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RULES GOVERNING ASYMMETRIC SYNTHESIS WITH ORGANOTRANSITION METAL COMPLEXES

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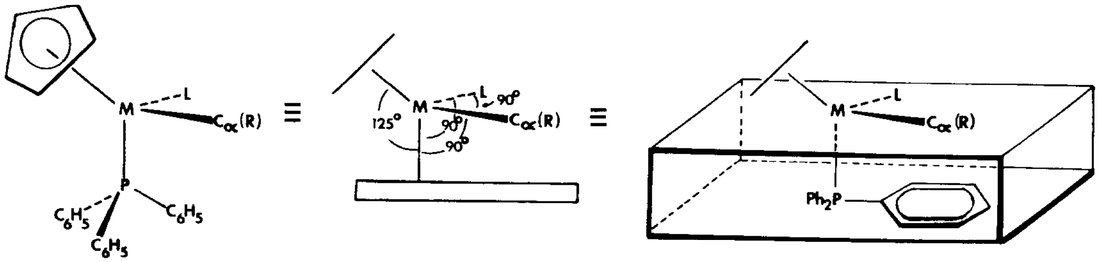
Abstract A set of rules are presented which allow prediction of (1) the conformational properties of organotransition metal complexes of the type $(\eta^5\text{-}C_5H_5)M(Ph_3P)(L)R$ [M = Fe,Co,Re; L = CO, NO]; and (2) the stereochemical consequences of their reactions.

Organotransition metal chemistry now plays a significant and ever increasing role in organic synthesis.[1-3] As would be expected in any newly developing field, unifying theories or general rules concerning structure-reactivity relationships have lagged behind the discovery of the reactions which these organometallics can undergo.[4] We now present a series of rules which allow the prediction of the stereochemical consequences of reactions on conformationally flexible ligands in chiral iron and related complexes. These rules utilise conformational analysis of the substrate organotransition metal complexes to predict structure-product relationships in a manner strictly analogous to that used for traditional topics in organic chemical reactivity.[5-6]

Complexes of the type 1 are frequently referred to as "pseudotetrahedral",[7-12] not only in written descriptions of these molecules but also in two dimensional drawings. These misleading representations are subsequently used to explain structural, spectroscopic and chemical reactivity characteristics of the complexes. To perform conformational analysis on complexes containing acyclic ligands, especially those which can react to form more than one diastereomer, one must follow the most stringent stereochemical considerations. We now present six rules which form the basis of structure-reactivity correlations for complexes generalized by 1. We then illustrate and provide experimental support for these rules with a number of pertinent examples. It is to be emphasised that Rules 1-5 form a logical sequence.



1a 1b 1c

Rule 1. Complexes of the type 1 $CpM(Ph_3P)(L)R$ [$Cp = \eta^5-C_5H_5$; M=Fe,Co,Mn,Re; L= CO,NO] are pseudo octahedral with the following crucial structural features: bond angles $<P-M-R \sim <P-M-L \sim <R-M-L \sim 90^o$ and $<P-M-Cp \sim 125^o$.[13a]

Rule 2. The PPh_3 ligand forms a plane[14] approximately parallel to and ca. 3-4 Å below the plane defined by $\{C_\alpha-M-L\}$. (To avoid confusion, we adopt the convention {x-y-z} to indicate the plane defined by atoms x, y, and z)

Rule 3. Conformations of the R ligand in 1 which would place alkyl or aryl group(s) in between the $\{C_\alpha-M-L\}$ plane and the $\{PPh_3\}$ plane are energetically unfavourable.[13]

Rule 4. All reactivity at the ligand R in 1 occurs above the $\{C_\alpha-M-L\}$ plane rather than between this plane and the $\{PPh_3\}$ plane.[13] See 1c for pictorial representation of the "excluded" volume.

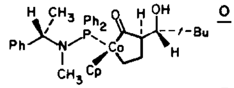
Rule 5. High diastereoselectivities will be obtained when new chiral centres are formed in or near the $\{C_\alpha-M-L\}$ plane.

Rule 6. (A) If C_α is sp^2 hybridized and has one oxygen substituent, then the two oxygen atoms are anti, i.e., $\tau(OC_\alpha ML)$ = ca. 180°. (B) Reactions of such compounds (e.g. 2 and 5 below) will occur exclusively from anti-oxygen conformations.

We now examine a number of structural and chemical examples which illustrate and support these rules.

