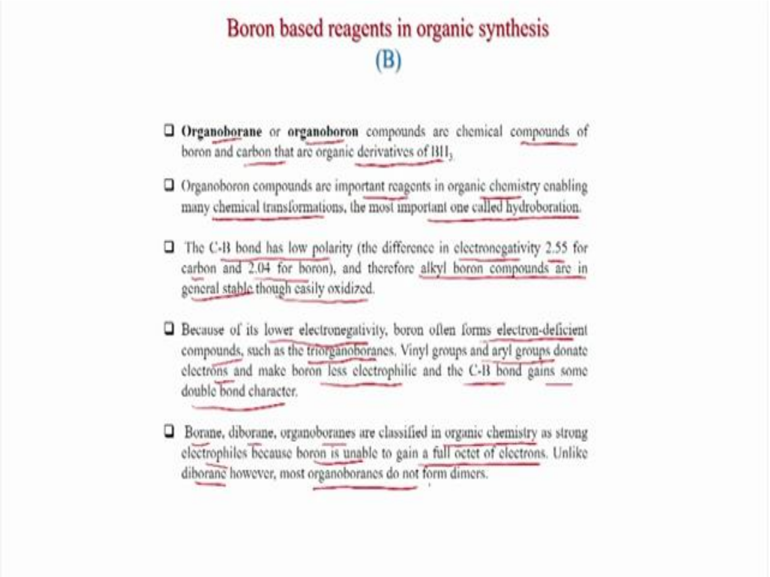
Reagents in Organic Synthesis
Professor Subhash Cr. Pan
Department of Chemistry
Indian Institute of Technology Guwahati
Lecture 14
Boron Based Reagents in Organic Synthesis

(Refer Slide Time: 00:33)



Boron based reagents in organic synthesis

(B)

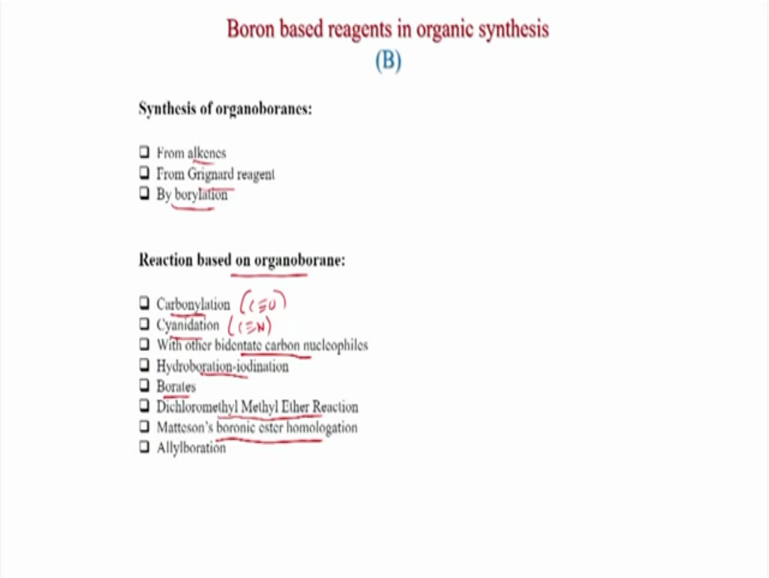
- ☐ **Organoborane** or **organoboron** compounds are chemical compounds of boron and carbon that are organic derivatives of BH_3
- ☐ Organoboron compounds are important reagents in organic chemistry enabling many chemical transformations, the most important one called hydroboration.
- ☐ The C-B bond has low polarity (the difference in electronegativity 2.55 for carbon and 2.04 for boron), and therefore alkyl boron compounds are in general stable though easily oxidized.
- ☐ Because of its lower electronegativity, boron often forms electron-deficient compounds, such as the triorganoboranes. Vinyl groups and aryl groups donate electrons and make boron less electrophilic and the C-B bond gains some double bond character.
- ☐ Borane, diborane, organoboranes are classified in organic chemistry as strong electrophiles because boron is unable to gain a full octet of electrons. Unlike diborane however, most organoboranes do not form dimers.

Welcome again! Today, we will discuss boron based reagents in organic synthesis. So, organoborane or organoboron compound are chemical compounds of boron and carbon that are organic derivatives of BH3. Organoboron compounds are important reagents in organic chemistry enabling many chemical transformations, the most important one called hydroboration. This is very useful reaction, because the hydroborated products you can convert to other compounds.

And CB bond has low polarity, the difference in electronegativity 2.55 for carbon and 2.04 for boron, and therefore, alkyl boron compounds are in general stable though easily oxidized. Also boron is not so electronegative, so because of its lower electronegativity boron often forms electron deficient compounds such as the triorganoboranes. Vinyl groups and aryl groups donate electrons and make boron less electrophilic and the CB bond gains some double bond character.

So, when vinyl and aryl groups are present then boron becomes less electrophilic. Borane, and diborane and organoboranes are classified in organic compounds as strong electrophiles because boron is unable to gain a full octet of electrons, this we know there are 6 electrons on the boron because it is tricordinated, unlike diborane however most organoboranes do not form dimers.

(Refer Slide Time: 02:04)



Boron based reagents in organic synthesis

(B)

Synthesis of organoboranes:

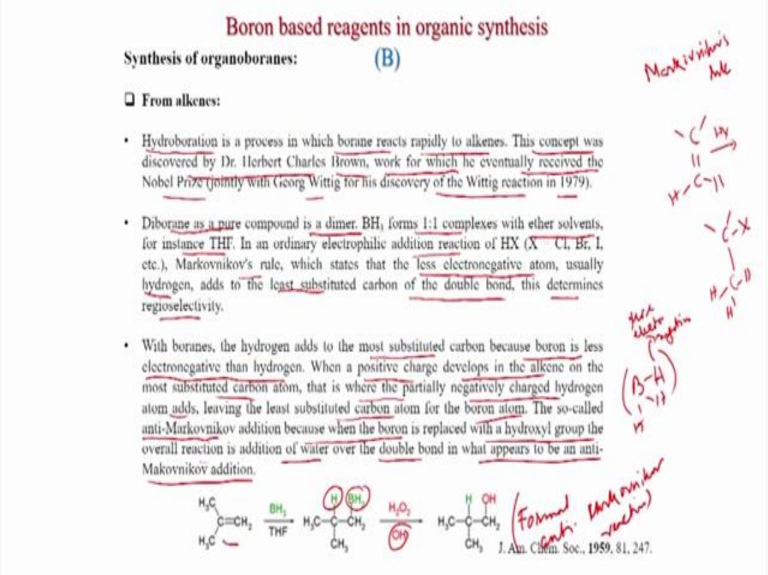
- ☐ From alkenes
- ☐ From Grignard reagent
- ☐ By borylation

Reaction based on organoborane:

- ☐ Carbonylation $(C\equiv O)$
- ☐ Cyanidation $(C\equiv N)$
- ☐ With other bidentate carbon nucleophiles
- ☐ Hydroboration-iodination
- ☐ Borates
- ☐ Dichloromethyl Methyl Ether Reaction
- ☐ Matteson's boronic ester homologation
- ☐ Allylboration

Now, in this talk we will first discuss synthesis of organoboranes that we will discuss first from alkynes, then from Grignard reagent and borylation also, 1transition metal catalyzed borylation. Also reaction based on organoborane we will discuss carbonylation, first we will discuss, then cyanidation, this is with carbon monoxide, this is with cyanide and with other bidentate carbon nucleophiles, this also we will discuss. Hydroboration iodination we will discuss, borates, dichloromethyl methyl ether reaction that we will discuss. Matteson's boronic ester homologation that is useful for allylic, and crotyl boronic ester because they are stable, allylboration.

(Refer Slide Time: 02:56)



Boron based reagents in organic synthesis

Synthesis of organoboranes: (B)

❑ **From alkenes:**

- Hydroboration is a process in which borane reacts rapidly to alkenes. This concept was discovered by Dr. Herbert Charles Brown, work for which he eventually received the Nobel Prize (jointly with Georg Wittig for his discovery of the Wittig reaction in 1979).
- Diborane as a pure compound is a dimer. BH_3 forms 1:1 complexes with ether solvents, for instance THF. In an ordinary electrophilic addition reaction of HX (X Cl, Br, I, etc.), Markovnikov's rule, which states that the less electronegative atom, usually hydrogen, adds to the least substituted carbon of the double bond, this determines regioselectivity.
- With boranes, the hydrogen adds to the most substituted carbon because boron is less electronegative than hydrogen. When a positive charge develops in the alkene on the most substituted carbon atom, that is where the partially negatively charged hydrogen atom adds, leaving the least substituted carbon atom for the boron atom. The so-called anti-Markovnikov addition because when the boron is replaced with a hydroxyl group the overall reaction is addition of water over the double bond in what appears to be an anti-Makovnikov addition.

J. Am. Chem. Soc., 1959, 81, 247.

So, first we will discuss synthesis of organoboranes from alkynes, this is the hydroboration process. Hydroboration is a process in which borane reacts rapidly to alkenes and this concept was first discovered by Doctor Herbert Charles Brown, and for his work he eventually received the Noble Prize jointly with Georg Wittig fort his discovery of Wittig reaction in 1979. So, this is a pioneering discovery that hydroboration and they gave many other conversion to this hydroborated products and that has been used in many natural product synthesis also.

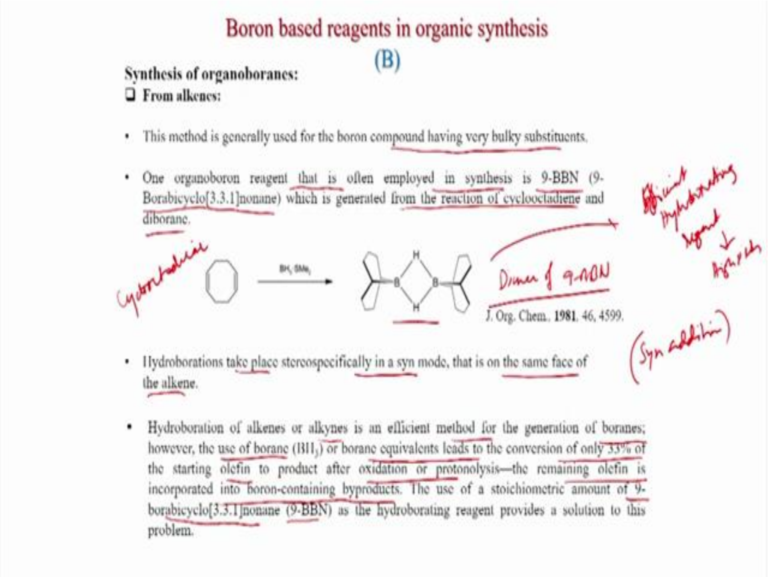
So, diborane as a pure compound is a dimer. BH3 forms 1 is to 1 complex with ether solvents for instant THF. In an ordinary electrophilic addition reaction of HX Markovnikov's rule, which states that the less electronegative atom usually hydrogen because X is the halide, so halide is the more electronegative and hydrogen is less electronegative, adds to the least substituted carbon of the double bond this determines regioselectivity.

So, hydrogen adds to least substituted carbon atom that is the terminal carbon, so when there is like this, hydrogen-hydrogen, then HX addition happens like this, so X goes to there and hydrogen comes at the terminal. This is the Markovnikov's rule. Now, with boranes, the hydrogen adds to most substituted carbon because boron is less electronegative than hydrogen. So, in this case hydrogen is the more electronegative, when let us say it is called boron hydride.

