Intramolecular Transmission of Chiral Information: Conformational Enantiomers in Crystalline Organocobalt Complexes Generated by Self-Organization

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Summary: The conformations of alkylcobalt tricarbonyl tertiary phosphine complexes, $ROC(O)CH_2Co(CO)_3L$ (L = PPh_3; R = Me, Et, n-Pr, i-Pr, s-Bu, t-Bu, c-Hex (two modifications), CH_2Ph, (S)-{[EtOC(O)]CH(Me)}, (1S,2R,5S)-menthyl, (1R,2S,5R)-menthyl; L = P(1S,2S,5R-menthyl)Ph_2, R = i-Pr), have been studied in crystalline phases by single-crystal X-ray diffraction. The geometries of the complexes are of a trigonal-bipyramidal type with the non-carbonyl ligands in the two axial positions. We find that the (chiral) conformations of the alkyl ligand and the phosphine group develop concertedly.

We have found that the self-organization of flexible organometallic molecules (alkylcobalt tricarbonyl tertiary phosphine complexes) in crystalline phases proceeds enantioselectively. It is generally accepted and well substantiated that the origin, function, and organization of living matter are based on pure enantiomers of "organic" substances with configurational asymmetry on carbon atoms.[2] Chemical reactions, however, yield single enantiomers only with previously introduced source(s) of chirality.[3] Thus, clear understanding of the ultimate reasons of the enantiomeric homogeneity in the biosphere has not been provided[4,5] yet. These problems are not only of philosophical significance. Many pharmaceuticals contain (carbon) centers of chirality; however, in many instance these are commercialized as racemates. Furthermore, it is also well-known that enantiomeric forms of some pharmacologically active compounds act in an agonist−antagonist fashion.[7a] These and correlated recent discoveries have focused legislative attention[6] on urging the pharmaceutical industry to produce pure enantiomers by methods of emerging "chirotechnology".[7] These also comprise reactions catalyzed by transition-metal complexes of ligands with configurational[8] or/and conformational[9,10] chirality. The latter are often very efficient[10] but mechanistically less explored.[11]

We have used the alkylcobalt carbonyls, known as intermediates in various C−C-bond making reactions,[12a] as models for comparison of configurational and conformational chiral induction. The preliminary results with $R^1OC(O)CH_2Co(CO)_3(PR^2_3)$ type alkylcobalt carbonyls[12] are described in this communication.

Our attention was drawn to these complexes by a recent X-ray diffraction crystal and molecular structure determination[13] of $i\text{-}PrOC(O)CH_2Co(CO)_3(PPh_3)$. This study provided additional evidence for the solvation-like interaction between the cobalt carbonyl and ester fragments of the molecule, which was suspected on the basis of spectroscopic results ("auto-solvation")[14,15] by the relatively short Co−C(carboxyl) distance (295−298 pm). Along with this result, an additional stereochemical analysis showed an interesting correlation between the conformation of the ester and PPh_3 groups. Namely, the unit cell contains two almost enantiomerically independent molecules (Figure 1) which *both* show (opposed) helical chirality of the PPh_3 fragment[11c,16] (Figure 2a), and each of these enantiomeric structures is accompanied by *only one* conformation of the ester fragment (Figure 1). This phenomenon can be interpreted in terms of interaction between the (prochiral) carboxyl group and the transition metal (Figure 2b,c)

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Table 1. Chirality of the Conformers of $R^1OC(O)CH_2Co(CO)_3(PR^2_3)$ Complexes in Crystalline Phases