Results 1. Table I summarises some of the available x-ray crystallographic data

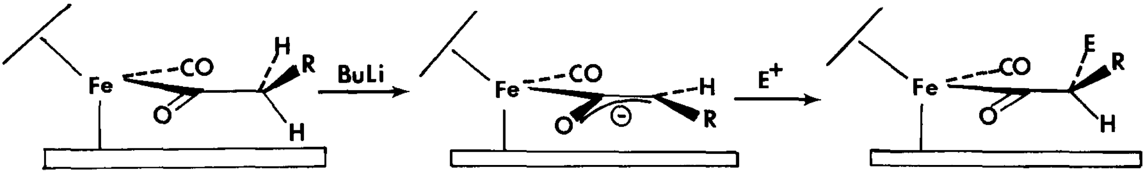
Table I. Important Structural Features for complexes 1 as Determined by X-Ray Crystallography

Complex	bond angle[a] (deg)				perpendicular distance[b,c] from atom x to $\{PPh_3\}$ (Å)			sp^2-O... CO(NO) geometry
	$<PMC_\alpha$	$<PML_\alpha$	$<C_\alpha ML_\alpha$	$<PMCp$	$d_{\alpha:Ph}$	$d_{\beta:Ph}$	$d_{\gamma:Ph}$	
$CpFe(PPh_3)(CO)-CH_2O$ Menthyl [d]	92.0	91.7	89.3	126.9	2.66	3.95	--	--
$CpFe(PPh_3)(CO)-CH_2CO_2$ Menthyl [d]	90.9	92.7	95.9	126.2	2.75	3.28	2.55[e] 4.18[f]	--
$[CpRe(PPh_3)(NO)-=CHPh]^+$ [g]	93.2	91.4	100.1	118.6	2.72	2.86	2.21[h] 3.63[h]	--
$CpRe(PPh_3)(NO)CHO$[i]	84.9	92.8	92.6	123.6	2.95	3.15	--	anti
(RR,SS)$CpFe(PPh_3)-(CO)\{COCH(Me)Et\}$ [j]	89.3	92.1	94.8	127.8	2.89	3.17[k] 3.39[l]	3.89[m] 4.52[n]	anti
 [o]	92.2	94.0	84.2	129.5	[angle between $\{PPh_3\}$[b] and {cyclopentanone ring} = 24.8°]			[p]
$CpMn(CO)_2=C(OEt)Ph$[q]	90.3[r]	91.0[r]	97.8[r]	119.6[r]	--	--	--	--

[a] In this paper, the following nomenclature is defined for complex 1 as follows: P refers to the phosphorus atom in PPh_3, M refers to the metal atom, C_α refers to the α-carbon in ligand R; L_α refers to the α-atom in the CO or NO ligand; Cp refers to the centroid of the cyclopentadienyl moiety. [b] See reference 14 for discussion of the definition of "perpendicular distance". [c] The parameters $d_{\alpha:Ph}$, $d_{\beta:Ph}$ and $d_{\gamma:Ph}$ refer to the distance to the α, β, and γ atoms respectively. [d] Chou, C.-K.; Miles, D.L.; Rau, R.; Flood, T.C. J.Am.Chem.Soc. 1978, 100, 7271. [e] $d_{C-O\gamma—C:Ph}$. [f] $d_{C=O\gamma:Ph}$. [g] Kiel, W.A.; Lin, G.-Y.; Constable, A.G.; A.G.; McCormick, F.B.; Strouse, C.E.; Eisenstein, O.; Gladysz, J.A. J.Am.Chem.Soc. 1982, 104, 4865. [h] γ:atom refers to the two different ortho-phenyl carbons. [i] Wong, W.-K.; Tam, W.; Strouse, C.E.; Gladysz, J.A. J.Chem.Soc., Chem. Commun. 1979, 530. [j] Reference 16. [k] β:atom = O. [l] β:atom = C. [m] γ:atom = CH_2CH_3. [n] γ:atom = $CHCH_3$. [o] Reference 20b. [p] Fixed syn. [q] Schubert, U. Organometallics 1982, 1, 1085. [r] The carbon atom of one of the CO ligands is considered to be P for this bond angle.