When a positive charge develops on the alkene on the most substituted carbon atom, that is why the partially negative charged hydrogen atom adds leaving the least substituted carbon atom for the boron atom and the so called anti-Markovnikov addition, because when the boron is replaced with the hydroxide group, the overall reaction is addition of water over the double bond in what appears to be an anti-Markovnikov addition. So, the positive charge is generated at the most substituted carbon atom. Now, here what happens, the hydride, hydrogen is the more electronegative here.

So, the hydrogen adds to the more substituted carbon atom, that is what is happening here, when this one unsymmetrical olefin is here, and now this is the terminal carbon so, here BH2 will add and most substituted carbon hydrogen will add. And after H2O2 and hydroxide treatment the BH2 can be converted to alcohol. So, this is actually formal anti-Markovnikov reaction. Because ultimately hydrogen adds to the most substituted carbon and OH has the least substituted carbon.

(Refer Slide Time: 06:14)



Boron based reagents in organic synthesis

(B)

Synthesis of organoboranes:

❏ **From alkenes:**

- This method is generally used for the boron compound having very bulky substituents.
- One organoboron reagent that is often employed in synthesis is 9-BBN (9-Borabicyclo[3.3.1]nonane) which is generated from the reaction of cyclooctadiene and diborane.

J. Org. Chem. **1981**, 46, 4599.

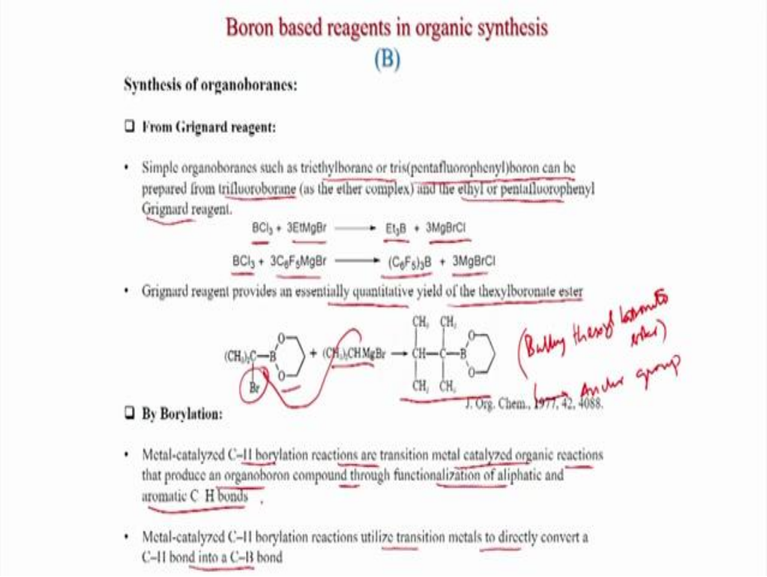
- Hydroborations take place stereospecifically in a syn mode, that is on the same face of the alkene.
- Hydroboration of alkenes or alkynes is an efficient method for the generation of boranes; however, the use of borane (BH_3) or borane equivalents leads to the conversion of only 33% of the starting olefin to product after oxidation or protonolysis—the remaining olefin is incorporated into boron-containing byproducts. The use of a stoichiometric amount of 9-borabicyclo[3.3.1]nonane (9-BBN) as the hydroborating reagent provides a solution to this problem.

This method is generally used for the boron compound having very bulky substituents. One organoboran reagent that is often employed in synthesis is 9 BBN that is 9 borabicyclo 3.3.1 nonane which is generated from the reaction of cyclooctadiene and diborane. So, this is the reaction cyclooctadiene and this is the borane Me2S complex, there it is acting as the boron reagent and here two cyclooctadienyl molecule reacts like this and you get a dimer of 9 BBN.

So, hydroboration takes place stereospecifically in a syn mode that is on the same face of the alkene so this is very important. The syn addition happens in hydroboration reaction. Also hydrboration of alkenes or alkynes is an efficient method for the generation of boranes, this we already told, however, the use of borane or borane equivalents leads to the conversion of only 33 percent of the starting olefin to product after oxidation or protonolysis -- the remaining olefin is incorporated into boron containing byproducts.

So, this problem can be solved if you use bulky like this one, the use of stoichiometric amount of 9 borabicyclo 3.3.1 nonane that is the 9 BBN as the hydroboratic reagent provides a solution to this problem. So this is an efficient hydroborating reagent. And then, we will give the product in high yield and that means you can get high yields for the hydroborated products.

(Refer Slide Time: 08:12)



Boron based reagents in organic synthesis

(B)

Synthesis of organoboranes:

☐ **From Grignard reagent:**

- Simple organoboranes such as triethylborane or tris(pentafluorophenyl)boron can be prepared from trifluoroborane (as the ether complex) and the ethyl or pentafluorophenyl Grignard reagent.

$$BCl_3 + 3EtMgBr \longrightarrow Et_3B + 3MgBrCl$$

$$BCl_3 + 3C_6F_5MgBr \longrightarrow (C_6F_5)_3B + 3MgBrCl$$

- Grignard reagent provides an essentially quantitative yield of the thexylboronate ester

(Bulky thexyl boronate ester)

long, Anchor group

J. Org. Chem., 1977, 42, 4088.

☐ **By Borylation:**

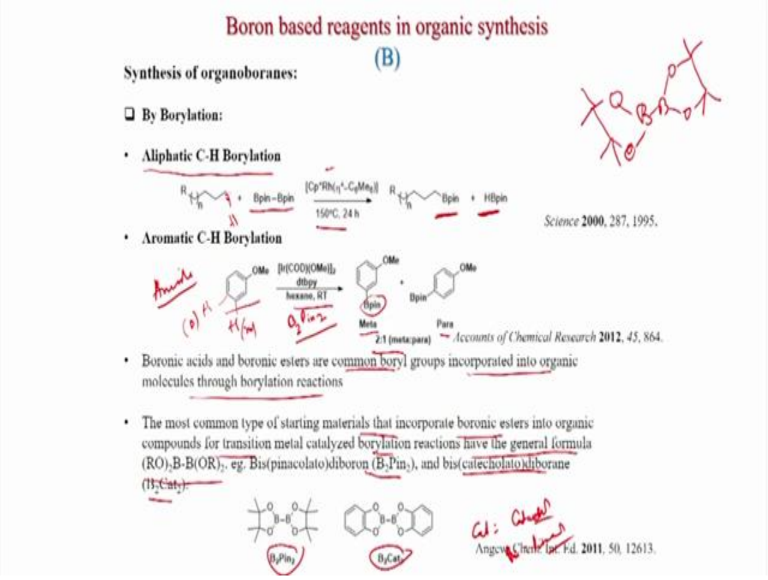
- Metal-catalyzed C–H borylation reactions are transition metal catalyzed organic reactions that produce an organoboron compound through functionalization of aliphatic and aromatic C H bonds .
- Metal-catalyzed C–H borylation reactions utilize transition metals to directly convert a C–H bond into a C–B bond

Also from Grignard reagent you can prepare organoboranes, simple organoboranes such as triethylborane or tris pentafluorophenyl boron can be prepared from triflouroborane as the either complex and the ethyl or pentafluorophenyl Grignard reagent. So, corresponding Grignard reagent we have used like, BCl3 trifluoroborane or borontrfluoride and then 3 equivalent of ethyl magnesium bromide then what happens, 3 ethyl comes to the boron, you get the triethylborane and 3 equivalent of MgBrCl. Similarly, boron trichloride can be reacted with pentafluorophenyl magnesium bromide and also 3 equivalent then 3 pentafluorophenyl groups come to the boron and you get this, is the boron reagent and 3 MgBrCl.

Grignard reagent provides an essentially quantitative yield of the thexylboronate ester. Like this one there is an alpha bromo, and this is the boronate and, now if you use just one equivalent then you get a substitution reaction so this adds here, and this is an useful thexylboronate ester. And this is a bulky, bulky thexylboronate ester. So we will see this thexylboronate are useful in the migration because it will migrate and it acts as an anchor group, we will see.

By borylation metal catalyzed CH borylation reaction are transition metal catalyzed organic reactions that produced an organoboron compound through functionalization of aliphatic and aromatic CH bonds, so this is also an important reaction and metal catalyzed is borylation reactions utilize transition metal should directly convert a C H bond in to CB bond so this is very important reaction transition metal catalyzed borylation.

(Refer Slide Time: 10:24)



Boron based reagents in organic synthesis

(B)

Synthesis of organoboranes:

☐ **By Borylation:**

- **Aliphatic C-H Borylation**

Science **2000**, 287, 1995.

- **Aromatic C-H Borylation**

Accounts of Chemical Research **2012**, 45, 864.

- Boronic acids and boronic esters are common boryl groups incorporated into organic molecules through borylation reactions
- The most common type of starting materials that incorporate boronic esters into organic compounds for transition metal catalyzed borylation reactions have the general formula $(RO)_2B$-$B(OR)_2$, eg. Bis(pinacolato)diboron (B_2Pin_2), and bis(catecholato)diborane (B_2Cat_2).

Angew. Chem. Int. Ed. **2011**, 50, 12613.

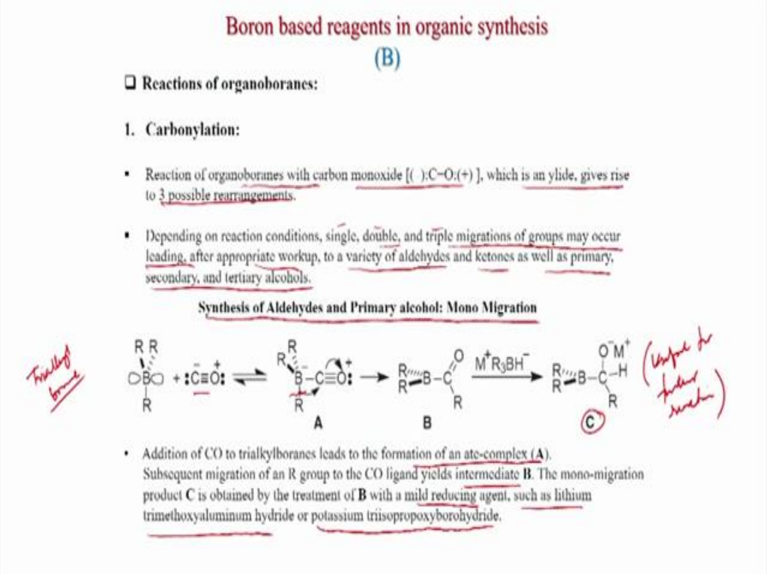
And aliphatic CH borylation, and aliphatic CH bond also can be activated that means it can be borylated, and if you use this one which is this Bpin-Bpin and this is the long chain alkane and here with this CP* rodium catalyst 150 degree centigrade after 24 hours you get this terminal carbon atom is borylated that is the terminal CH, one CH is replaced by Bpin and this is the byproduct, HBpin, this was published in Science.

Also aromatic CH borylation also is possible like this one anisole, if you treat with iridium cod methoxy dimeric and dtbpy as the ligand in hexane room temperature you get a mixture 2 is to 1, so meta is more, here the, this hydrogen is borylated, and alternatively that is the para, para and meta the para is getting borylated, then you get the para put, that is the minor.

Boronic acids and boronic esters are common boryl groups incorporated into organic molecules through borylation reactions and the most common type of starting materials that incorporate boronic esters into organic compounds for transition metal catalyzed borylation reactions have the general formula of RO to BOR2 that is Bis (pinacolato) diborane B2Pin2, so here also activated B2Pin2 is there, B2Pin2, and bis (catecholato) diborane.

B2 catecholato, so these are the structure these structure I have already drawn, B2Pin2 and this is the B2 Cat means Cat is catechol and Pin means pinacol, some these are the short forms, B2Pin2 and B2 catechol 2 they are the useful reagents that are reused in the transition metal catalyzed CH borylation reactions.

