

**Pericyclic Reactions and Organic Photochemistry**  
**S. Sankararaman**  
**Department of Chemistry**  
**Indian Institute of Technology, Madras**

**Module No. #03**


**Lecture No. #14**

**Pericyclic Reactions –  $[4\pi+4\pi]$ ,  $[4\pi+6\pi]$  and Higher Order Cycloaddition reactions**

(Refer Slide Time: 00:11)

**PERICYCLIC REACTIONS AND ORGANIC PHOTOCHEMISTRY**

MODULE 14: Pericyclic reactions:  $[4\pi+4\pi]$ ,  $[4\pi+6\pi]$  and Higher order cycloaddition reactions



S. SANKARARAMAN  
DEPARTMENT OF CHEMISTRY  
IIT MADRAS  
CHENNAI 600036, INDIA  
sanka@iitm.ac.in



Hello, welcome back to Module Fourteen of the course on Pericyclic Reactions and Organic Photochemistry. We are still in the Cycloaddition stage only. This will be the last module on Cycloaddition reaction, wherein, we will consider higher order Cycloaddition reactions. Until now, the Cycloaddition reactions that we have discussed, are only 2+2 involving, 4 Electron Cycloadditions, and 4+2 involving, 6 Electron Cycloaddition reaction.

(Refer Slide Time: 00:38)

Cycloaddition reaction involving  $4\pi$  and  $6\pi$  electrons are the most commonly encountered reactions.

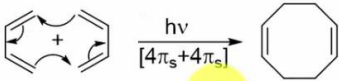
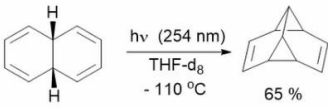
Cycloaddition reactions of larger  $\pi$  systems containing  $8\pi$ ,  $10\pi$ ,  $12\pi$  and  $14\pi$  electrons are also known but less common.

Higher order cycloaddition reactions also obey the Woodward Hoffmann rules.


Those are the most commonly involved Cycloaddition reactions, that we encounter in organic synthesis. There are Cycloaddition reactions involving larger PI systems, typically 8 Electron, 10 Electron, 12 Electron, and 14 Electron systems, are also known. But, they are not very common in nature. The higher order Cycloaddition reactions, also obey the Woodward-Hoffmann rule. But, there are certain differences, that one can observe in the higher order Cycloaddition reactions, which we will consider in this particular module.

Examples of  $[4\pi+4\pi]$  cycloaddition reactions

cis 9,10-dihydronaphthalene

Roof shaped molecule  
C1-C8 and C4-C5 are within 3 Å distance, overlap is feasible



(Refer Slide Time: 01:09)

Here is an example of a  $4\pi-4\pi$  Cycloaddition reaction, involving two molecules of Butadiene in a face-to-face manner, resulting in a Suprafacial-Suprafacial Cycloaddition reaction, to give Cycloocta-1,5-Diene as the product. Now, this reaction mechanism could be that, initially a  $2+2$  Cycloaddition reaction is formed, involving the formation of a 1,2-

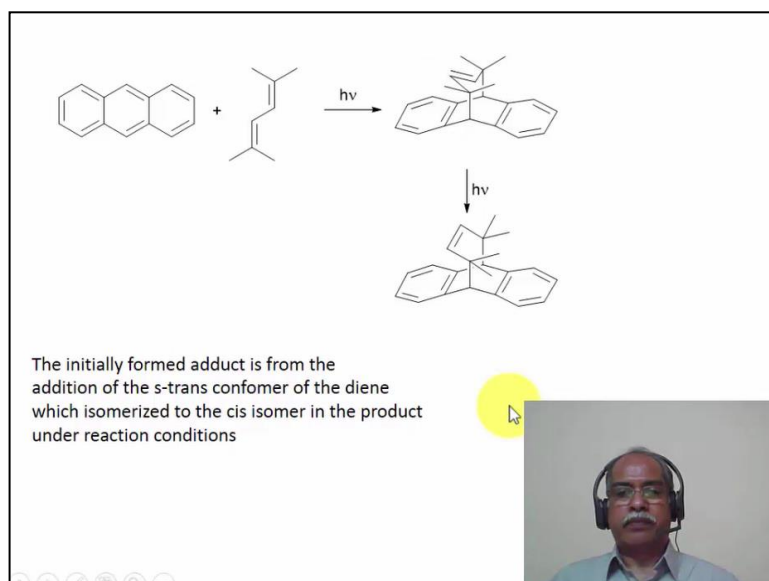
Divinyl Cyclobutane derivative. The 1,2-Divinyl Cyclobutane derivative, can undergo 3,3-Sigmatropic rearrangement, to still give the same product.

