Chapter 2

Formation of Carbon–Carbon Bonds

2.1. Formation of Carbon–Carbon Single Bonds

Despite the fundamental importance of carbon–carbon bond formation in organic synthesis, there are only a very limited number of "classical" methods available which proceed selectively, in high yield, under mild conditions. However, transition-metal-mediated addition, substitution, dimerization, oligomerization, and coupling reactions often do proceed in this way, and the present chapter is concerned with applications of such chemistry to organic synthesis.

The ability of transition metal reagents and catalysts to promote carbon–carbon bond formation has been recognized for many years. The "Kharasch" reactions, involving copper-catalyzed addition of Grignard reagents to activated alkenes, and cobalt-catalyzed substitution of organic halides by Grignard reagents were, for example, described in 1941, but it is only relatively recently that the full potential of transition metals in this area has been appreciated. The involvement of transition metals in organic reactions, via $d$-orbital participation, can in fact give access to a wide range of novel reaction pathways leading to carbon–carbon bond formation. Simple alkenes, for example, react readily with electrophiles and are not normally susceptible to nucleophilic attack, but coordination of the alkene to a transition metal inverts this reactivity and allows nucleophilic addition of carbanions to the double bond [Eq. (1)]. Other pathways more or less specific to transition metal chemistry include reductive elimination of two...
organic fragments from the metal, with C–C bond formation [Eq. (2)], alkene “insertion” into a metal–carbon or metal–hydrogen bond [Eq. (3)], and alkene elimination from a metal center by β-hydrogen abstraction [Eq. (4)].

\[ \text{R-M-R} \rightarrow [\text{M}] + \text{R-R} \]  \hspace{1cm} (2)

\[ \text{M-R} \rightarrow \text{M-R} \rightarrow \text{M-R} \]  \hspace{1cm} (3)

\[ \text{M-R} \rightarrow \text{H} + \text{M-R} \]  \hspace{1cm} (4)

These elementary steps can lead to catalysis of known reactions, e.g., alkene dimerization, by providing low-energy pathways, but perhaps more importantly, they can also generate entirely new syntheses such as the catalytic arylation of alkenes described in Section 2.1.4.2.

2.1.1. Preparation of Substituted Alkenes

2.1.1.1. Dimerization of Alkenes

The nonoxidative dimerization of alkenes is catalyzed by a variety of transition metal complexes, zero-valent nickel complexes and rhodium and palladium halides being among the most commonly used. The range of substrates that has been examined tends to be limited to simple alkenes like ethylene and propylene, but of potential commercial interest is the rhodium-catalyzed dimerization of methyl acrylate [Eq. (5)].

\[ \text{CH}_2=\text{CHCO}_2\text{Me} \xrightarrow{\text{RhCl}_3, \text{MeOH}} \text{MeO}_2\text{CCH}=\text{CHCH}_2\text{CH}_2\text{CO}_2\text{Me} \]  \hspace{1cm} (5)

Nickel catalysts convert alkenes into a mixture of dimers, trimers and higher oligomers, the rate being generally first order in nickel, second order in alkene, and decreasing in the order

\[
\text{CH}_2=\text{CH}_2 > \text{CH}_3\text{CH}=\text{CH}_2 > \text{cycloalkene} > \text{MeCH}=\text{CHMe}
\]

The catalyst can be prepared in situ from various nickel(II) complexes by reduction in the presence of a Lewis acid, using diethylaluminum