechanism:** The proposed catalytic cycle involves oxidative addition followed by reductive elimination via transmetallation and cis-trans isomerization

And the proposed catalytic cycle involves oxidative addition followed by reductive elimination via transmetallation and cis-trans isomerization. This is the mechanism, nickel 0 and RX. This is similar like palladium chemistry, this Kumada coupling reaction here first step is the oxidative addition will happen and RX comes and now the transmetallation will happen. So, R dash will incorporate with nickel, nickel now and MgX2 will be byproduct, byproduct and now cis-trans isomerization will happen. So, there will come in the cis position now, so, that the reductive elimination will be facilitated and after reductive elimination you get this product and nickel 0 will be regenerated.

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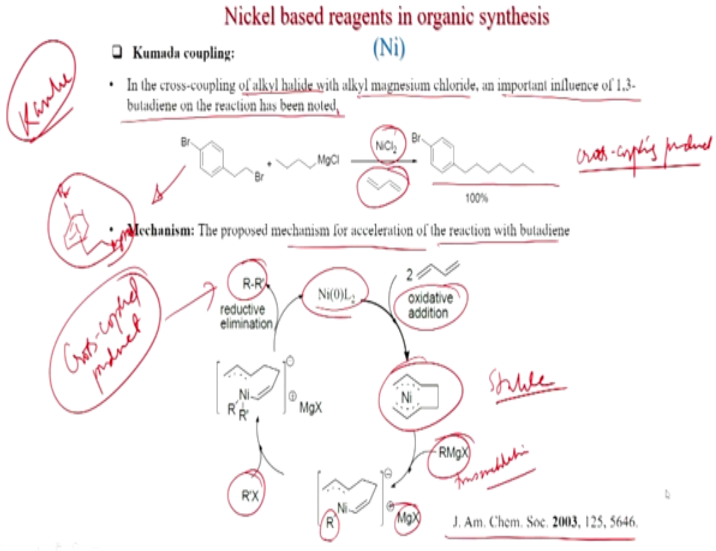

Nickel based reagents in organic synthesis

(Ni)

- ☐ **Kumada coupling:**
  - In the cross-coupling of alkyl halide with alkyl magnesium chloride, an important influence of 1,3-butadiene on the reaction has been noted,
  - **Mechanism:** The proposed mechanism for acceleration of the reaction with butadiene

J. Am. Chem. Soc. **2003**, 125, 5646.

So, Kumada coupling of alkyl halide with alkyl magnesium chloride, an important influence on 1, 3-butadiene on the reaction has been noted. So, this is very important that earlier we told that alkyl halide cannot be used in Kumada coupling, because Grignard will react. So, what discover is that with nickel chloride and 1, 3-butadiene if it is there then you can get this cross coupled product. So, this is the cross coupling. So, if you do not use this system what will happen? This can be give a metal halogen exchange, also MgBr2 can be formed, and that will create problem, but it has been found with nickel chloride and 1, 3-butadiene, so, this is also important, this is Kambe that we will discuss its mechanism also, developed by Kambe and this product is formed in 100 percent yield.

So, the proposed mechanism for acceleration of the reaction with butadiene, of course, this nickel 0 will coordinate with the butadiene and that is the oxidative addition will happen and you get this kind of system, nickel is here nicely sitting between 2 allyl system. So, it is very much stable and now the transmetallation will happen. So, this is the transmetallation and R will coordinate with the nickel, so, nickel comes to the terminal carbon now and this R group from the Grignard and then this is forming and after that R dash X will come, R dash X also will react with nickel and you get this species and after reductive elimination you get the cross coupled products. So, this is the product. So, the cross coupled product is forming here after reductive elimination, this was published in JACS 2003, page number is 5646.

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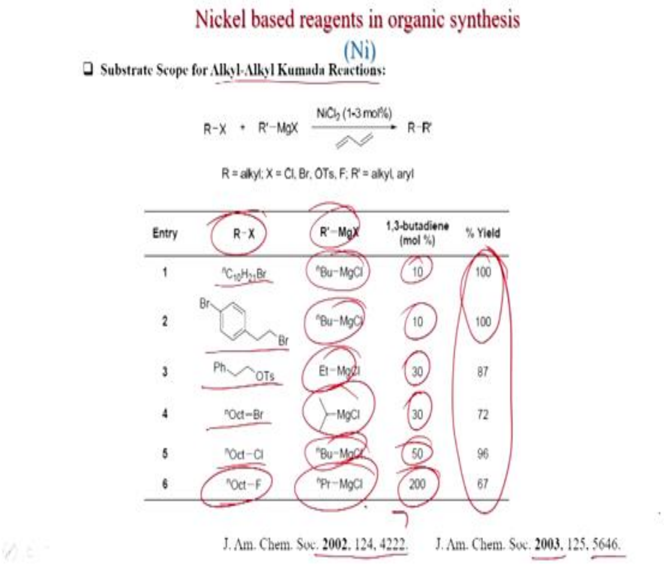