So, one cannot distinguish a 4+4 Cycloaddition reaction, from a reaction involving 2+2 Cycloaddition reaction, followed by a 3,3-Sigmatropic rearrangement, which is a cope rearrangement to give this product. However, a more convincing evidence comes from this molecule, which undergoes 4PI-4PI Cycloaddition reaction. If you want to visualize this particular molecule, this is like a roof shaped molecule, because of the Cis fusion on the 9,10 position of the Dihydro Naphthalene.

This molecule possesses the shape of a roof, which brings the Carbon number-1 and Carbon number-8, as well as Carbon number-4 and Carbon number-5, in close proximity, such that bond can be formed between Carbon number-1 and Carbon number-8, that would result in the formation of a 3-Membered ring, which is this 3-Membered ring in the product here. Similarly, they are bonding between Carbon number-4 and Carbon number-5, will involve the formation of another Cyclopropane ring, which is this Cyclopropane ring, here.

So, this is a true example of a 4PI-4PI-Suprafacial-Suprafacial Cycloaddition reaction. This is feasible only because of the fact, this molecule has the necessary geometry, which is the roof shaped geometry, which allows the overlap of Carbon 1 and 8, and Carbon 4 and 5. So, such a facility is necessary probably for involvement of a 4 Electron, 4 Electron, overall an 8PI Electron Cycloaddition reaction, to give this interesting molecule, which is a polycyclic molecule, in this case.

(Refer Slide Time: 03:16)



4PI-4PI Cycloaddition reactions, are also known in an Intramolecular version. This is an Intermolecular version. The one, that we saw here, is an Intramolecular version. The one, we

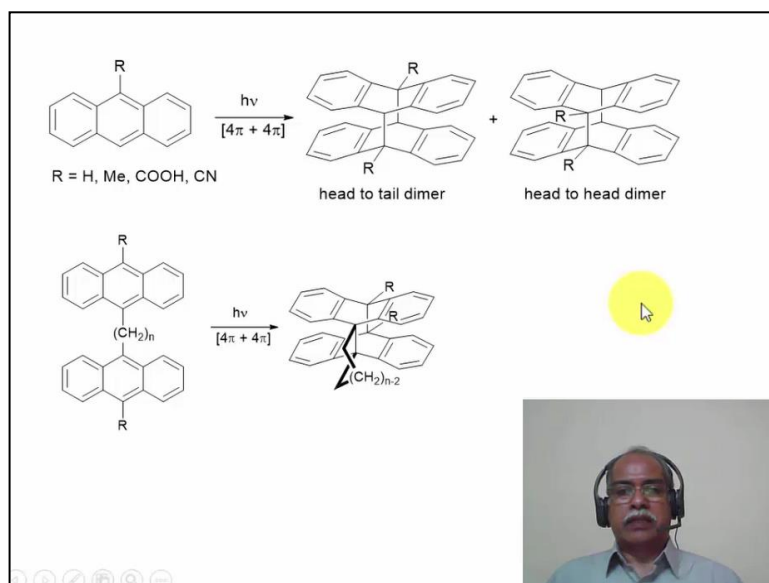
see here, is an Intermolecular version of this molecule. The Tetramethyl Butadiene, that is shown here, it is shown in the Transoid confirmation. It undergoes a 4PI-4PI Cycloaddition reaction, between Anthracene and itself, resulting in the formation of a cycloadduct.