(Refer Slide Time: 12:56)



Boron based reagents in organic synthesis

(B)

❑ **Reactions of organoboranes:**

1. **Carbonylation:**

- Reaction of organoboranes with carbon monoxide [( ):C−O:(+)], which is an ylide, gives rise to 3 possible rearrangements.
- Depending on reaction conditions, single, double, and triple migrations of groups may occur leading, after appropriate workup, to a variety of aldehydes and ketones as well as primary, secondary, and tertiary alcohols.

Synthesis of Aldehydes and Primary alcohol: Mono Migration

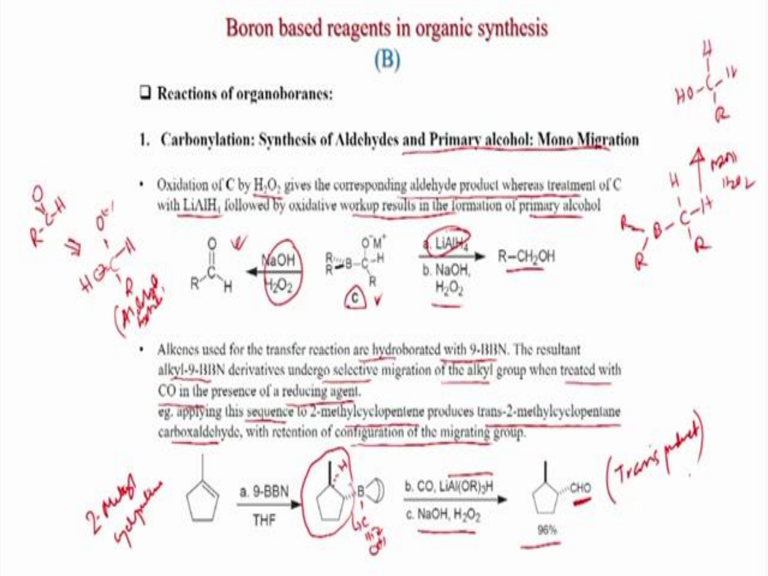
- Addition of CO to trialkylboranes leads to the formation of an ate-complex (**A**). Subsequent migration of an R group to the CO ligand yields intermediate **B**. The mono-migration product **C** is obtained by the treatment of **B** with a mild reducing agent, such as lithium trimethoxyaluminum hydride or potassium triisopropoxyborohydride.

Now, we discuss reactions of organoboranes, so various reactions on organoboranes are known because the migration is possible the C-BR bond that can be migrated, that alkyl group can be migrated, to other carbon atoms, so like carbonylation reactions organoboranes with carbon monoxide which is an ylide, gives rise to 3 possible rearrangements. Depending on reaction conditions, single, double and triple migrations of groups may occur leading after appropriate work up, to a variety of aldehydes and ketones as well as primary secondary and tertiary alcohols.

So, these are very useful reactions different kind of migration is possible, in fact, 3 kinds of migrations single, double and triple that is the single alkyl group, then two alkyl groups and three alkyl groups migrate. So, first we will discuss synthesis of aldehydes and primary alcohol via mono migration. So, this is the reaction actually, so this is the trialkyl borane, and now when you react with carbon monoxide it leads to the formation of an ate-complex, so this is an ate-complex. And now, boron gets a negative charge and there is a positive charge, of course, with oxygen here because carbon monoxide structured like this, and now this is an electrophilic species.

So, then also this is a boron is negative charge, so this B-R, this bond will cleave and this R will migrate to the carbonyl group and now after migration you get the intermediate B. Now, intermediate B, if you treat with some other reducing agents, hydride reducing agents such as lithium trimethoxyaluminum hydride or potassium triisopropoxyborohydride, then this carbonyl group can be reduced and you get an intermediate like this C. This intermediate is useful for further reaction that we will see in the next slide actually.

(Refer Slide Time: 15:14)



Boron based reagents in organic synthesis

(B)

❑ **Reactions of organoboranes:**

1. **Carbonylation: Synthesis of Aldehydes and Primary alcohol: Mono Migration**

- Oxidation of C by H_2O_2 gives the corresponding aldehyde product whereas treatment of C with $LiAlH_4$ followed by oxidative workup results in the formation of primary alcohol

- Alkenes used for the transfer reaction are hydroborated with 9-BBN. The resultant alkyl-9-BBN derivatives undergo selective migration of the alkyl group when treated with CO in the presence of a reducing agent.
eg. applying this sequence to 2-methylcyclopentene produces trans-2-methylcyclopentane carboxaldehyde, with retention of configuration of the migrating group.

So, reactions this is the carbonylation, mono migration we have discussed in. Now, oxidation of C whatever we have seen so oxidation of C by H2O2 to gives the corresponding aldehyde product. So, if you treat this compound with NaOH H2O2 what happens, this one, so this will be O minus this is the hydrogen R and now, when we do this NaOH H2O2 what happens, this there an oxygen will come, so ultimately after hydrolysis you get this one. So, this is what, this is an hydride aldehyde hydride actually, so this will be equilibrium with aldehyde so, aldehyde hydride is formed and passed, and that is actually aldehyde hydride and that is converted into the aldehyde.

On the other hand if you treat with lithium aluminum hydride followed by oxidative workup results in the presence of primary alcohol, so if you treat again with hydride reagent, so 2 hydride first one hydride that gives this product intermediate actually, and now if you treat with lithium aluminum hydride so another hydride will come here, and after NaOH H2O2 treatment you get this one, so what happens so after hydride treatment this OM group will eliminate and you get this one actually intermediate possibly.

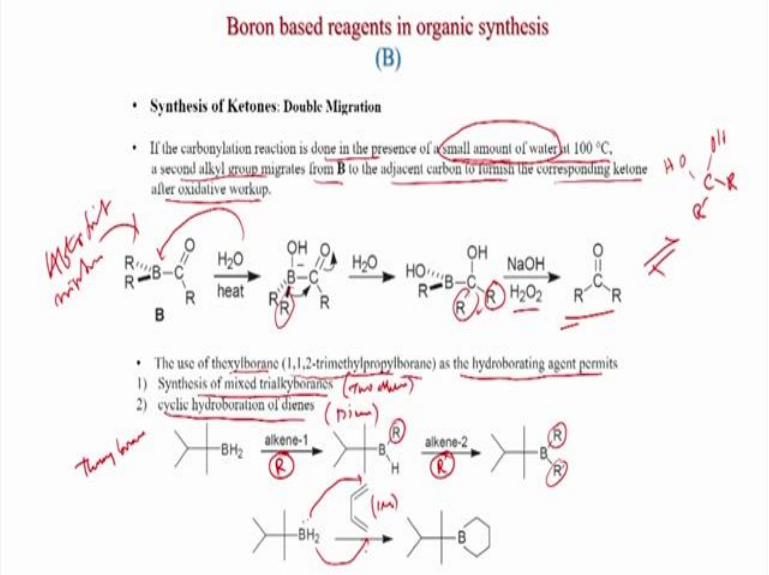
And now, NaOH H2O2, so this NaOH H2O2 you get OH because H2O2 NaOH what happens there the oxygen is formed here between CB bond so ultimately this goes to a primary alcohol. Alkenes used for the transfer reactions are hydrborated with 9 BBN, the resultant alkyl 9 BBN derivatives undergoes selective migration of the alkyl group when treated with CO in the presence of a reducing agent.

So, now we will see an example, a 9 BBN is the boronating reagent actually, applying this sequence to 2 methyl cyclopentene produces trans 2 methyl cyclopentane carboxaldehyde, we with retention of configuration of the migrating group, so this is 2 methyl cyclopentene, its 9 BBN first is treated and we know this is the less substituted carbon here, boron comes and this is the syn addition.

Now, after carbon monoxide and lithium aluminum trialkoxyhydride so, after CO means this is formed and now, what happens now these group will migrate because the 9 BBN that group does not migrate, the migrating power also we will discuss later, but primary migrates faster than secondary, secondary migrates faster than tertiary also there is steric group in the 9 BBN. So, this group migrates selectively to here.

And you get the carbonyl then the reduction and after that hydrolysis you get the aldehyde. So this is followed here so after reduction after carbon monoxide you get this, then the rearrangement then the reduction makes this intermediate, after that NaOH treatment you get this aldehyde. At this aldehyde you get the trans product so, trans product is found.

(Refer Slide Time: 19:14)



Boron based reagents in organic synthesis

(B)

- **Synthesis of Ketones: Double Migration**
- If the carbonylation reaction is done in the presence of a small amount of water at 100 °C, a second alkyl group migrates from **B** to the adjacent carbon to furnish the corresponding ketone after oxidative workup.

- The use of thexylborane (1,1,2-trimethylpropylborane) as the hydroborating agent permits
1) Synthesis of mixed trialkyboranes
2) cyclic hydroboration of dienes

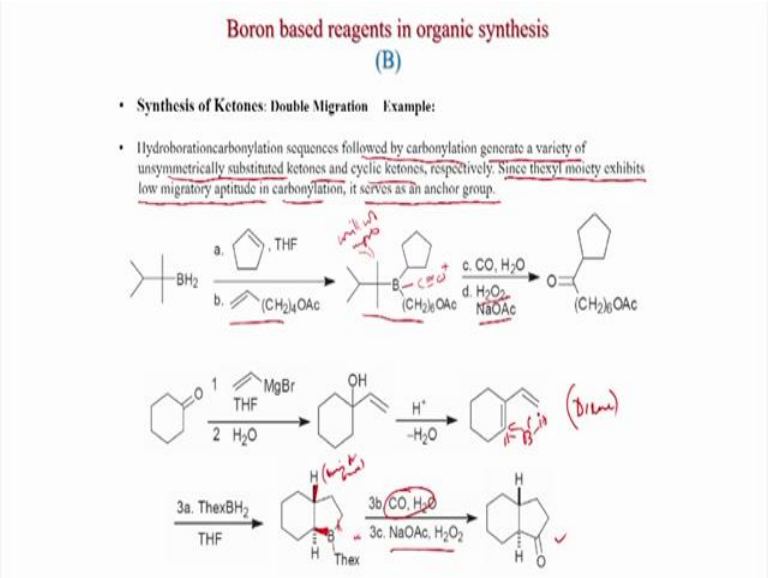
Synthesis of ketones double migration, if the carbonylation reaction is done in the presence of a small amount of water at 100 degrees centigrade, a second alkyl group migrates from B to the adjacent carbon to furnish the corresponding ketone after oxidative workup. So, now we will see double migration, so in the double migration this is very important, if you do small amount of water at 100 degrees centigrade, the reaction same reaction carbonylation reaction you get this intermediate after so this is formed after first migration.

Now, what have and if you put water heat then this water will add to this, boron center and you get boron becomes negative and when boron becomes negative only possible that the alkyl group will migrate to the carbonyl and this migration give this intermediate. After this intermediate in this case you do not need any reduction because already OH is formed here after double migration to R groups migrated and after that NaOH H2O2 treatment, similarly, here we will give this one, ketone hydride actually.

So, OH and that will be converted to ketone, so ketone hydride will be formed first with NaOH H2O2 this will be an equilibrium with the ketone. The use of thexylborone 1, 1,2 tri methyl propyl borane as the hydroboratic reagent permits synthesis of mixed tri alkyl boranes and cyclic hydroboration of dienes. So, this is two alkynes we will see and this diene. Like this is the thexyl borane so this is thexyl borane this is you can see there is a tertiary carbon group that is the tertiary carbon alkyl group which is connected to BH2 now alkene 1, so after alkene1 that is the R means the R after hydroboration you get this alkyl group R.

And now, there is a second R’, R’ dash will come how, now if you put this R dash means that the olefin you have to treat so that the alkene 2 then you get this trialkylborane, like here you can get two different alkyl groups, so that will discuss in the next slide. Now, if you treat with the diene, like contributed and what you get, you get this one, because this is one equivalent and now boron adds to this two terminal carbon atom and you get this borane.