Nickel based reagents in organic synthesis

(Ni)

❑ Substrate Scope for Alkyl-Alkyl Kumada Reactions:

$$R-X + R'-MgX \xrightarrow{NiCl_2\ (1\text{-}3\ mol\%)} R-R'$$

R = alkyl; X = Cl, Br, OTs, F; R' = alkyl, aryl

Entry	R-X	R'-MgX	1,3-butadiene (mol %)	% Yield
1	$^{n}C_{10}H_{21}Br$	^{n}Bu–MgCl	10	100
2	Br Br	^{n}Bu–MgCl	10	100
3	Ph OTs	Et–MgCl	30	87
4	^{n}Oct–Br	–MgCl	30	72
5	^{n}Oct–Cl	^{n}Bu–MgCl	50	96
6	^{n}Oct–F	^{n}Pr–MgCl	200	67

J. Am. Chem. Soc. **2002**, 124, 4222. J. Am. Chem. Soc. **2003**, 125, 5646.

So, what is the scope of this reaction, alkyl-alkyl Kumada coupling the scope. Cross coupling of primary alkyl halides and Grignard reagents. So, here are R-X, R dash MgX, nickel chloride, 1, 3-butadiene, you get this, X is equal to can be fluoride, chloride, bromide. So, all halides can work and you get this cross coupling product. Also, alkyl fluorides can also be used as the coupling partners. So, R-F also can be used. So, this is very important that alkyl fluoride can also be used in this Kumada coupling and catalytic nickel chloride or copper chloride also, and 1, 3-butadiene you get this cross coupled product, this was published JACS 2002. Now, substrate scope that is what we are looking for what kind of substrates can be used for this nickel catalyses Kumada coupling.

So, this is the R-X, so, this is the bromide, alkyl bromide, this is tosylate, this is bromide, chloride and fluoride also, and what kind of Grignard generally magnesium chlorides are used, N-butylmagnesium chloride because they are less reactive than bromide, N-butyl, ethyl, isopropyl magnesium chloride, N-butyl, N-propyl and 1, 3-butadiene you can use mol percent earlier also you have seen the additive, you can use mol percent like here 10 mol percent, here 30, 30 and octyl chloride here used 50 and when it is fluoride then 2 equivalent.

So, this is important because fluoride are unreactive substrates so for that you need 2 equivalent of 1, 3-butadiene and the yields are moderate to excellent. So, here, in this case, you get almost quantitative yield, almost 100 percent. So, this method is very useful that define alkyl bromide, alkyl tosylate as well as alkyl fluoride can be used and you get this cross coupling products in good yield and this was published in JACS 2002, 4222 also JACS 2003, 5646.

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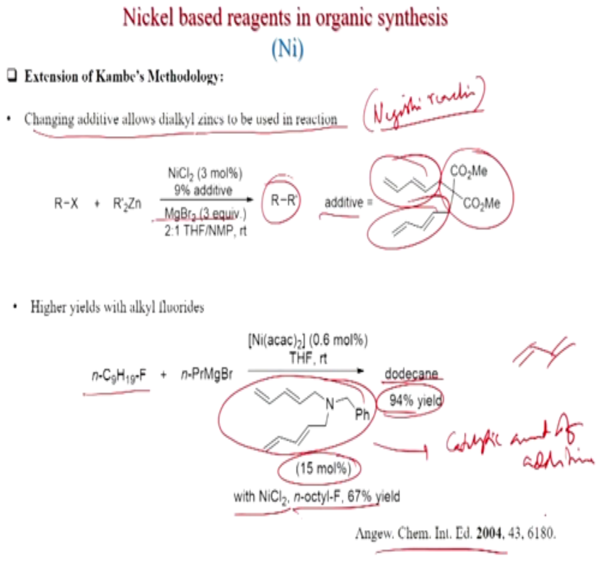

Nickel based reagents in organic synthesis

(Ni)

☐ **Extension of Kambe's Methodology:**

- Changing additive allows dialkyl zincs to be used in reaction (Negishi reaction)

$R{-}X + R'_2Zn \xrightarrow[\text{MgBr}_2\text{ (3 equiv.)},\ 2:1\text{ THF/NMP, rt}]{\text{NiCl}_2\text{ (3 mol\%)},\ 9\%\text{ additive}} R{-}R'$ additive =

- Higher yields with alkyl fluorides

$n\text{-}C_9H_{19}\text{-}F + n\text{-PrMgBr} \xrightarrow{[\text{Ni(acac)}_2]\text{ (0.6 mol\%)},\ \text{THF, rt}}$ dodecane 94% yield

(15 mol%)

with $NiCl_2$, n-octyl-F, 67% yield

Catalytic amount of addition

Angew. Chem. Int. Ed. **2004**, 43, 6180.