Please note the stereochemistry of the initially formed product, that is coming from this reaction. This has to undergo a Cycloaddition reaction, in a transoid geometry, to give this particular Trans isomer of this Olefin, which is in the Cycloadduct. So, the 9, 10 position of Anthracene, reacts with the 1 and 4 position of the transoid Butadiene molecule, resulting in the formation of this Trans isomer of the Cycloadduct, which is shown here. Under the photochemical condition, Cis Trans isomerization prevails, and the Trans isomer isomerizes to the Cis isomer, in this particular case.

So, the initially formed Trans isomer, undergoes photochemical isomerization, to give the Cis product, which is the final product in this particular case. This is again a true example of a 4PI-4PI Cycloaddition reaction, presumably involving the formation of an Exciplex, that is initially the photo excitation of Anthracene, results in the formation of the singlet excited state of Anthracene.

The singlet excited state of Anthracene, forms a PI complex with a Transoid Butadiene, in this particular case, forming an Exciplex kind of a molecule. The Exciplex intermediate, is what is actually undergoing the Cycloaddition reaction, to give this initial Trans adduct, which isomerizes to the Cis adduct, during the course of the Photochemical Isomerization reaction.

(Refer Slide Time: 05:08)



The more common reaction, that one observes in the laboratory, is the dimerization of Anthracenes. Anthracenes are very reactive in the 9 and 10 position. Upon photochemical

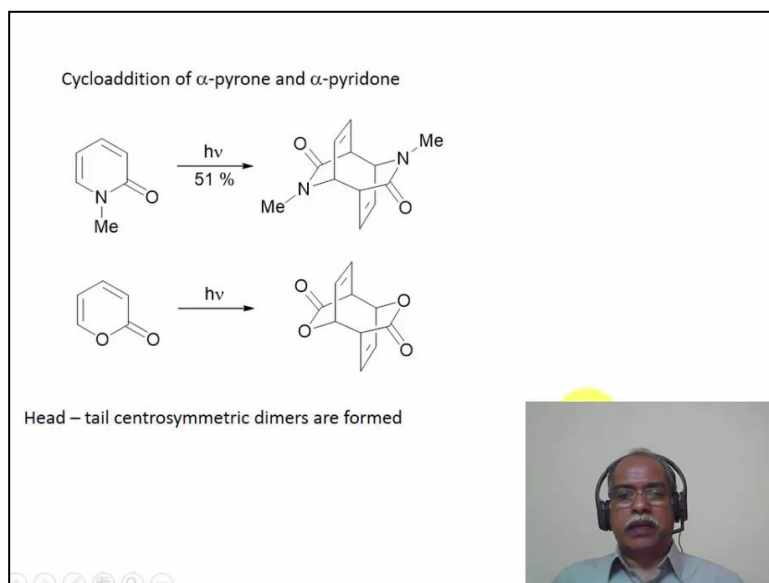
excitation, they do undergo 4PI-4PI Cycloaddition reaction, in a Suprafacial-Suprafacial manner. Anthracene, itself undergoes the Cycloaddition reaction, to give the photo dimer of Anthracene, the structure of which is shown here. However, if you take substituted Anthracene, there are two possible products that can be formed, depending upon the relative orientation of the two molecules, that undergo the Cycloaddition process.

The two molecules can be oriented in such a way, that the R-group of one molecule, and R-group of another molecule, can be Cis or eclipsing with respect to each other, during the transition state, that would form the Head to Head Dimer. On the other hand, the molecule can orient in such a way, that one molecule with a R-group up, the other molecular with the R-group down, which will result in the formation of a Head to Tail Dimer. So, whether the molecules orient Head to Head with respect to the R-group, or Head to Tail with respect to the R-group, will ensure the formation of the Head-to-Head Isomer, or the Head-to-Tail Isomer, of this Cycloaddition process.

Now, this is again an Intermolecular version of the 4PI-4PI Cycloaddition reaction, involving a Suprafacial-Suprafacial overlap, which obeys the Woodward-Hoffmann rule. When the two Anthracene units are tied up with a long chain. The long chain can be, anywhere from 6 to 8 Carbon atoms, in this particular case. The minimum number of Carbon atoms, that is necessary is 2 Carbon atoms, in this particular instance.

