Skills to Develop

In this lecture you will learn the following

- The metal−allyl complexes.
- The metal−diene complexes.
- The metal−cyclobutadiene complexes.
- The respective metal−ligand interactions.

The allyl ligand is often referred to as an “actor” ligand rather than a “spectator” ligand. It binds to metals in two ways, i.e., in a $\eta^1$ (monohapto) form and a $\eta^3$ (trihapto) form (Figure 1). (i). In its monohapto ($\eta^1$) form, it behaves as an anionic $1e$–$donor$ $X$ type of a ligand analogous to that of a methyl moiety while (ii) in a trihapto ($\eta^3$) form, it acts as an anionic $3e$–$donor$ $LX$ type of a ligand.

Figure 1. Metal−allyl interaction.

**Metal−allyl interaction**

Of particular interest are the molecular orbitals namely $\Psi_1$, $\Psi_2$ and $\Psi_3$ of the allyl ligand that interact with the metal in a metal allyl complex. The energy of these molecular orbitals increase with the increase in the number of nodes. Of the three, the $\Psi_1$ and $\Psi_2$ orbitals usually engage in ligand to metal $\sigma$–donation, with $\Psi_1$ involving in a dative $L$–type bonding and $\Psi_2$ participating in a covalent $X$–type bonding with the metal $d$ orbitals (Figure 2).
Synthesis of the metal allyl complexes

The metal allyl complexes are synthesized by the following methods.

1. From an alkene complex as shown below.

2. By a nucleophilic attack of an allyl compound as shown below.

3. By an electrophilic attack of an allyl compound as shown below.
Reactions of metal allyl complexes

The reactivities of the metal allyl complexes toward various species are illustrated below.

1. Reaction with nucleophiles

2. Reaction with electrophiles
3. Insertion reaction

4. Reductive elimination

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**Diene complexes**

1,3-Butadiene is a *4e−donor* ligand that binds to a metal in a *cisoid* conformation. The *Dewar–Chatt* model, when applied to 1,3-butadiene, predicts that the ligand may bind to metal either as a L₂ (π₂) donor type, similar to that of an alkene, or as an LX₂ (σ₂π) donor type, similar to that of a metalacyclopropane form. The L₂ binding of 1,3-butadiene is rare, e.g. as in (butadiene)Fe(CO)₃, while the LX₂ type binding is more common, e.g. as in Hf(PMe₃)₂Cl₂. An implication of the LX₂ type binding is in the observed shortening of the C₂–C₃ (1.40 Å) distance alongside the lengthening of the C₁–C₂ (1.46 Å) and C₃–C₄ (1.46 Å) distances (Figure 3).
Figure 3. Metal–diene interaction in cisoid binding.

The molecular orbitals of the 1,3-butadiene ligand comprises of two filled $\Psi_1$ (HOMO−1) and $\Psi_2$ (HOMO) orbitals and two empty $\Psi_3$ (LUMO) and $\Psi_4$ (LUMO+1) orbitals. In a metal–butadiene interaction the ligand to metal $\sigma$–donation occurs from the filled $\Psi_2$ orbital of the 1,3-butadiene ligand while the metal to ligand $\pi$–back donation occurs on to the empty $\Psi_3$ orbital of the 1,3-butadiene ligand (Figure 4).
Though *cisoid* binding is often observed in metal butadiene complexes, a few instances of *transoid* binding is seen in dinuclear, e.g. as in Os$_3$(CO)$_{10}$(C$_4$H$_6$), and in mononuclear complexes e.g. as in Cp$_2$Zr(C$_4$H$_6$) (Figure 5).

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**Synthesis of metal butadiene complex**

Metal butadiene complexes are usually prepared by the same methods used for synthesizing metal alkene complexes. Two noteworthy synthetic routes are shown below.
Metal cyclobutadiene complexes

Cyclobutadiene is an interesting ligand because of the fact that its neutral form, being anti-aromatic (4π-electrons), is unstable as a free molecule (Figure 6), but its dianionic form is stable because of being aromatic (6π-electrons). Consequently, the cyclobutadiene ligand is stabilized by significant metal to ligand π-back donation to the vacant ligand orbitals.
Problems

1. The hapticities displayed by an allyl moiety in binding to metals are? Ans: 1 and 3.

2. Identify which molecular orbitals of an allyl moiety engage in $\sigma$-interaction with a suitable $d$ orbital of a metal in a $\eta^3$-metal allyl complex? Ans: $\Psi_1$ and $\Psi_2$.

3. Predict the product of the reaction.

Ans:
4. Identify which molecular orbitals of a butadiene moiety engage in σ−interaction with a suitable d orbital of a metal in a η⁴−metal butadiene complex? Ans: Ψ₂.

Self Assessment test

1. Predict the product of the reaction.

Ans:


Summary

Allyl, 1,3−butadiene and cyclobutadiene together constitute an important class of σ−donor/π−acceptor ligands that occupy a special place in organometallic chemistry. The complexes of these ligands with metals are important intermediates in many catalytic cycles and hence an understanding of their interaction with metal is of significant importance. In this context, the synthesis, characterization and the reactivities of the organometallic complexes of these ligands are described alongside the respective metal−ligand interactions.