So, changing additive allows dialkyl zinc to be used in the reaction that is of course, Negishi kind of reaction. So, just he found that whether this strategy can also work that is the di-ene strategy di-ene additive and then he found that this kind of additive there are 2 di-ene system and there is melanin moiety here and this additive, along with MgBr2, 3 equivalents will give this Negishi coupling product in good yield and with fluoride earlier we have found that fluoride you have to use the 2 equivalent but if you use the this di-ene then only 15 mol percent also is enough.

So, here catalytic amount of additive. So, that means that this additive is better than 1, 3-butadiene because this additive only 15 mol percent is enough to give this Kumada coupling product dodecane in 94 percent yield and with NiCl2 this also works, but the yield is less. So, it would displace nickel acetylacetone with nickel chloride and the yield is less; this was published in Angew. Chem. 2004.

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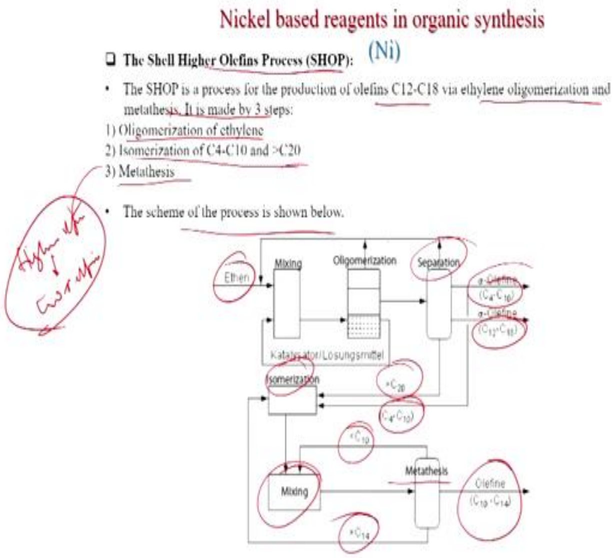

Nickel based reagents in organic synthesis

- The Shell Higher Olefins Process (SHOP): (Ni)

- The SHOP is a process for the production of olefins C12-C18 via ethylene oligomerization and metathesis. It is made by 3 steps:

1) Oligomerization of ethylene
2) Isomerization of C4-C10 and >C20
3) Metathesis

- The scheme of the process is shown below.

Now we will discuss Shell Higher Olefins process, so, this is from ethylene you can get the higher olefin. So, this is an industry-process for the production of olefins C12-C18 by ethylene oligomerization and metathesis, it is made by 3 steps oligomerization of ethylene, first, then the isomerization of C4-C10 and greater than C20 and then metathesis. Metathesis is important we will see that in metathesis you can get higher olefins to lower olefins. So, higher olefins to lower olefins conversation and the scheme of the process is shown below, this is the ethylene is coming, mixing, oligomerization, separation, so, you separate this C4-C10, C12-C18 also isomerization you can do, greater than C20 here isomerization, here C4-C10 isomerization, then mixing, then less than C10 and greater than C14, you do the metathesis and you get the olefins C10-C14. So, this is an important thing that different molecular weight, olefins you get.

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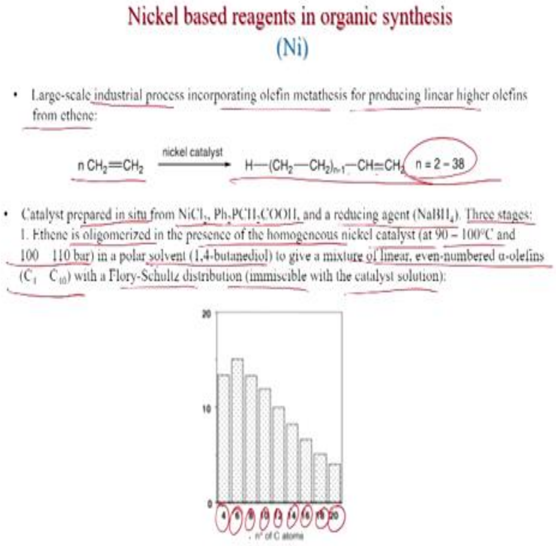

Nickel based reagents in organic synthesis

(Ni)