Here, the involvement of Herxheimer is possible. Excited state of one Anthracene unit, with the neighboring Anthracene unit, forming a complex in the excited state, resulting in the formation of an Herxheimer, may be an intermediate stage, before the product is actually formed. You can see here; the bridge is essentially forming a cycle here. This is possible only as a Head-to-Head dimerization, because of the linking Methylene groups in this particular instance, resulting in the formation of a very interesting photo dimer of this particular Dianthracene derivative.

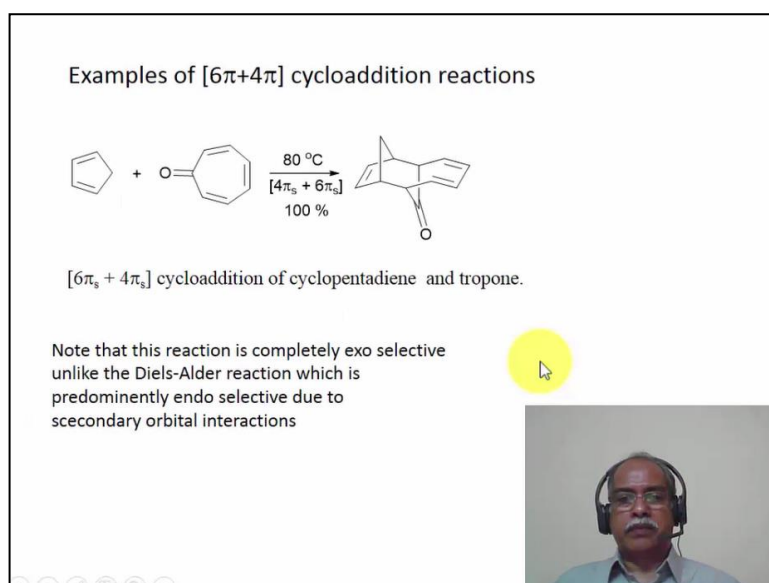
(Refer Slide Time: 07:21)



Alpha Pyrones and Alpha Pyridones are also known to undergo a 4PI-4PI Cycloaddition reaction. They do so, by means of Head to Tail orientation, resulting in the formation of Centrosymmetric dimer. These dimers have a center of symmetry, which is a center of this molecule, that is shown here. Similarly, this molecule as a center of symmetry, which is the center of this molecule, in this particular instance.

The photo dimerization of Pyridone gives this photo dimer, by a Head to Tail orientation, of the two units of the Pyridone. Similarly, in the case of Pyrone also, the Head to Tail orientation of the two units of Alpha Pyrone, results in the formation of this Bis Lactone, that is shown in the structure, which is center of symmetry.

(Refer Slide Time: 08:06)

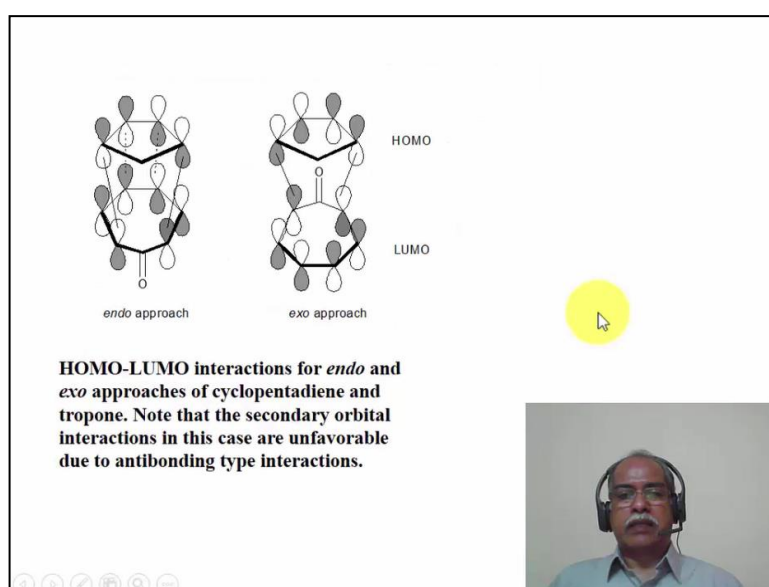


Example of 10 Electron cyclisation is also known. This is between Tropone and Cyclopentadiene, for example. The Tropone is a 6 Electron-PI system, whereas

Cyclopentadiene is a 4 Electron-PI system. The 4PI-6PI Cycloaddition of Cyclopentadiene with Tropone, is what is shown, to yield this particular product, which is the Carbonyl bridged tricyclic compound of this nature, for example.