(Refer Slide Time: 22:19)



Boron based reagents in organic synthesis

(B)

- **Synthesis of Ketones: Double Migration Example:**
- Hydroborationcarbonylation sequences followed by carbonylation generate a variety of unsymmetrically substituted ketones and cyclic ketones, respectively. Since thexyl moiety exhibits low migratory aptitude in carbonylation, it serves as an anchor group.

So, example, hydroboration carbonylation sequences followed by carbonylation generate a variety of unsymmetrically substituted ketones and cyclic ketones respectively, since thexyl moiety exhibits low migratory aptitude in carbonylation it serves as an anchor group this we already discussed that thexyl group will act as an anchor group, it will not migrate. Now, you see we have two different alkenes are reacted with thexyl borane so what happens the cyclopentene we first treat then you get this one, then you get then you react with this one in terminal a cyclic olefin with acetate group is present then you get this one.

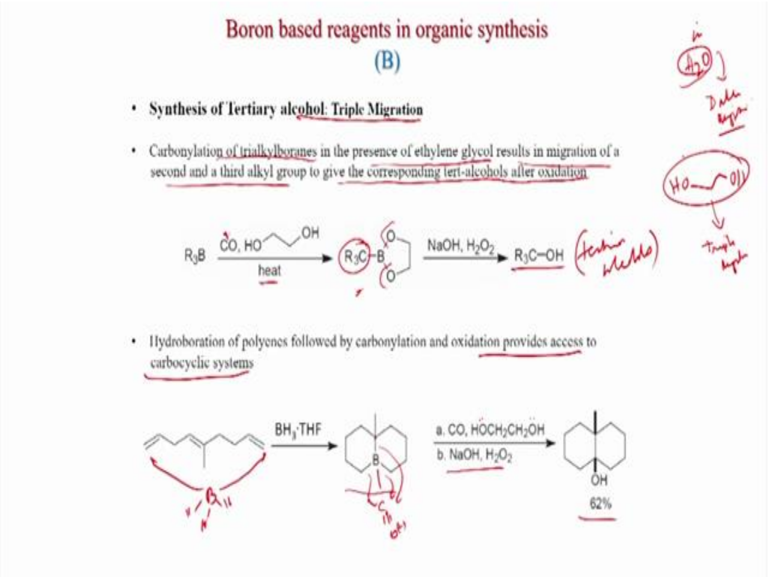
This is the 3 different group presented in the borane, this is a thexyl so this will not migrate. Now, what we migrate, now these two groups can migrate, so when you treat with carbon monoxide followed by H2O2 NaOAC, so what will happen you get this ketone so, what happen this is the mechanism same that carbon monoxide means this one now, first this group will migrate and after that the second group will migrate.

To see the mechanism here, there is the double migration is happening here and you get the ketone, so double migration gives the ketone also cyclohexanone when a magnesium bromide THF, water, you get this alcohol phenyl alcohol means allylic alcohol and now, H plus H2O will give this diene and, now thexylborane what we will do, it will add to this so, this two center the hydroboration will happen, so boron will add here and here. Now, you get this cyclic borane compound, and now if you treat with carbon monoxide, so carbon monoxide with this and after that 2 alkyl groups will migrate.

So, first this group will migrate on this one and then this one, also if you see the geometry so this hydrogen is coming from borane and this is the geometry, so these two are seen and after that you get this compound, so this is the trans now because the this is coming from the this and this also boron so, this trans geometry is formed and you get the ketone after sodium acetate, this is base and H2O2 you get the carbonate compound.

So, the mechanism is same what is happening here the, two different alkyl groups are used, the cyclic diene, so this is the diene, diene is used, the diene is used which is made the cyclic borane compound and after carbon monoxide and base you get this ketone.

(Refer Slide Time: 25:32)



Boron based reagents in organic synthesis

(B)

- **Synthesis of Tertiary alcohol: Triple Migration**
- Carbonylation of trialkylboranes in the presence of ethylene glycol results in migration of a second and a third alkyl group to give the corresponding tert-alcohols after oxidation
- Hydroboration of polyenes followed by carbonylation and oxidation provides access to carbocyclic systems

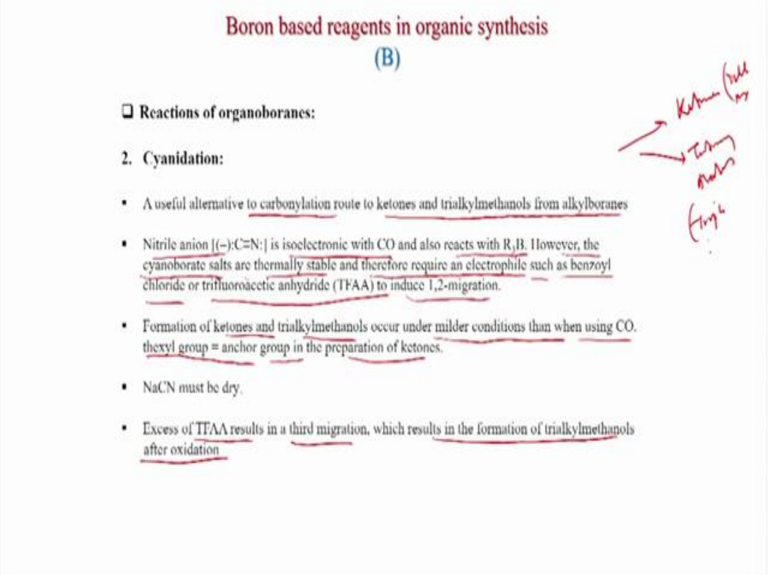
Synthesis of tertiary alcohol triple migrations. Now carnbonylation of trialkylboranes in the presence of ethylene glycol results in migration of a second and the third alkyl group to give the corresponding tertiary alcohols after oxidation. So, earlier we have seen that in H2O, we get double migration. Now, if you use ethylene glycol so this is interesting because 2OH are present that can satisfy the two coordination of boron, means another will be connected to the alkyl group of it and this can give triple migration.

This will see that after carbon monoxide and this one ethylene glycol heat, what happens see this two OH is bind to boron and three alkyl groups are migrated, so you get CR3BR, so three alkyl groups are migrated to the carbon atom, so that is why CR3 is formed. And after that NaOH H2O2 treatment you get this tertiary alcohol. Hydroboration of polyenes followed by carbonylation and oxidation provides acess to carbocyclic systems like here, a triene three double bonds are present and.

Now, what happens, the boron adds to here, here and also to here. This carbon, this carbon also is adding so that you get this bond so, boron is adding, so that I think this addition is taking place because of this favored conformation of two six members rings. And now, with carbon monoxide and ethylene glycol so carbon monoxide and ethylene glycol what will happen, this one will happen, this intermediate and now this will migrate, this will migrate, and this will migrate.

And now what will happen that boron will coordinative to two OH groups of ethylene glycol, so this intermediate will form and after NaOH H2O2 treatment you get this tertiary alcohol. So, these are very useful reactions and you can get different alcohols, primary secondary and tertiary alcohol depending on the addition of simple what are ethylene glycol you can change the course of the reaction.

(Refer Slide Time: 28:21)



Boron based reagents in organic synthesis

(B)

☐ **Reactions of organoboranes:**

2. Cyanidation:

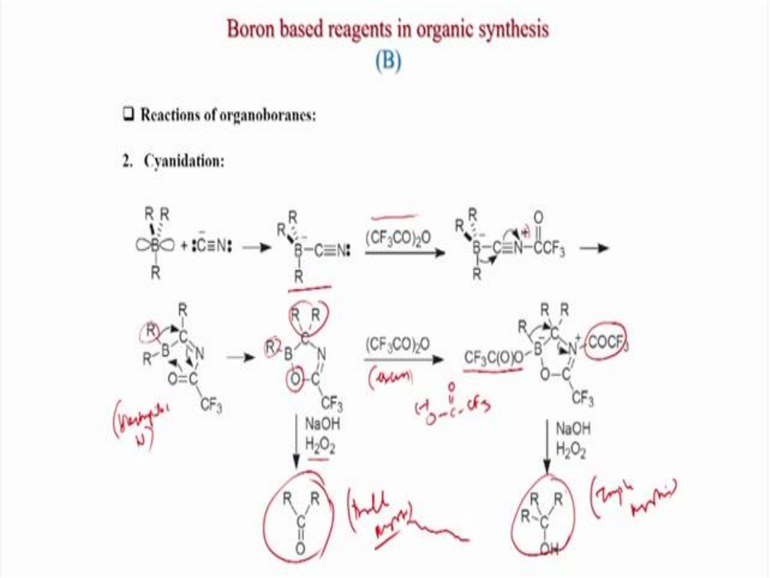
- A useful alternative to carbonylation route to ketones and trialkylmethanols from alkylboranes
- Nitrile anion [(−):C≡N:] is isoelectronic with CO and also reacts with R_3B. However, the cyanoborate salts are thermally stable and therefore require an electrophile such as benzoyl chloride or trifluoroacetic anhydride (TFAA) to induce 1,2-migration.
- Formation of ketones and trialkylmethanols occur under milder conditions than when using CO. thexyl group = anchor group in the preparation of ketones.
- NaCN must be dry.
- Excess of TFAA results in a third migration, which results in the formation of trialkylmethanols after oxidation

Now, we will discuss cyanidation. A useful alternative to carbonylative route to ketones and trialkylmethanols from alkyl boranes. Nitrile anion that is a CN minus is isoelectronic with carbon monoxide and also reacts with R3B, however, the cyanoborate salts are thermally stable and therefore, requires an electrophile such as benzoyl chloride or trifluoroacetic anhydride to induced 1, 2 migrations. So, this salts, the cyanoborate salts are thermally stable and therefore, require an electrophile such as benzoyl chloride or trifluoroacetic anhydride to induced 1,2 migrations.

So this is important you have trifluoroacetic anhydride and we will see that depending on how much you had that, double or triple migration will happen. Formation of ketones and trialkylmethanols occur under milder condition than when using carbon monoxide thexyl group also here acts as anchor group in the preparation of ketones, and sodium cyanide must be dry.

Excess of TFAA results in a third migration which results in the formation of trialkylmethanols after oxidation. So, in general it gives ketones or tertiary alcohol, ketones in double migration and tertiary alcohol in triple migration, and the mechanism is little bit different.

(Refer Slide Time: 29:54)



Boron based reagents in organic synthesis

(B)

❑ Reactions of organoboranes:

2. Cyanidation:

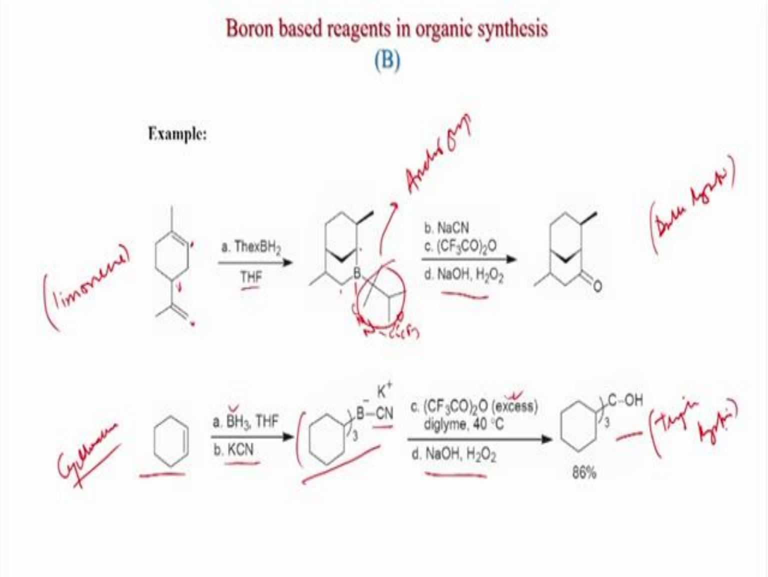
Then carbonylation, so what happens here, also first term is same, this 8 complex will form and now, because earlier we have seen the oxygen there is a plus, that is what this rearrangement was facile, now here this nitrogen has to be activated with trifluoroacetic anhydride now, there is a positive charge, now this can migrate, so after migration you get this intermediate and interestingly here, also because of this intermediate, this nitrogen again this is an electrophilic nitrogen, electrophilic nitrogen so what happens this bond is polarize.