- Large-scale industrial process incorporating olefin metathesis for producing linear higher olefins from ethene:

$$n\,CH_2{=}CH_2 \xrightarrow{\text{nickel catalyst}} H{-}(CH_2{-}CH_2)_{n-1}{-}CH{=}CH_2 \quad \boxed{n = 2 - 38}$$

- Catalyst prepared in situ from $NiCl_2$, Ph_2PCH_2COOH, and a reducing agent ($NaBH_4$). Three stages:
  1. Ethene is oligomerized in the presence of the homogeneous nickel catalyst (at 90 – 100°C and 100 110 bar) in a polar solvent (1,4-butanediol) to give a mixture of linear, even-numbered α-olefins (C_4 C_{10}) with a Flory-Schultz distribution (immiscible with the catalyst solution):

Large scale industrial-process incorporating olefin metathesis for producing linear higher olefins from ethene. So, this is the ethylene nickel catalyst, you can get this H-(CH2-CH2) n -1 CH =CH2. So, this is the olefin and n is equal to 2 to 38. So, different higher olefins you can get. So, this is an important reaction and the catalyst is prepared in situ from nickel chloride, diphenyl phosphino acetic acid and reducing agent sodium borohydride. There are 3 stages, first one in the ethylene is oligomerized in the presence of the homogeneous nickel catalyst and 90 to 100 degree centigrade and 100 to 110 bar in a polar solvent like 1, 4-butanediol to give a mixture of linear even numbered alpha-olefins with a Flory-Schultz distribution immiscible with the catalyst solution. So, this is the C4, C6, C8, C10, C12, C14, 16, 18, 20.

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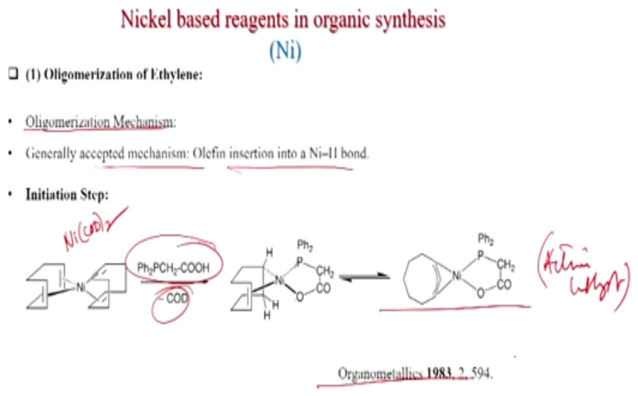

Nickel based reagents in organic synthesis

(Ni)

❑ (1) Oligomerization of Ethylene:

- Oligomerization Mechanism:
- Generally accepted mechanism: Olefin insertion into a Ni–H bond.
- Initiation Step:

Organometallics 1983, 2, 594.

And generally accepted mechanism olefin insertion into a nickel hydrogen bond that we will see, so, first this step is happening this is the nickel COD2 and after that Ph2 PCH2 COOH when it is reacting because it is bidentate you can see. So, COD is eliminated one COD. And now also you see this kind of one double bond is already reduced in this process also. And now, this allyl system will coordinate with the nickel. So, this is the active catalyst actually, active catalyst and this was published in organometallics, 1983.

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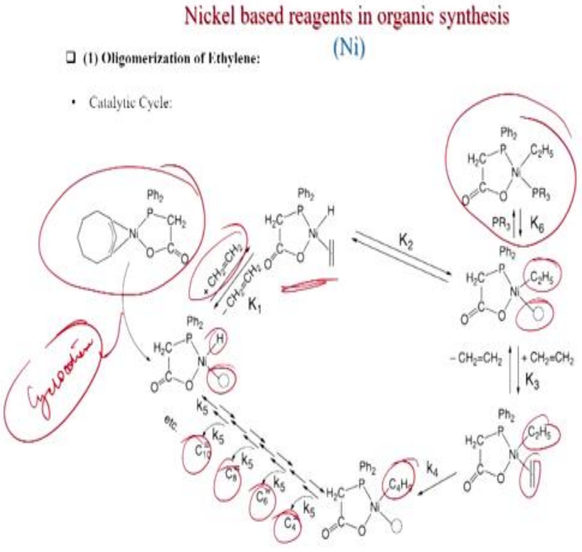

Nickel based reagents in organic synthesis

(Ni)

❑ (1) Oligomerization of Ethylene:

- Catalytic Cycle:

So, this is the active catalyst. So, after cyclooctene. So, here cyclooctene elimination, cyclooctene elimination you get this there is a vacant site and this vacant site will be taken by ethylene. So, after cyclooctene elimination you get this vacant site there is of course a nickel hydride bond and then you get this and now this hydride will add this kind of polymerization reaction we have seen already; titanium catalyzed and here also this ethyl group coming there is a vacant site now, again this ethylene will come, this ethylene will go to this, so, the higher will form C4H9 now. So, like that C4, C6, C8, C10 all even number of carbon atoms you get because ethylene multiplication of ethylene. So, C4, C6, C8, C10 different olefin components you can get and this is also K6 is phosphine PR3 is reacting with to the vacant site, this is syn reaction.