Please note that, this reaction is completely Exo selective in the sense, the PI system is Exo to the bridging Methylene unit. In other words, this Carbonyl PI system is Endo, to the bridging PI unit. This is unlike the Diels-Alder reaction, which predominantly undergo Endo selective Diels-Alder reaction, because of the Secondary Orbital interaction. Here, the Secondary Orbital interactions are unfavorable, to form the Endo adduct. Therefore, it forms Exo adduct, which is explained in the next slide.

(Refer Slide Time: 09:03)



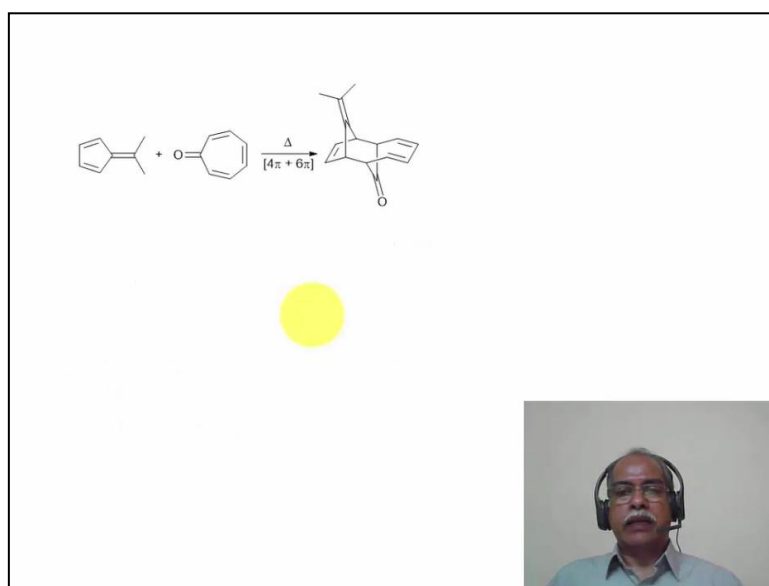
If we consider for example, the Diels-Alder reaction between the Cyclopentadiene and Maleic Anhydride, the Secondary Orbital interactions are generally bonding in nature. On the other hand, if you take Tropone and Cyclopentadiene, to undergo a 6PI-4PI Cycloaddition reaction. This is the primary interaction between, these two Carbons, Carbon number 1 and 4 of the Cyclopentadiene, and Carbon number 1 and 6 of the Tropone, for example. This primary interaction, essentially leads to the sigma bond formation.

But, in the Endo approach, if you see the Secondary Orbital interaction, is an unfavorable antibonding type of an interaction. Such an antibonding type of an interaction in the transition state, will essentially destabilize the transition state. Moreover, the Endo approach is actually a sterically hindered approach. It does not have the Thermodynamic stability of the Secondary Orbital interaction. However, in the Exo approach, such a Secondary Orbital interaction does not exist.

So, this is likely to be, both from the Steric point of view, as well as from the Thermodynamics stability point of view, this is a more favorable transition state. And, that is a reason, this Exo adduct is formed, in this case of 6PI-4PI Cycloaddition reaction. Unlike for example, in the 4PI-2PI Cycloaddition reaction, where Endo is favorable, because of the Secondary Orbital interaction is being, bonding type of an interaction.

This is an essential difference between the Diels-Alder reaction, and the higher order Cycloaddition reaction.