So, again another R group will add and this oxygen will satisfy the boron tri coordination, see this is the rearrangement is happening here, so one R group migrated and here the double bond is forming and this oxygen is satisfying the trivalency of boron, that is the dual role of trifluoroacetic anhydride ,not only it activates the nitrogen but, also satisfy this oxygen of trifluoroacetic anhydride satisfies the trivalency boron and after NaOH H2O2 treatment you can get the ketone because two R groups migrated.

Alternatively if you use excess trifluoroacetic anhydride, another group will migrate, this group will migrate and so excess trifluoroacetic anhydride will give first this intermediate because then the boron will have a negative charge for this migration you have to first make the negative charge, so what happens this anion actuality adds to the boron, this boron and this makes the borate with the negative charge.

Now, another migration will happen, also activates this one COCF3 activates, because trifluoroacetic anhydride has two parts, so COCF3 activates this one and this adds to this boron and after NaOH treatment you get this alcohol. So here triple migration and after double migration so that only if you excess then the triple migration will happen.

(Refer Slide Time: 32:29)



Boron based reagents in organic synthesis

(B)

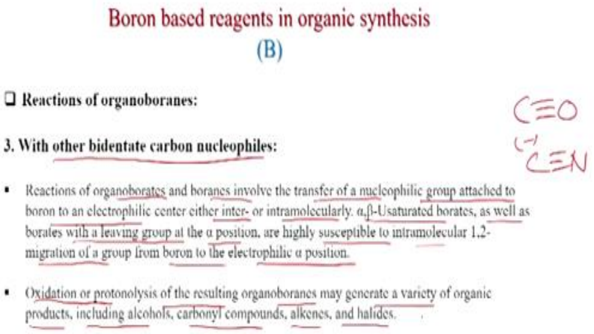
Example:

So, this is limonene and this is a chiral center actually, so here two double bonds are there, where one is in the ring another is outside ring and when we treated with thexylborane in THF what happens, this carbon and this carbon reacts with boron, this and this and now, you get this borane compound, see this borane compound is formed and here also I told chiral center is formed is there, so you get this kind of geometry and now, what happen after CN treatment you get this one, and after that CF3 will activate this one, COCF3 something like this and now, the migration will happen.

And this group cannot migrate, we already told this is an anchor group and after sodium hydroxide H2O2 treatment, you get this ketone, similarly, this one cyclohexene, if you just treat with borane, THF, what will happen. Now, three, of course, three cyclohexene will come and you get this tricyclohexyl borane which treat, reactivate potassium cyanide to generate this intermediate.

Now, if you use trifluoroacetic anhydride excess, so excess we have seen that excess the three migrations will happen and after sodium hydroxide H2O2 treatment you get this one, alcohol, so three migrations will happen when you have to used excess one because at the after double migration again this trifluoroacetic will add to the boron and will make feasible for the third migration and after hydrolysis you get the tertiary alcohol. So, there double migration and here triple migration.

(Refer Slide Time: 34:53)



Boron based reagents in organic synthesis

(B)

☐ **Reactions of organoboranes:**

3. With other bidentate carbon nucleophiles:

$C\equiv O$

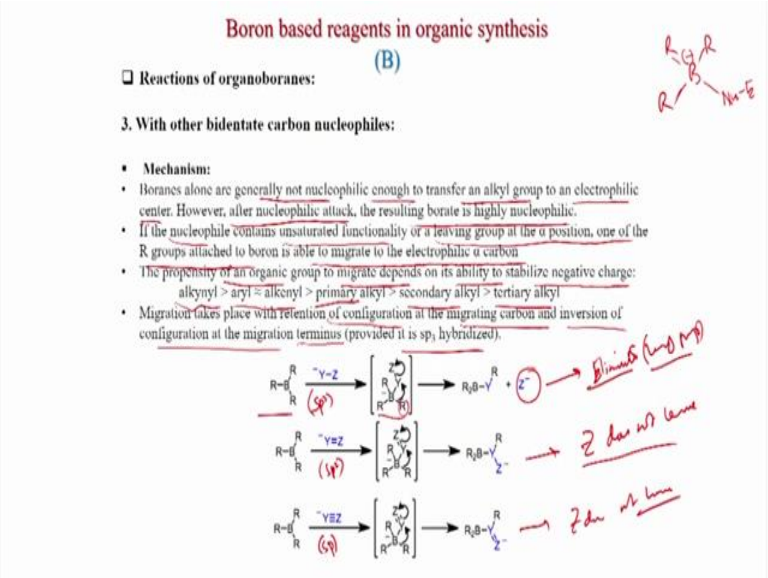
$^{(-)}C\equiv N$

- Reactions of organoborates and boranes involve the transfer of a nucleophilic group attached to boron to an electrophilic center either inter- or intramolecularly. α,β-Usaturated borates, as well as borates with a leaving group at the α position, are highly susceptible to intramolecular 1,2-migration of a group from boron to the electrophilic α position.
- Oxidation or protonolysis of the resulting organoboranes may generate a variety of organic products, including alcohols, carbonyl compounds, alkenes, and halides.

So, we will be discussing boron based reagents in the organic synthesis, reactions of organoboranes and now, we will discuss with other bidentate carbon nucleophiles. So, so far we have discussed carbon monoxide and cyanide reactions of organoborates and borane involve the transfer of the transfer of nucleophilic group attached to boron to an electrophilic center either inter or intramolecularly, alpha beta unsaturated borates as well as borates with a leaving group at the alpha position are highly susceptible to intramolecular 1, 2 migration of a group from boron to the electrophilic alpha position.

So, now, if there is a bidentate ligand and if it is corrected to the boron now the one group from the borate will transfer to the alpha position because that is the electrophilic position and that is very important reactions because oxidation or protonolysis of the resulting organoboranes may generate a variety of organic products including alcohols, carbonyl compounds, alkenes and halides.

(Refer Slide Time: 36:02)



Boron based reagents in organic synthesis

(B)

❑ **Reactions of organoboranes:**

3. With other bidentate carbon nucleophiles:

- **Mechanism:**
- Boranes alone are generally not nucleophilic enough to transfer an alkyl group to an electrophilic center. However, after nucleophilic attack, the resulting borate is highly nucleophilic.
- If the nucleophile contains unsaturated functionality or a leaving group at the α position, one of the R groups attached to boron is able to migrate to the electrophilic α carbon
- The propensity of an organic group to migrate depends on its ability to stabilize negative charge:
  alkynyl > aryl ≈ alkenyl > primary alkyl > secondary alkyl > tertiary alkyl
- Migration takes place with retention of configuration at the migrating carbon and inversion of configuration at the migration terminus (provided it is sp_3 hybridized).

So we will see some examples and first we will discuss the different types boranes alone are generally not nucleophilic enough to transfer an alkyl group to an electrophilic center. However, after nucleophilic attack the resulting borate is highly nucleophilic. So this is important that after boron become tetra coordinated so this is the nucleophile, electrophile something.

Now, this one will form so this when it is formed then only the migration will be possible that only we have seen when it is tetra coordinated the migration will possible. If the nucleophile contains unsaturated functionality or a living group at the alpha position, one of the R groups attached to boron is able to migrate to the electrophilic alpha carbon. The propensity of an organic compound to migrate depends on its ability to stabilize negative charge.

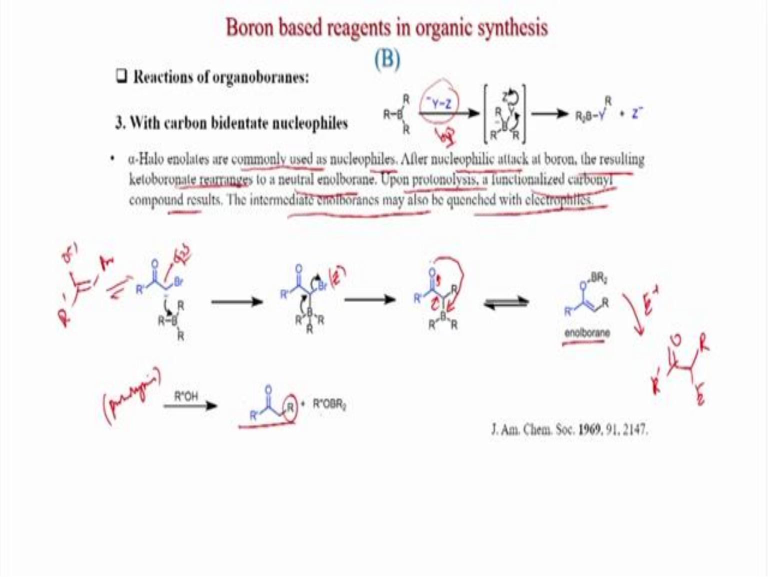
So alkynyl will migrate faster because we know alkynyl is SP hybridized, so that is the stable, and then aryl alkenyl because they are SP2 and after that primary alkyl, secondary alkyl and tertiary alkyl. So, tertiary alkyl group we have seen in the thexyl boron, so that is why it does not migrate it acts as a anchor group. Migration takes place with retention of configuration at the migrating carbon and inversion of configuration at the migration terminus provided it is Sp3 hybridized.

So this we have also seen the retention of configuration will happen of the migrating carbon and inversion will happen at the migration terminus. So this is the SP3. and, now this is the borane tri alkyl borane and after that you get these tecta coordinated borate and there is a negative charge and when negative charge is there, this group will migrate to y and this will eliminate.

So, this is eliminating or living group here, when a carbon-carbon bond is present and now, if there is a double bond here, so this is SP2 hybridized and after that borane adds to this you get this and, now there is a double bond so when R migrates to this double bond becomes single bond see, and so, here Z does not leave, so here because there is a single bond Z is of course a leaving group because it will has to leave and here Z does not leave the molecule and this double bond becomes a single bond.

Now, SP hybridized this carbon also can be used this, of course, we have seen that CN, CO cases and here what happen after migration this becomes double bond, we have seen earlier we mean our carbonyl compounds are forming and here also Z does not leave of course, Z does not leave and so here double bond becomes single, and triple bond becomes double bond.

(Refer Slide Time: 39:28)



Boron based reagents in organic synthesis

(B)

☐ **Reactions of organoboranes:**

3. With carbon bidentate nucleophiles

- α-Halo enolates are commonly used as nucleophiles. After nucleophilic attack at boron, the resulting ketoboronate rearranges to a neutral enolborane. Upon protonolysis, a functionalized carbonyl compound results. The intermediate enolboranes may also be quenched with electrophiles.