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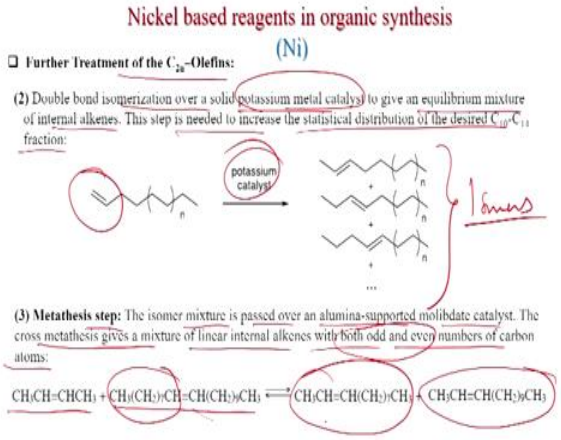

Nickel based reagents in organic synthesis

(Ni)

☐ **Further Treatment of the C_{2n}–Olefins:**

(2) Double bond isomerization over a solid potassium metal catalyst to give an equilibrium mixture of internal alkenes. This step is needed to increase the statistical distribution of the desired C_{10}-C_{14} fraction:

(3) Metathesis step: The isomer mixture is passed over an alumina-supported molibdate catalyst. The cross metathesis gives a mixture of linear internal alkenes with both odd and even numbers of carbon atoms:

$CH_3CH{=}CHCH_3 + CH_3(CH_2)_7CH{=}CH(CH_2)_9CH_3 \rightleftharpoons CH_3CH{=}CH(CH_2)_7CH_3 + CH_3CH{=}CH(CH_2)_9CH_3$

Now, further treatment of the C, C2n olefins double 1 isolation over a solid potassium metal catalyst to give an equilibrium mixture of internal alkenes, this step is needed to increase the statistical distribution of the desired C10-C14 fraction. So, whatever we have got from the oligomerization that is only the terminal olefins. So, these terminal olefins if you want to isomerize you have to use potassium catalyst and you can see different isomerics, so, here it migrated to here, here in migrate to another carbon atoms so this kind of isomers you can get. Metathesis step; the isomer mixture is passed over an alumina-supported molybdate catalyst.

The cross metathesis gives a mixture of linear internal alkenes with both odd and even numbers of carbon atom. So, after metathesis now you can get odd and even. So, here you can 2 butene, here another internal olefin doing cross metathesis. So, after cross metathesis this part is adding to this part. So, this is becoming shorter now, and this part also is catering to this, this has become shorter now and now there might be possibility of. So, this cross metathesis is a very important because here you can get the odd number olefins also.

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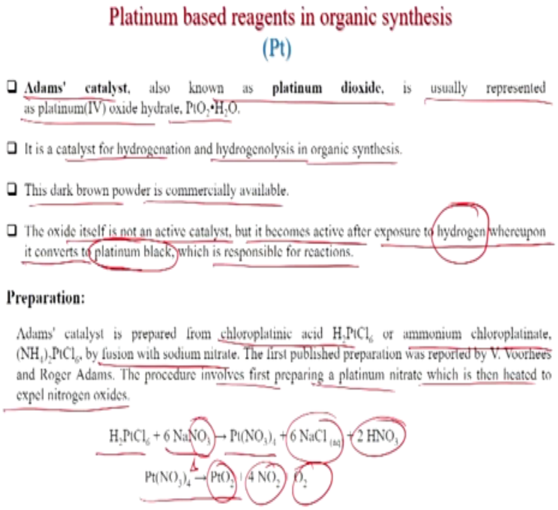

Platinum based reagents in organic synthesis

(Pt)

- ☐ **Adams' catalyst**, also known as **platinum dioxide**, is usually represented as platinum(IV) oxide hydrate, $PtO_2{\bullet}H_2O$.
- ☐ It is a catalyst for hydrogenation and hydrogenolysis in organic synthesis.
- ☐ This dark brown powder is commercially available.
- ☐ The oxide itself is not an active catalyst, but it becomes active after exposure to hydrogen whereupon it converts to platinum black, which is responsible for reactions.