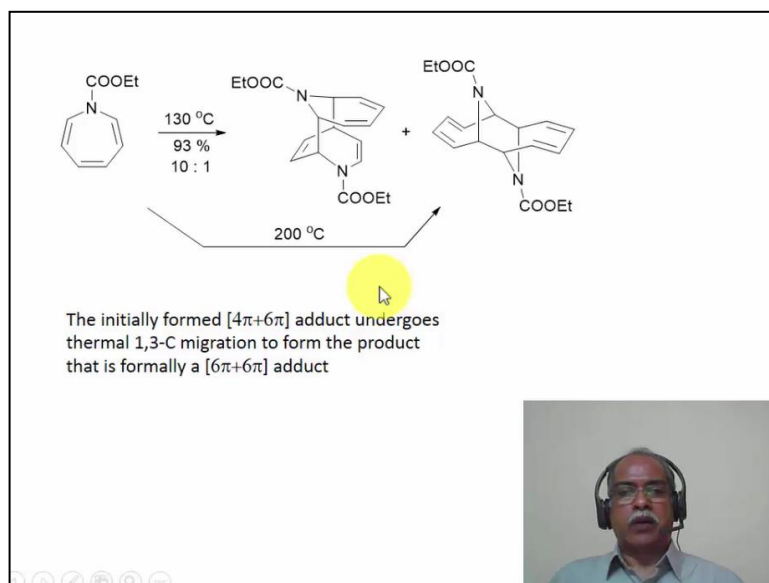
(Refer Slide Time: 10:33)



The same type of reaction is also seen, in the case of the Fulvalene, which is this molecule here. Sorry. This Fulvene molecule, undergoing a Cycloaddition reaction with the Troponone. Again, an Exo stereo chemistry is what is observed, with respect to the bridge, that is shown here. This PI system is Exo, for the identical reason that we discussed earlier, with the Troponone and the Cyclopentadiene. So, the Exo isomer is a more favorable isomer, in the case of the 4PI-6PI Cycloaddition reaction, in this case.

(Refer Slide Time: 11:02)

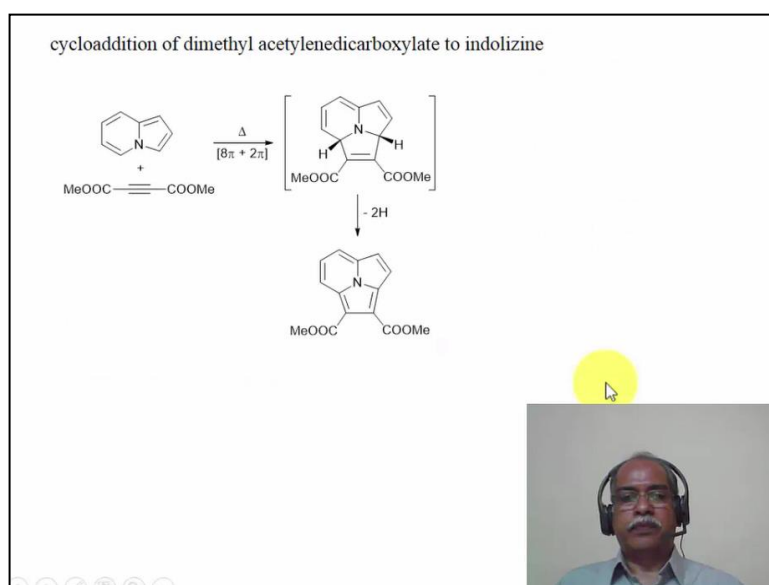




Now, Cycloaddition reaction of this kind of Azepine, is very well known. Azepine undergoes a Cycloaddition reaction, to give two possible products. The one product that is shown here, is a 6PI-4PI Cycloaddition reaction, which is this particular reaction. This reaction essentially produce a 6PI-6PI Cycloaddition reaction, which would correspond to this particular adduct. A 4PI-6PI Cycloaddition reaction, which would correspond to this particular adduct. The initially formed 4PI-6PI Cycloaddition reaction, under the reaction condition, undergoes a 1,3-Thermal shift, 1,3-Carbon shift.

If you consider this Carbon-Carbon bond, this can undergo a 1,3-Shift, to this particular Carbon, with the concomitant migration of this double bond to the next position, resulting in the formation of a 6PI-6PI Cycloaddition product. So, the reaction involves, there are two reactions that are involved. The initially formed 6PI-4PI Cycloaddition adduct, is this particular adduct. This undergoes a thermal migration, to give a 6PI-6PI, formally a 6PI-6PI type of a Cycloaddition product, which is the centrosymmetric molecule, that is shown in this particular case.