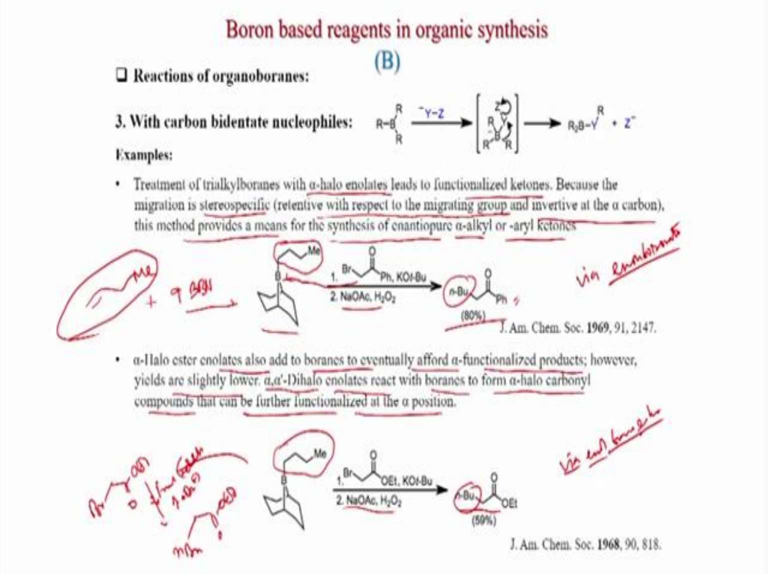
J. Am. Chem. Soc. 1969, 91, 2147.

So, let see some examples, so first we will discuss this step here, there is SP3 carbon and one group has to leave alpha Halo enolates are commonly used as nucleophiles after nucleophilic attack at boron, the resulting ketoboronate rearranges to a neutral enol borane upon protonlysis a functionalized carbonyl compound results. The intermediate enol boranes may also be quenched with electrophiles.

So, this is an SP3 center alpha bromo ketone that is the ketoenolate actually so this treats like this o minus br R dash this reacts with trialkylborane to generate the compound like this now. So, I told that Z is a leaving group so Br is Z here. So Br is Z, Z is leaving and after leaving you get this one, so R group migrated to here, alpha carbon atom and now, what will happen, this will be equilibrium with this enol borane. So, how it is forming, this oxygen is attacking to boron and this carbonyl become a single bond.

So, that is happening here, you get the inner borane here you get double bond and this becomes single bond and oxygen B bond is formed, enol borane, this enol borane can be treated with alcohol, so this protonlysis, you get a ketone, so what happen actually the Br is replaced with a R group, so it is higher derivative of ketone and this is the byproduct. Alternatively, you can treat this also with electrophile so, then you can get electrophilic substitutions also, further.

(Refer Slide Time: 41:40)



Boron based reagents in organic synthesis

(B)

☐ **Reactions of organoboranes:**

3. With carbon bidentate nucleophiles:

Examples:

- Treatment of trialkylboranes with α-halo enolates leads to functionalized ketones. Because the migration is stereospecific (retentive with respect to the migrating group and invertive at the α carbon), this method provides a means for the synthesis of enantiopure α-alkyl or -aryl ketones

J. Am. Chem. Soc. **1969**, 91, 2147.

- α-Halo ester enolates also add to boranes to eventually afford α-functionalized products; however, yields are slightly lower. α,α'-Dihalo enolates react with boranes to form α-halo carbonyl compounds that can be further functionalized at the α position.

J. Am. Chem. Soc. **1968**, 90, 818.

Reaction of organoboranes now, more examples also will discuss in this end. Treatment of trialkylboranes with alpha halo enolates leads to functionalized ketones because the migration is stereospecific retentive with respect to the migrating group and inversion at the alpha carbon this method provides a means for the synthesis of enantiopure alpha alkyl or aryl ketones, like here, this is a borane, so here this one is formed after you treat 1-butene with 9 BBN so after that you get this borane.

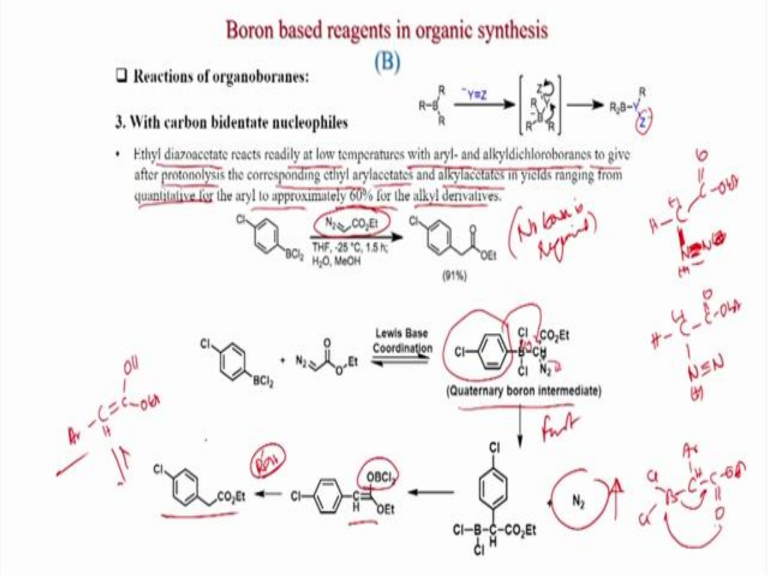
Hydroboration happens to this center here and hydrogen here, then you get this borane and now if you treat this one with the enolate of this bromoketone then, of course, this center will add to boron and the n-butyl group will migrate and after sodium acetate H2O2 treatment you get this one ketone. This was published in Jack's 1969, so this mechanism is same that the enol borane so via enol boronate, or via enol borane you are getting this compound.

Alpha Halo ester enolates also add to boranes to eventually afford alpha functionalized products however yields are slightly lower, ester also can be used alpha alpha dash dihalo enolates reacts with boranes to form alpha halo carbonyl compounds that can be further functionalized at the alpha position. So, here the bromo esters have been used and similarly, the migration will happen, similarly, the first reaction followed by this n-butyl ester, migration will happen, and after NaOH treatment similarly here the ester is formed here, n-butyl ester.

And this mechanism also via enol borane, via enol borane, or enol borane ester. So, here also you get this butyl group at the alpha position. So, what is the formal reaction is happening here so this one, OEt and this one, you get formally a butyl group is coming so, n-butane group is formal nucleophilic addition, so formal addition of butyl minus however, here we have seen this is the one butane is used so one butane is the butyl group that is adding to the 9 BBN and now a borane is formed and that is adding to this first tetra coordinated boronate is forming after that butyl group is migrating.

So, this is the inherent chemistry and that is the beauty of the borane chemistry that if do not need a Grignard reagent further substitutions on reaction, you can have a borane where this group cannot migrate, because there is an anchor group. And only the butyl group will migrate and after that you get a substitution at the alpha position of the carbonyl compounds.

(Refer Slide Time: 45:36)



Boron based reagents in organic synthesis

(B)

❑ Reactions of organoboranes:

3. With carbon bidentate nucleophiles

- Ethyl diazoacetate reacts readily at low temperatures with aryl- and alkyldichloroboranes to give after protonolysis the corresponding ethyl arylacetates and alkylacetates in yields ranging from quantitative for the aryl to approximately 60% for the alkyl derivatives.

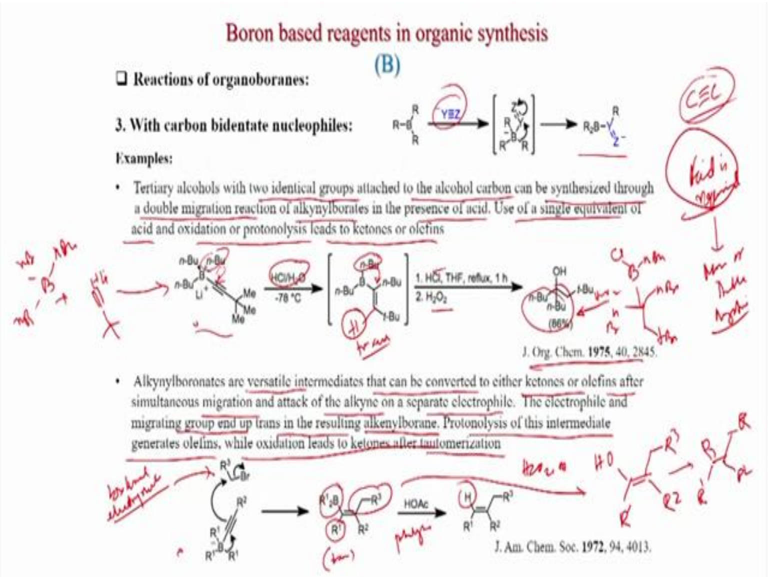
Here, an SP2 system is used and we have seen that when SP2 system is used then this Z will not eliminate and examples are ethyl diazoacetate reacts rapidly at low temperature with aryl and alkenyl, dichloroboranes to give after protonlysis the corresponding ethyl aryl acetate and alkyl acetates in yields ranging from quantitative for the aryl to approximately 60 percent for the alkyl derivatives.

So, this is the diazo esters so, diazo esters actually can be written like this also. C, C double bond here so C-C so these are neutral compound and interesting here, no base is required, so this is the base here, there is a hydrogen H minus CO2 and now this can add to the this one to the boron and after rearrangement you get this one so we will discuss the detailed mechanism what happens first the Lewis acid coordination will happen, and there is a negative charge on the boron, after the addition and this nitrogen is a positive charge.

So, what will happen, first intermediate will form and because the nitrogen elimination leaving group is very facile, this migration will be very facile, so this group will migrate to here and this nitrogen will eliminate. Because nitrogen is a gas so this process is very fast and after that what will happen, this coordination will happen, so we have seen earlier with ketone but, also with ester this kind of a will happen that this bond will break the carbon, and oxygen this carbonyl oxygen will coordinate the boron that what is happening here and you get the enolate.

After this protonlysis with alcohol you can get this ester is this will be OH and that is the enolate the ester so this will be the intermediate, this is the enol of the ester.

(Refer Slide Time: 48:58)



Boron based reagents in organic synthesis

(B)

☐ **Reactions of organoboranes:**

3. With carbon bidentate nucleophiles:

Examples:

- Tertiary alcohols with two identical groups attached to the alcohol carbon can be synthesized through a double migration reaction of alkynylborates in the presence of acid. Use of a single equivalent of acid and oxidation or protonolysis leads to ketones or olefins

J. Org. Chem. **1975**, 40, 2845.

- Alkynylboronates are versatile intermediates that can be converted to either ketones or olefins after simultaneous migration and attack of the alkyne on a separate electrophile. The electrophile and migrating group end up trans in the resulting alkenylborane. Protonolysis of this intermediate generates olefins, while oxidation leads to ketones after tautomerization

J. Am. Chem. Soc. **1972**, 94, 4013.

With carbon bidentate nucleophiles now we will discuss when a triple bond is present and here what will happen, like carbon monoxide systems or cyanide system, we have seen this triple bond and the triple bond will first go to a double bond so, here we will see the carbon-carbon that is the simple triple bond we will discuss now C-C triple bond systems. Tertiary alcohol with two identical groups attached to the alcohol carbon can be synthesized through a double migration reaction of alkenyl borane, borates in the presence of the acid. Use of a single equivalent of acid and oxidation or protonolysis leads to ketones or olefins.

So, depending on the amount of the acid, So here acid is required and depending on the acid either mono or double migration so if use more acid then double migration like this system, so this is already, boronate so this is obtained from tributylborane plus this one lithium this. So this will give this boronate peas is, because negative charge is their so this is we have discussing now carbon carbon triple bond now this is anion this is adding after that you have to add acid.