Preparation:

Adams' catalyst is prepared from chloroplatinic acid H_2PtCl_6 or ammonium chloroplatinate, $(NH_4)_2PtCl_6$, by fusion with sodium nitrate. The first published preparation was reported by V. Voorhees and Roger Adams. The procedure involves first preparing a platinum nitrate which is then heated to expel nitrogen oxides.

$$H_2PtCl_6 + 6\,NaNO_3 \rightarrow Pt(NO_3)_4 + 6\,NaCl_{(aq)} + 2\,HNO_3$$

$$Pt(NO_3)_4 \xrightarrow{\Delta} PtO_2 + 4\,NO_2 + O_2$$

Now, we will discuss platinum based reagents in organic synthesis. So, first we will discuss Adam's catalyst. Adam's catalyst also known as platinum dioxide is usually represented as platinum oxide hydrate PtO to H2O. It is a catalyst for hydrogenation and hydrogenolysis in organic synthesis. This dark brown powder is commercially available. The oxide itself is not an active catalyst, but it becomes active after exposure to hydrogen whereupon it converts to platinum black, which is responsible for the reactions.

So, after exposure to hydrogen it is going to platinum black and that is the active catalyst for the reaction. So, how Adam's catalyst can be prepared? It is prepared from chloroplatinic acid by fusion or ammonium chloroplatinate by fusion with sodium nitrate, so, here you can see chloroplatinic acid H2PtCl6, so, there nitrate you get platinum NO3 4. So, 4 NO3 is coming here 6NaCl and 2NO3 is going to 2HNO3. And now this platinum nitrate can convert to platinum oxide, 4NO2, O2, so, both are gas and platinum oxide you get. This procedure involved first preparing a platinum nitrate which is then heated to expel nitrogen oxides. So, this you have to heat. Platinum nitrate you have to heat then platinum oxide, nitrogen dioxide and oxygen is formed.

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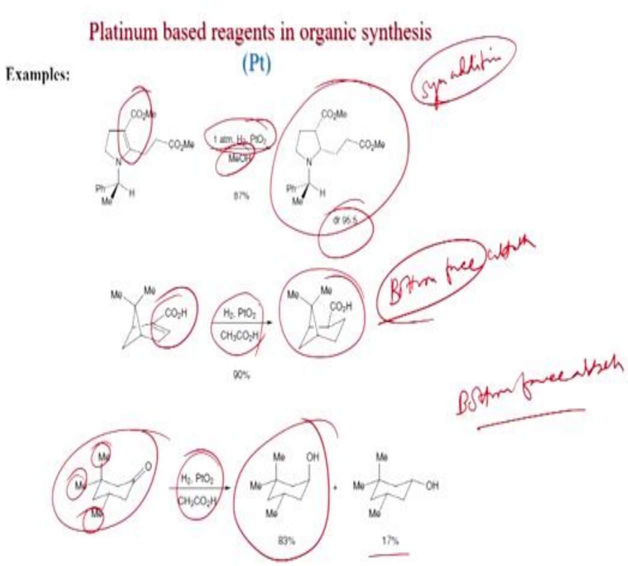

Platinum based reagents in organic synthesis

(Pt)

Examples:

Examples, hydrogenation is mainly used here you can see 1 atmosphere hydrogen platinum oxide to get this. So, this is syn addition the hydrogenation is happening, so, syn addition only possible here and dr is 95 is to 5. Here in alpha-beta unsaturated ester, here it is an acid, alpha-beta unsaturated with H2, PtO2, acetic acid, so, protic solvent generally you have to use and you get this. So, here also syn addition is happening mostly and from the bottom face the attack is taking from the bottom face, bottom face attack and in this case also, the cyclohexanone here methyl is there, 3 methyl groups but this is in the axial. So, this will block the top face, so reduction will take place from only bottom face. So, bottom face attack here also and you get this product as a major in 83 percent and this is the minor 70 percent yield. So, not only the double bond, a carbonyl also can be reduced with this platinum oxide hydrogen system.

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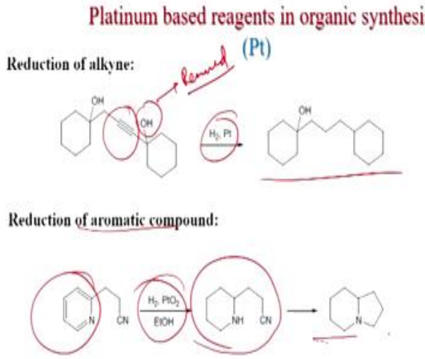

Platinum based reagents in organic synthesis

(Pt)

Reduction of alkyne:

Reduction of aromatic compound:

This is a triple bond reduction. So, here H2Pt platinum oxide only and then you get this triple bond reduction as well as the propargylic OH group. This also removed, this is important, this OH is for the, this thing or propargylic alcohol is getting removed. So, reduction of aromatic compounds is also possible here pyridine moiety is there H2PtO2 ethanol you get this piperidine moiety and then you can cyclize to get this bi-cyclic compound.