(Refer Slide Time: 12:17)

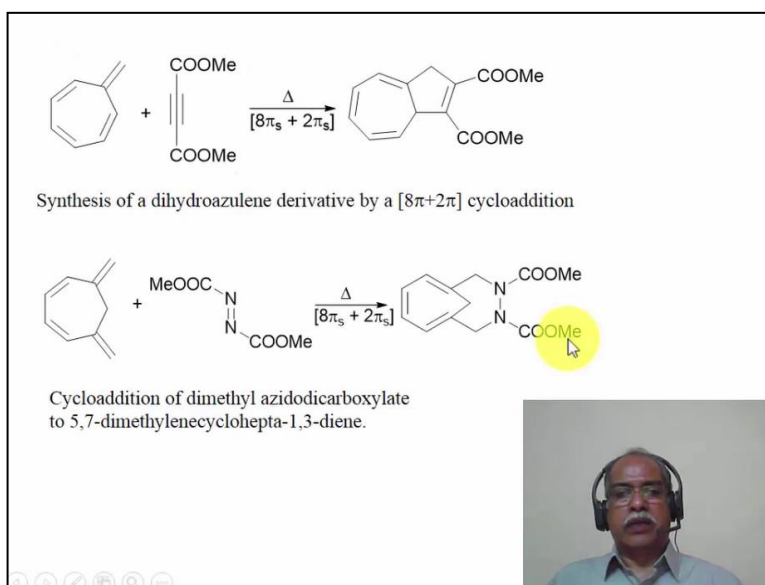


Here is a higher order Cycloaddition reaction of the type, 8PI-2PI Cycloaddition reaction. If you consider this molecule here, this can undergo a Cycloaddition reaction, involving all the 8PI Electrons in this particular system, with the 2PI Electrons of the Dimethyl-Acetylene-Dicarboxylic acid, resulting in the formation of an 8PI-2PI Cycloadduct, which is a 10 Electron Cycloadduct.

Under thermal condition, this should be Suprafacial-Suprafacial in nature, because it is a  $4N+2$  system, according to the Woodward-Hoffmann rule. The  $4N+2$  system under thermal conditions, will undergo a Suprafacial-Suprafacial Cycloaddition reaction. How do we know that, it is Suprafacial on both components? From the Acetylene component, you cannot tell, whether it is Suprafacial or not, because there is no stereo chemical center. However, from the 8PI Electron system, because these two Hydrogens are Cis with respect to each other. These two Hydrogens, we are talking about, Cis with respect to each other.

One can very clearly tell that, the 8PI component has also been a Suprafacial component, in this particular case. Under the reaction condition, it undergoes aromatization by loss of Hydrogen, to undergoes oxidation by loss of Hydrogen, to give this fully aromatic system, as a final product during the course of the Cycloaddition process.

(Refer Slide Time: 13:33)



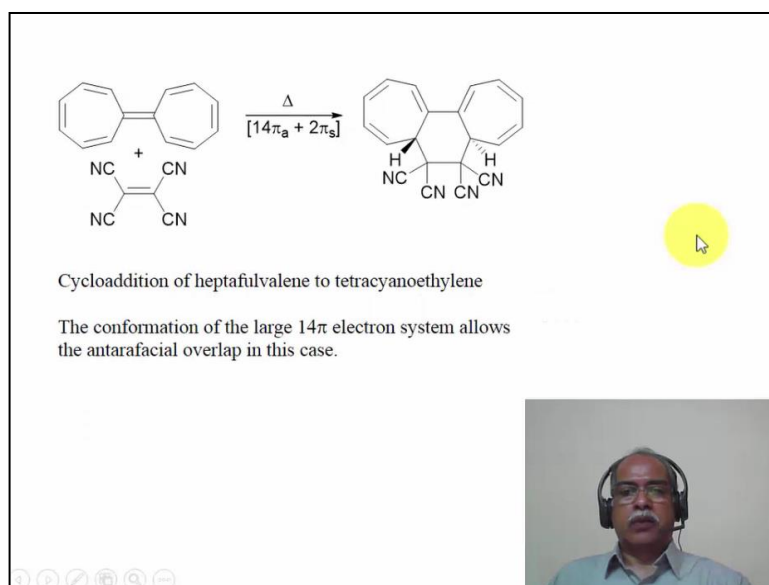
Dihydroazulene is formed, during the Cycloaddition reaction of this Exo-Methylene-Cycloheptatriene, with Dimethyl-Acetylene-Dicarboxylic acid. Here again, the Cycloaddition is between this Carbon here, and this Carbon here, to form a 5-Membered ring. So, all the 8 Electrons of the Exo-Methylene-Cycloheptatriene is involved, along with a 2 Electrons of the Dimethyl-Acetylene-Dicarboxylic acid, resulting in the formation of the Dihydroazulene derivative, which is this particular derivative.