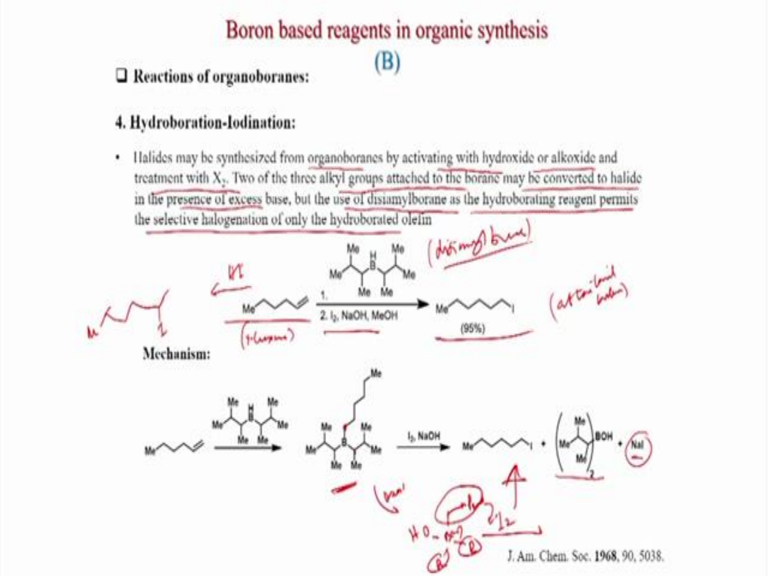
So after acid treatment what happens, this triple bond getting activated so acid is helping to activate the triple bond and then the n-butyl group will migrate and migrate to the alpha carbon atom here. And this triple bond, of course, will be double bond and this hydrogen is coming from the acid. This hydrogen is coming from the acid and now, this intermediate will form, again if you add more acid so what will happen, other group will migrate to the alpha carbon only so two n butyl group at the same carbon atom and this double bond will be single bond and after H2O2 treatment you get the alcohol.

So this will be intermediate type n butyl, n butyl and this is n butyl may be CL minus and after that this on H2O2 treatment will get the alcohol. This was published in JOC 1975. Alkynylboronates are versatile intermediate that can be converted to either ketones or olefins after simultaneous migration and attack of the alkyne on a separate electrophile. So another electrophile can be also used the electrophile and migrating group end up trans in the resulting alkynylborane. Protonolysis of this intermediate generates olefins while oxidation leads to ketone after tautomarization.

So suppose here similar system this system is here, now here you not treat with acid here, here you do external electrophile, like alkyl bromide so what happens, so among this triple bond because there is a bifunctionalization possible so this react under this condition and after this addition this is the migration is happening this is the R1 and R3. So R1 and this CH2R3 they are trans, they are adding the trans fashion of the triple bond. So they are adding trans fashion, after this addition you get this one, and now this compound if you treat with acid just the protonolysis with the hydrogen here.

Alternatively, if you use H2O2 what will happen, then R1 R2 we get the OH here, and this is actually ketone. R3, R2 so you can get a ketone or a olefin depending on the treatment, if you do oxidative method then you get the ketone, alternatively protonolysis you get the olefins, so these are very useful methods that the a triple bond is getting di functionalized with this boron system.

(Refer Slide Time: 53:54)



Boron based reagents in organic synthesis

(B)

❑ **Reactions of organoboranes:**

4. Hydroboration-Iodination:

- Halides may be synthesized from organoboranes by activating with hydroxide or alkoxide and treatment with X_2. Two of the three alkyl groups attached to the borane may be converted to halide in the presence of excess base, but the use of disiamylborane as the hydroborating reagent permits the selective halogenation of only the hydroborated olefin

Mechanism:

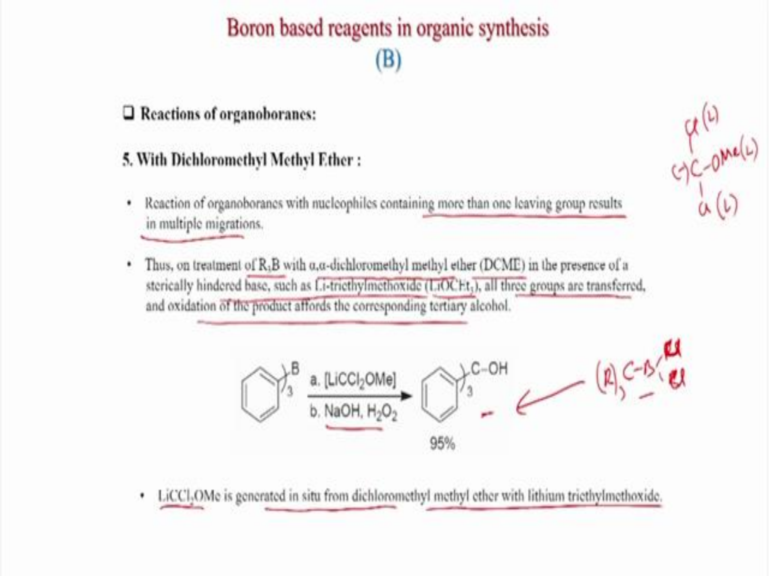
J. Am. Chem. Soc. **1968**, 90, 5038.

Hydroboration iodination we will discuss, halides may be synthesized from organoboranes by activating with hydroxide or alkoxide and treatment with X2. Two of the three alkyl group attached to the borane may be converted to halide in the presence of excess base, but the use of disiamylborane this is another sterically hindered borane, as the hydro borating reagent permits the selective halogenation of only one of the hydro borated olefin, so this is the disiamylborane and when this 123456, 1-hexene is used for the hydroboration and.

After that, if you treat with iodine NaOH methanol you get this iodine and iodine at the terminal carbon, so, this is a very useful reaction because if you want to do HI addition then the iodine will add actually here, so for terminal carbonate on the iodine is attached for that of course do is the boronation. And this is the mechanism that after hydroboration you get this one, is the terminal carbon boron is attached and now, what will happen, the NaOH make the this is actually, n butyl base is the R-R this intermediate OH.

And after iodine what will happen, these are the bulky group, these will not migrate, also this is secondary alkyl group this is primary, so this group will migrate to the iodine and you get this one. So, here the migration happens to the iodine and I minus is reacting with also sodium plus you get the sodium, iodine byproduct and this one OH hydroxyl containing disiamylborane is the byproduct. That is what the OH is adding so, OH is helping to generate the boron minus such here, tecta coordinated boronate and that is reacting with iodine. After that, migration is happening.

(Refer Slide Time: 56:16)



Boron based reagents in organic synthesis

(B)

❑ **Reactions of organoboranes:**

5. With Dichloromethyl Methyl Ether :

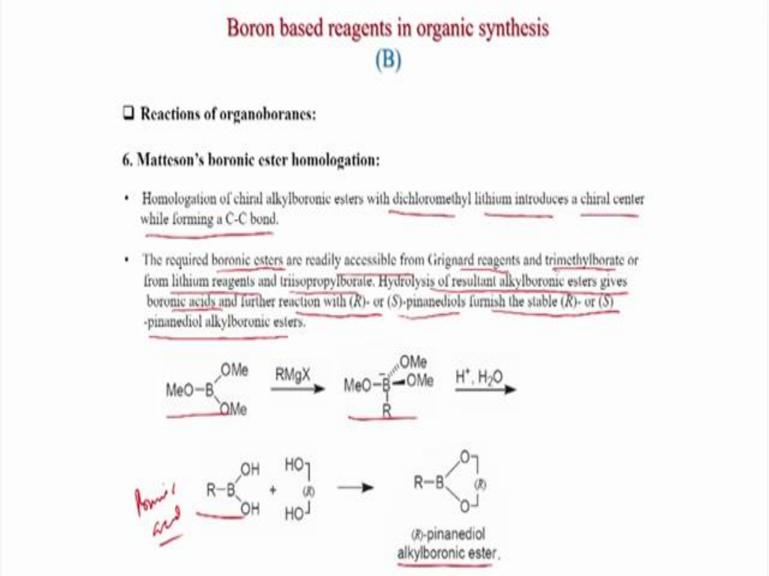
- Reaction of organoboranes with nucleophiles containing more than one leaving group results in multiple migrations.
- Thus, on treatment of R_3B with α,α-dichloromethyl methyl ether (DCME) in the presence of a sterically hindered base, such as Li-triethylmethoxide ($LiOCEt_3$), all three groups are transferred, and oxidation of the product affords the corresponding tertiary alcohol.

- $LiCCl_2OMe$ is generated in situ from dichloromethyl methyl ether with lithium triethylmethoxide.

Reaction of organoboranes with nucleophiles containing more than one leaving group results in multiple migration. Thus, on treatment of R3B with alpha dichloromethyl methyl ether in the presence of sterically hindered base such as LiOCEt3, all three groups are transferred and oxidation of the product affording the corresponding tertiary alcohol. So, this is also not only triple bond here what happen this Cl Cl OMe and negative charge, so all three groups are leaving group, this is also leaving, this also leaving, this also leaving, and ultimately leaving you get this one after NaOH H2O2 treatment.

Because, this B may be this RR and this is the R, 3 R group is adding, this might be Cl, and now after hydrolysis you get this one. LiCCl2Me is generated in situ from dichloromethyl, methyl ether with lithium tri ethyl methoxide.

(Refer Slide Time: 57:40)



Boron based reagents in organic synthesis

(B)

❑ **Reactions of organoboranes:**

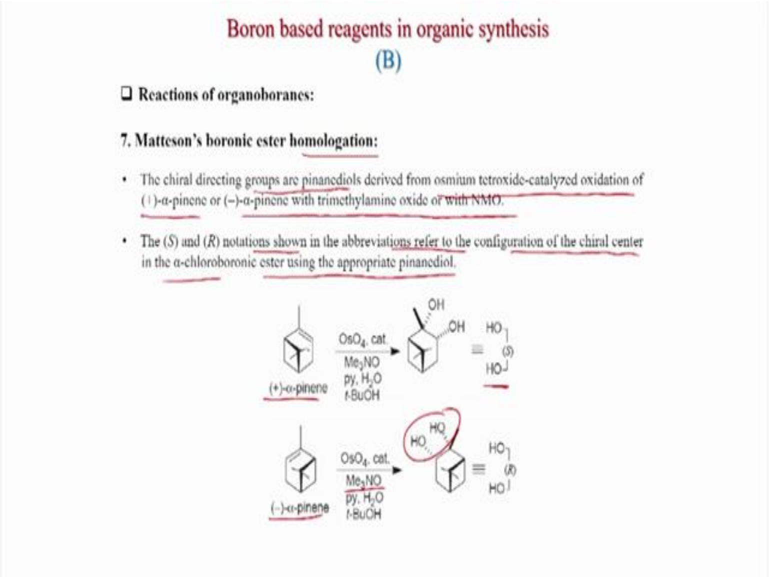
6. Matteson's boronic ester homologation:

- Homologation of chiral alkylboronic esters with dichloromethyl lithium introduces a chiral center while forming a C-C bond.
- The required boronic esters are readily accessible from Grignard reagents and trimethylborate or from lithium reagents and triisopropylborate. Hydrolysis of resultant alkylboronic esters gives boronic acids and further reaction with (*R*)- or (*S*)-pinanediols furnish the stable (*R*)- or (*S*) -pinanediol alkylboronic esters.

Homologation of chiral alkyl boronic esters with dichloromethyl lithium introduces a chiral center while forming a C-C bond, the required boronic esters are readily accessible from Grignard reagents and trimethylborate or from lithium reagents and triisopropyl borate. hydrolysis of the resultant alkyl boronic ester gives boronic acid and further reaction with R or S pinanediols furnish the stable R S pinanediols alkyl boronic esters.

So, this is the trialkyl borate with Grignard reagents this one tecta coordinated after H plus you get this boronic acid and when it treats with chiral alcohol you get this alpha pinanediol alkyl boronic esters.