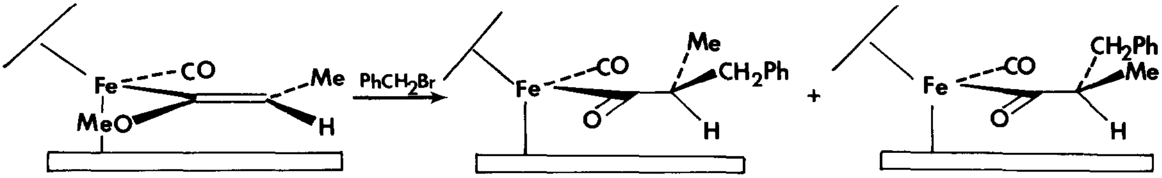
chosen to illustrate the structural features pertinent to Rules 1-6A. The pseudo-octahedral character of complexes generalised by structure 1 (Rule 1) and the "roughly" parallel nature of plane {C_α-M-L} and {PPh_3} (Rule 2) are evident from Table I. All these entries also indicate that the region between the planes {PPh_3} and {C_α-M-L} is "forbidden" for non-hydrogen substituents (Rule 3). Entries 4,5 illustrate anti oxygen atom disposition (Rule 6A).

Results 2. Treatment of alkyl acyl complexes 2 (oxygen atoms anti, Rule 6A) with n-butyllithium forms enolate 3 with the E-configuration 16 (Rule 6B). Alkylation of 3 with various electrophiles E^+ leads via topside attack (Rule 4) to 4[16] with a high degree (> 95%) of diastereofacial selectivity (Rule 5).



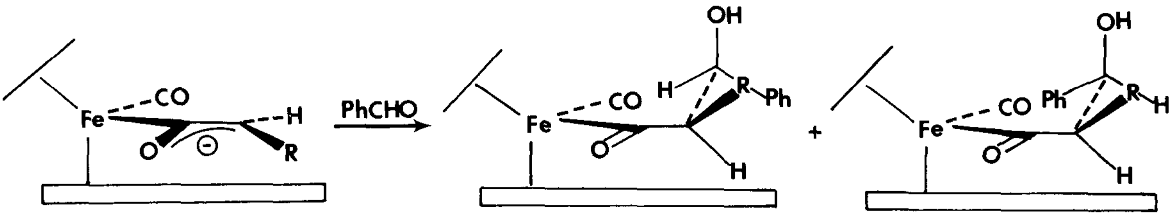
2 3 4

Results 3. In direct analogy with example 2, alkylation of the "methoxyvinyl" complex 5 affords 6 in preference to 7 (>95%)[17] [oxygen atoms anti, Rule 6; topside attack, Rule 4; diastereoselectivity due to chiral atom being formed in {C_α-M-L plane} (Rule 5)].



5 6 7

Results 4. Reaction of anion 8 with benzaldehyde results in 1:1 mixture of the two possible diastereomers 9 and 10,[18,19] consistent with Rule 5 in that no chiral atom is being formed in the {C_α-M-L} plane. However, condensation of anion 11 with PhCHO produces 12 and 13 in a ratio of 70:30. Essentially complete diastereoface selectivity is observed at C_α (Rule 5). Diastereoselectivity at C_β is decreased proportional to its distance from the {C_α-M-L} plane, also according to Rule 5. The erythro stereostructure of the major product 12 is consistent with the *Zimmerman* cyclic transition state model for aldol condensations.[20]



8 R = H
11 R = Me

9 R = H
12 R = Me

10 R = H
13 R = Me

These examples indicate that the Rules 1-6 cited herein will have far reaching applicability. In our full paper, we will detail numerous additional chemical reactions, including ligand insertion, ligand migration, α- and β-hydride abstractions, and a variety of nucleophilic and electrophilic additions, in which these Rules accurately predict both product stereoselectivities and starting material and product structures and their predominant conformations.[21]

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13. (a) Pseudo tetrahedral geometry for 1 would imply bond angles $<P-M-R \simeq <P-M-L \simeq <R-M-L <P-M-Cp \simeq 109^0$ (b) Significant tilting of the $\{C_\alpha-M-L\}$ plane (c.f. 1) away from the $\{PPh_3\}$ plane would result in the pseudo tetrahedral geometry thereby opening the volume between these two plane and permitting both chemical reactivity and access for alkyl and substituents on R into that region.
14. Examination of x-ray crystallographic results of a variety of complexes 1, including those indicated in Table I, indicates that one phenyl ring of the PPh_3 ligand - that below the L and C_α groups - is "roughly" parallel to $\{C_\alpha-M-L\}$ plane while the other phenyl groups can be somewhat splayed. Rotation about the M-P bond effectively averages the steric relationships[15] of the three phenyl rings. To quantify this relationship, one can either consider (a) the plane of the phenyl ring below the ligands undergoing reaction or (b) the plane defined by the three ipso carbon atoms of the PPh_3 ligand. Essentially equivalent results obtain for either approach. We use approximation (a) herein.
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