In the case of this reaction here, this is also an example of an 8PI-2PI Cycloaddition reaction, involving a Suprafacial-Suprafacial overlap. Here, Dimethyl-Diaceto-Dicarboxylate is what is used, as the component of the Cycloaddition partner. Here, the reaction essentially proceeds between this Carbon over here, and this Carbon over here, resulting in the formation of a bridged bicyclic system of this type.

And, the Cycloaddition of Dimethyl-Diaceto-Dicarboxylate, to form to 5,7-Dimethylene Cyclopentadiene, is what is illustrated as the 10 Electron system, in this particular case. These are interesting examples of, higher order Cycloaddition reactions involving 10 Electrons, which is a  $4N+2$  system, involving a Suprafacial-Suprafacial overlap of the two components. Over there are no stereo chemical centers to ascertain, whether it actually underwent a Suprafacial-Suprafacial Cycloaddition reaction.

We conclude that, it could be Suprafacial- Suprafacial addition reaction by analogy, to the other known 8+2 Cycloaddition reactions, which are similar to the Diels-Alder reaction. Involving  $4N+2$  Electron system.

(Refer Slide Time: 15:23)



This is one of the largest Cycloaddition reaction, that is known, in terms of the number of PI Electrons involved. You can see here, there are 14PI Electrons in the Hepta Fulvalene. Hepta Fulvalene molecule is this one. And, it undergoes Cycloaddition reaction with Tetracyanoethylene. All the 14 Electrons of the Hepta Fulvalene is involved, as you can see from the rearrangement of the PI Electron system, during the course of the Cycloaddition reaction.

The Cycloaddition occurs, between this Carbon, and this Carbon of the Hepta Fulvalene, and these two Carbons of the Tetracyanoethylene. And, the reaction is very clearly Antarafacial,

with respect to the larger PI system. This is a 4N Electron system, involving totally a 16 Electron species. So, one of the component has to be a Antarafacial component, according to the Woodward-Hoffmann rule. It is that, the larger PI system, which has more flexibility is the one, that can undergo the Antarafacial component of this particular reaction.

This is 2PI Electron system, which is a Suprafacial component. And, this a 14PI Electron system, which is an Antarafacial component. The geometry of the molecule is such that, this is a twisted compound. These two Carbons can easily overlap in an Antarafacial manner, with Tetracyanoethylene. In other words, very similar to the perpendicular approach, is what is happening in the molecule, in terms of the geometry of the molecule, favoring the Antarafacial addition reaction.

How do we know that, it is an Antarafacial addition reaction? Whenever a molecule is undergoing an Antarafacial addition reaction, there will be an inversion of stereochemistry. So, these two hydrogens, which are pointing out now, should have been Cis with respect to each other, if it was a Suprafacial component. But, the stereo chemistry, crystal structure of this molecule shows very clearly the stereochemistry to be, the Trans stereochemistry. The Trans stereochemistry can arise only, if this component had undergone a Antarafacial type of a Cycloaddition reaction, with this as a Suprafacial type of a Cycloaddition partner.

So, overall, this is a 14PI Antarafacial, and 2PI Suprafacial, involving a 16 Electron. In other words, a 4N Electron system, undergoing a Cycloaddition reaction, to give this particular product. I hope, you enjoyed the higher order Cycloaddition reaction. These are a very interesting examples of a multiple Electron systems, more than six Electron system, is what we have considered in this module. Thank you very much, for your kind attention.