(Refer Slide Time: 58:28)



Boron based reagents in organic synthesis

(B)

❑ **Reactions of organoboranes:**

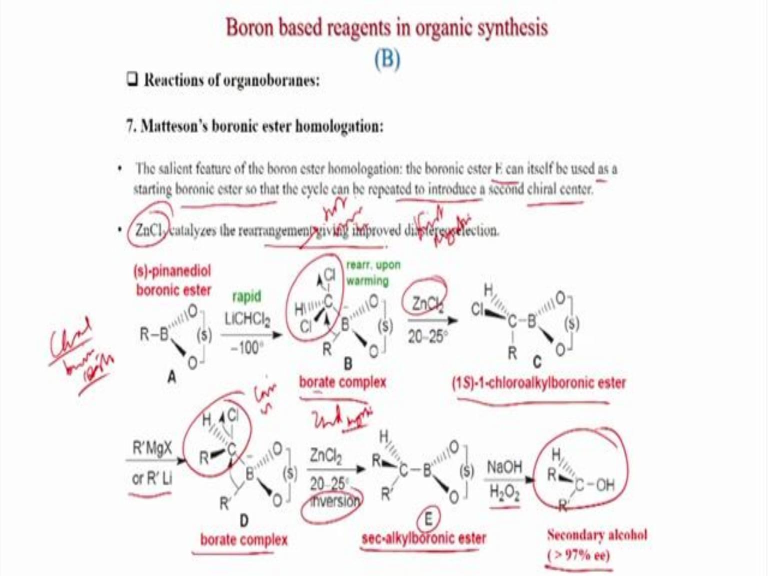
7. Matteson's boronic ester homologation:

- The chiral directing groups are pinanediols derived from osmium tetroxide-catalyzed oxidation of (+)-α-pinene or (–)-α-pinene with trimethylamine oxide or with NMO.
- The (*S*) and (*R*) notations shown in the abbreviations refer to the configuration of the chiral center in the α-chloroboronic ester using the appropriate pinanediol.

And Matteson’s boronic ester homologation, the chiral directing groups are pinanediols derived from osmium tetroxide catalyzed oxidation of alpha pinene and alpha pinene with trimethylamine oxide or with NMO. The S and R notations shown in the abbreviations refer to the configuration of the chiral center in the alpha chloroboronic ester using the appropriate pinnaediol.

So alpha pinene (+) alpha pinene when we treated the osmium tetroxide it generates this diol and this is the chiral diol similarly, (-)alpha pinene with osmium tetroxide catalyzed and this is the N-oxide you get this sys diol and chiral and also this osmylation is having from the opposite face of this group.

(Refer Slide Time: 59:17)



Boron based reagents in organic synthesis

(B)

❑ **Reactions of organoboranes:**

7. Matteson’s boronic ester homologation:

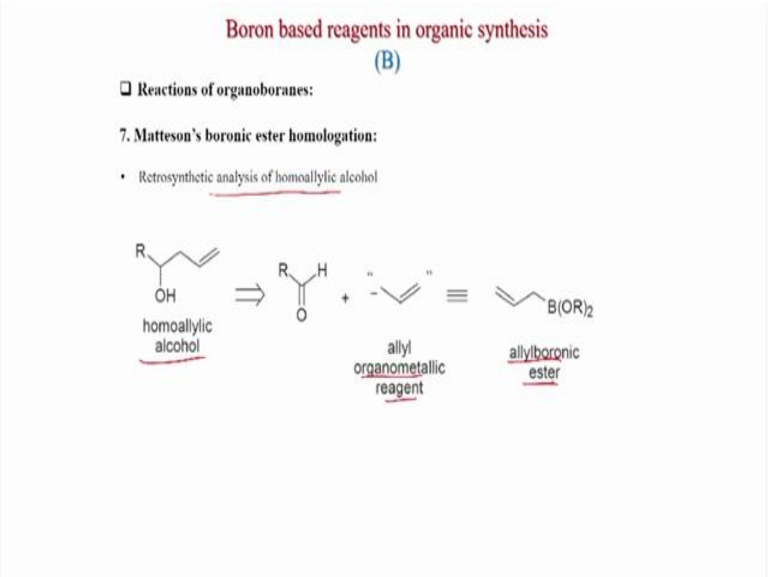
- The salient feature of the boron ester homologation: the boronic ester E can itself be used as a starting boronic ester so that the cycle can be repeated to introduce a second chiral center.
- $ZnCl_2$ catalyzes the rearrangement giving improved diastereoselection.

And these are useful reagents the chiral one because you can control the chirality so this is chiral boron ester or chiral boronic ester and now, if you treat with LICHCl2 tetra coordinated boronate complex will formed here, now because you have the chlorine two chlorines are there. So, what will happen, the rearrangement to we will happen with zinc chloride also, if you put zinc chloride then this group will migrate and this will form, one chloroalkylboronic esters and again after treatment with Grignard or R’Li another group can be borate and that gives the boron negative charge again borate complex and second alkyl group.

So this is the first migration, and here second migration and here also you see the inversion is happening, because now this is a chiral center and now the inversion is happening, because initially it was not a chiral center. This is a chiral center and you get the inversion and this is the secondary alkyl boronic ester and all these process are selective and after that you get this alcohol in greater than 97 percent ee.

So the silent feature of the boron ester homologation the boronic ester E, this can be also used as a starting boronic ester so the cycle can be repeated to introduce a second chiral center. This can be also used for this again treatment with LICHCl2 you can get some products here or from here also, and zinc chloride catalysis is important the rearrangement giving improve diastereoselection.

(Refer Slide Time: 61:31)



Boron based reagents in organic synthesis

(B)

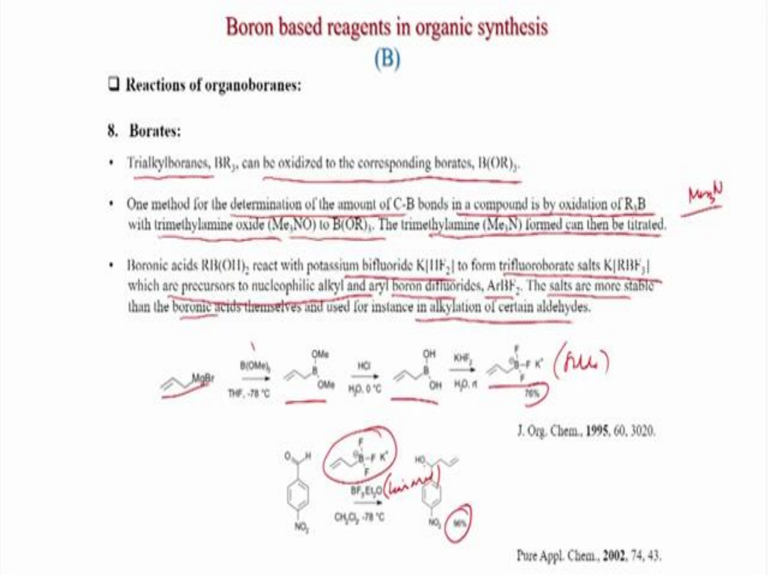
❑ **Reactions of organoboranes:**

7. Matteson's boronic ester homologation:

- Retrosynthetic analysis of homoallylic alcohol

And this homologation retrosynthetic analysis of homoallylic alcohol, this can be generated from the aldehyde and allyl organometallic reagent and this allyl boronic ester so allyl organometallic reagent mostly uses allylboronic ester, this can be reacting with aldehyde borates.

(Refer Slide Time: 61:51)



Boron based reagents in organic synthesis

(B)

❑ **Reactions of organoboranes:**

8. Borates:

- Trialkylboranes, BR_3, can be oxidized to the corresponding borates, $B(OR)_3$.
- One method for the determination of the amount of C-B bonds in a compound is by oxidation of R_3B with trimethylamine oxide (Me_3NO) to $B(OR)_3$. The trimethylamine (Me_3N) formed can then be titrated.
- Boronic acids $RB(OH)_2$ react with potassium bifluoride $K[HF_2]$ to form trifluoroborate salts $K[RBF_3]$ which are precursors to nucleophilic alkyl and aryl boron difluorides, $ArBF_2$. The salts are more stable than the boronic acids themselves and used for instance in alkylation of certain aldehydes.

Me_3N

J. Org. Chem., **1995**, 60, 3020.

Pure Appl. Chem., **2002**, 74, 43.

Now we will discuss, borates trialkylboranes can be oxidized to the corresponding borates one method for the determines of the amount of C-B bonds in a compound by oxidation of R3B with trimethylamine oxide or to BOR3. The trimethylamine formed that can be titrated. So this we have you can Me3N which is liberating that can be titrated. Boronic acid react with potassium bifluoride KH2 to form trifluoroborate salts which are precursors to nucleophilic alkyl and aryl boron difluorides ArBF2. The salts are most stable than the boronic acids themselves and used for instance of alkylation of certain aldehydes like this one, when it uses it with trimethoxide borate.

Then you get this allyl boronate species after HCl treatment with the allyl boronic acids and after treatment with KHF2, 3 fluorine comes to the boron and this product is stable. This was published in JOC and this is very useful allylating reagent so para nitro benzaldehyde when treated with allyl BF3 potassium reagent and this is a Lewis acid, then you get the allylation in 96 percent yield. This was published in pure applied chemistry.

So, today we have discussed first the borane synthesis and that is the first thing is the hydroboration, that is the borane addition to double bonds followed by we have discussed the Grignard addition via Grignard addition also you can because Grignard reagents can add to the boron and now, you can generate the borane compound.

Also via transition metal catalyzed C-H boralation because this is very important that CH bond not only aromatic the alkene C-H bond can also borylated and we have seen that

B2Pin2 there mostly uses and with iridium catalyzed or rhodium catalyzed you can get this borolation and mainly for long chain alkenes the terminal carbon atom that is borylated and for aromatic system you can get meta para mixture. Then we have discussed different reactions with boranes, so first we have discussed carbonylation, so carbonylation because carbon monoxide it is actually bidentate synthon, so it can react and make the boron negative and after that alkyl group can migrate.

So, after alkyl group migration it can reduce with a reducing reagents like trioxide lithium aluminum hydride and then after hydrolysis you get either aldehyde and alternatively with further treatment with another reducing reagent by lithium aluminum hydride and then NaOH H2O2 oxidant with condition you can get primary alcohol. Now, this is the mono migration, also double migration is possible when you treat with water, then the double migration is possible and you can get a ketone, also triple migration is possible and three alkyl groups can migrate.

And this case you can get like tri cycloalkyl alcohol or tertiary alcohol and in this case you have to use the ethylene glycol, so ethylene glycol is acting as the satisfying the bidentate because ethylene glycol is a bidentate, so it satisfies two coordination of boron and another is connected with another bulky alkyl groups. So, this is important and now, then we have discussed the cyanide so here the also depending on the trifluoroacidic anhydride, so is you use one equivalent of trifluoroacidic anhydride then the double migration is happening, because already one coordination is satisfied from the trifluoro acetyl group.

So, double migration is always possible and triple migration also is possible if you use excess trifluoroacidic anhydride and then, we have seen the other SP3, SP2 and SP systems other bidentatenucleophiles and like alpha bromo ketone enolate or alpha bromo ester enolate has been added to borane and we have seen the substitution of the boron by the alkyl group like n butyl group can be migrated when the bulky other like thexylborane is used as the anchor group then selectively only the n butyl group can migrate.

Also we have seen that SP2 system like the diazo ester that can also give the reaction and here also we are seen the migration of an alkyl group and then you can get the substitution at the ester group. Also we have seen the triple bond like, C-C triple bond can also give the reaction and then if you put the acid then the mono migration will happen, if you excess acid then double migration will happen, and tertiary alcohol will form.

Also we can put external electrophile so that electrophile can be added to the triple bond and the finally olefins with trans geometry is formed. And then we have seen that dichloro methyl methyl ether that is also useful and you can see the migration here possible, three groups can migrate and tricyclohexanol, tricyclohexalmethanol is formed also by this method.

And then we have seen the Matteson's boronate compound and which are good compound with chiral boron compound because there is alpha pinene that derived alcohol diols are there and that can give the products when treated with LiCCl2 then this double migration will happen, and you can get the secondary alcohol in very good yield. Thank you.