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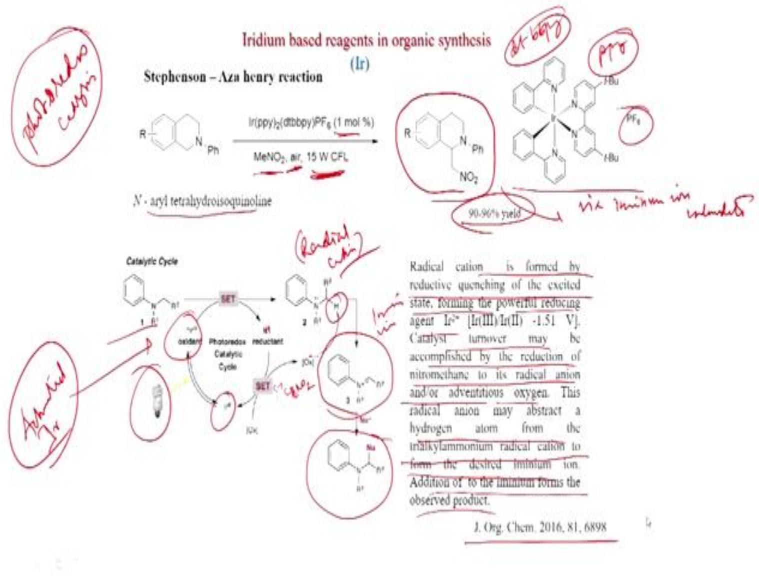

Iridium based reagents in organic synthesis

(Ir)

Stephenson – Aza henry reaction

N - aryl tetrahydroisoquinoline

Catalytic Cycle

Radical cation is formed by reductive quenching of the excited state, forming the powerful reducing agent Ir²⁺ [Ir(III)/Ir(II) -1.51 V]. Catalyst turnover may be accomplished by the reduction of nitromethane to its radical anion and/or adventitious oxygen. This radical anion may abstract a hydrogen atom from the trialkylammonium radical cation to form the desired iminium ion. Addition of to the iminium forms the observed product.

J. Org. Chem. 2016, 81, 6898

So, now, we will discuss the iridium base reagents and one important reaction the iridium carries that is the photo catalysis. So, photo redox catalysis. So, this is the catalyst structure. This you can see this is PPY group, PPY and this is dtbpy this one and PFC6 is the anion here and if you react with this N-aryl tetrahydroisoquinoline with this catalyst only 1 mol percent nitromethane, AR and 15 watt CFL lamp, then you get this product. So, this is a CH2NO2; that means the iminium ion is formed. So, this is via iminium ion intermediate, you get this product in 90 to 96 percent yield.

So, what could be the mechanism? know, this is the starting material, this is the lamp and you can see this is the iridium 3 and after lamp only it is getting activated iridium. So, this is the activated and in this activated the iridium only, it can do the reaction. So, after reaction, photo redox catalysis you get this radical cation, so, this is 2 is radical cation. Radical cation is formed by reductive quenching of the excited state, forming the powerful reducing agent iridium 2 plus. Catalyst turnover maybe accomplished by the reduction of nitromethane to its radical anion an adventitious oxygen and which will this can be also CH2NO2 also possible, minus dot. And this will deprotonate this one after that this iminium ion will form.

So, this is the iminium ion, iminium ion may abstract from the trialkyl ammonium radical cation to form the desired iminium ion and addition to the iminium ion forms the observed product. So, nucleophile is adding to the iminium ion. So, this is the single electron transfer process is happening here, one electron is taking by iridium 3 and it is going to iridium 2 and now again the oxidation is happening of iridium 2 this becoming iridium 3, so, this is iridium 2. Iridium 3 and after activation by light it is becoming the star, iridium star means that is the activated iridium and this was published JOC 2016, 6898.

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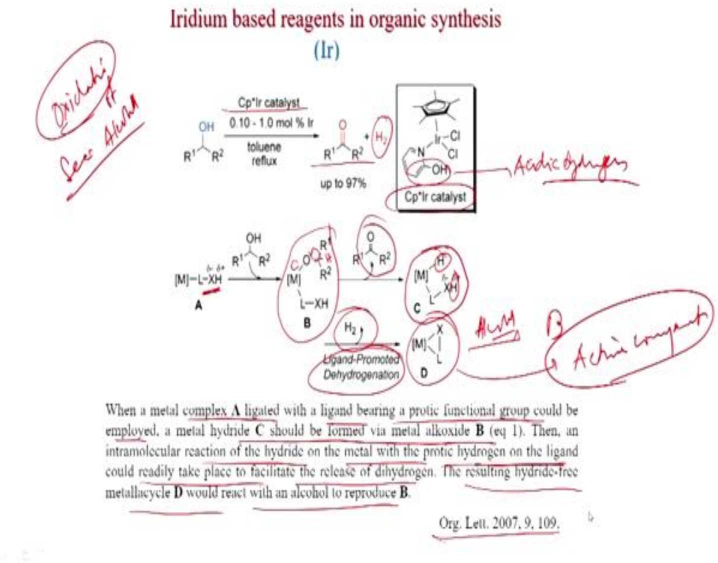

Iridium based reagents in organic synthesis

(Ir)

When a metal complex **A** ligated with a ligand bearing a protic functional group could be employed, a metal hydride **C** should be formed via metal alkoxide **B** (eq 1). Then, an intramolecular reaction of the hydride on the metal with the protic hydrogen on the ligand could readily take place to facilitate the release of dihydrogen. The resulting hydride-free metallacycle **D** would react with an alcohol to reproduce **B**.

Org. Lett. 2007, 9, 109.

Also, an oxidation can be possible with iridium, so, this is the oxidation of alcohol. Here secondary alcohol is used. So secondary alcohol is going to carbonyl compounds and H2 eliminating in this process. So, this is the catalyst Cp star iridium and you can see there is OH group. So, this is the acidic hydrogen that is important for the reaction, acidic hydrogen is present and cyclopentadiene star group is present there. So, what could we the mechanism? So, when a metal complex A ligated with a ligand bearing a protic functional group could be employed, a metal hydride C should be formed via metal alkoxide B. So, here, metal L-XH, so, XH is the OH here you can see.

So, this is the acidic hydrogen and now the alcohol will coordinate to the metal like this will form and now this metal hydride so, this hydrogen will come to metal now, metal hydride species is formed and oxidation is happening. So, main thing here the metal is coordinated to the ligand as well as the alcohol and in this process one molecule of hydrogen is liberating of course, later the one1 molecule of this one, C can liberate 1 molecule of hydrogen that is the ligand promoted dehydrogenation. So, on the metal with the protic hydrogen intramolecular reaction of the hydride on the metal with protic hydrogen on the ligand could readily take place to facilitate the release of dihydrogen.

So, from this metal hydride after elimination of a hydrogen, because this hydrogen is important now, because after this hydrogen only, it is going to hydrogen gas. The resulting hydride free metallacycle D this will form metallacycle D, will react further with an alcohol, so, if it will react with alcohol further then it will generate B. So, this is the active component actually, this is the active component of the catalyst system, this was published Organic letters 2007.

So, today we have seen first the nickel catalyzed reaction, we have seen different reaction with nickel that it can do the carbonylation reaction then tetramerization 2 plus 2 plus 2 that is the Reppe's synthesis we have seen. Also you have seen 2 plus 2 plus 2 reactions with benzyne so, you can get naphthalene derivatives. Then we have seen different C-C bond formation, reaction we have seen the 3 components reaction, alkyne and enone as diethyl zinc there you can get the products.

And when the enone and that alkyne is in the same molecule then you can get another cycle product and all cases we have seen the zinc component that is the like dimethyl zinc that methyl group as to the syn fashion of the newly generated double bond, this geometry is observed all cases. Then we have seen the nickel catalyzed cross coupling reaction, so that is an important discovery Knochel who use the first the olefin in the substrate and that case the Kumada coupling worked nicely.

Then he used CF3 containing styrene and that has been used an additive and that cases you can also use the substrates which does not have double bond and all our alkyl that is alkyl iodide as well as the alkyl Grignard and you can get this product. Then Kambe came up with 1, 3-butadiene and he found that this can be used for the Negishi cross coupling reaction with zinc and different alkyl zinc and alkyl iodide, bromide, tosylate even fluoride also can be used.

Also fluoride case, he has found that if you have additive where two diene system is there with the melanate group that is found to be better and giving the production high yield. Then we have seen the platinum catalysis and platinum we have seen the reduction of double bond. We have seen that platinum is the active catalyst here because after the reaction with hydrogen that is the platinum is forming and that is the active catalyst. And lastly we have seen iridium catalyzed photo catalysis, we have seen nitro methane addition to isoquinoline and oxidation of alcohol to ketone; that we have seen. Thank you.