					molecule 1		molecule 2	
compd no.	R^1	R^2_3	space group	inversion center[a]	P	$COOR^1$ [b]	P	$COOR^1$ [b]
1	Me	Ph_3	$P\bar{1}$	+	P	*si* (*S*)	M	*re* (*R*)
2	Et	Ph_3	$P2_1/n$	+	P	*re* (*R*)	M	*si* (*S*)
3	n-Pr	Ph_3	$P2_1/n$	+	P	*re* (*R*)	M	*si* (*S*)
4	i-Pr	Ph_3	$P1$	−	P	*si* (*S*)[c]	M	*re* (*R*)[c]
5	(*RS*) s-Bu	Ph_3	$P2_1/n$	+	P	*re* (*R*) [*R*][d]	M	*si* (*S*) [*S*][d]
6	t-Bu	Ph_3	$P2_1/c$	+	P	*si* (*S*)	M	*re* (*R*)
7a	c-Hex	Ph_3	$P\bar{1}$	+	P	*re* (*R*)	M	*si* (*S*)
7b	c-Hex	Ph_3	$P2_1/c$	+	P	*re* (*R*)	M	*si* (*S*)
8	CH_2Ph	Ph_3	$P\bar{1}$	+	P	*re* (*R*) (?)[e]	M	*si* (*S*) (?)[e]
9	(*S*)-Lact[f]	Ph_3	$P2_12_12_1$	−	M	*si* (*S*)	[g]	[g]
10	D-Menth[h]	Ph_3	$P2_1$	−	P	*re* (*R*)[i]	M	*si* (*S*)[i]
11	L-Menth[j]	Ph_3	$P2_1$	−	P	*re* (*R*)[i]	M	*si* (*S*)[i]
12	i-Pr	Ph_2(n-Menth)[k]	$P2_12_12_1$	−	M	*si* (*S*)	[g]	[g]

[a] Presence of a center of inversion in the unit cell. [b] Conformation given: (i) indicating the prochiral face turned toward the Co (Figure 2) and (ii) indicating the configuration around the carboxylic C supposing a Co−C(OOR^1) interaction (Figure 2). [c] Two independent molecules of very nearly enantiomeric conformation. [d] Configuration of the 2-C of the s-Bu group. [e] Uncertainty due to disorder in the $PhCH_2OC(O)CH_2$ part of the molecule, as reported earlier[12] (structure determination was repeated in the present work). [f] (*S*)-Lact = (*S*)-{α-[EtOC(O)]CH(CH_3)}. [g] Only one conformer in the crystal. [h] D-Menth = (1*S*,2*R*,5*S*)-menthyl. [i] Two independent molecules differing from each other also in the relative position of the methyl ring (rotated by ∼180°). [j] L-Menth = (1*R*,2*S*,5*R*)-menthyl. [k] n-Menth = (1*S*,2*S*,5*R*)-menthyl.

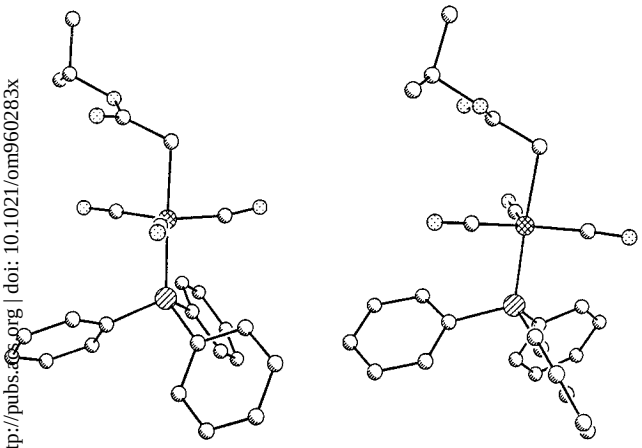

Figure 1. Schematic views of the two independent molecules in the crystal unit cell of i-$PrOC(O)CH_2Co(CO)_3(PPh_3)$ (**4**). Notation: open circles, C; dotted circles, O; cross-hatched circle, Co; lined circles, P. H atoms are omitted.

transmitting the dissymetric induction by the chiral (quasi-) enantiomeric conformers of the PPh_3 group. It would be expected that the structural behavior of similar complexes could result in determining the *extent* and contribute to the *understanding* of the *nature* of the dissymetric induction in chiral conformers. Thus, we have undertaken a systematic preparative and structural study on various representatives of this class of complexes. The results are summarized in Table 1. The most important general features can be summarized as follows:

(i) The $COOR^1$ fragment is always oriented quasi-parallel to the plane of the $Co(CO)_3$ group (∼30°). Other possible positions of this group allowed by the rotation around the $CH_2-C(sp^2)$ bond are not populated.

(ii) In all cases the PR^2_3 fragment is present in the unit cell as one or two *helical* enantiomeric conformer(s).

(iii) The enantiomeric conformers of the PPh_3 ligand are accompanied by *only one* conformer of the ROC(O)-CH_2- group, avoiding statistically equivalent and sterically possible combinations as e.g. (P)−PR^2_3/(*re*)-$COOR^1$ and (M)−PR^2_3/(*si*)-$COOR^1$ would be for complex **1** or (P)−PR^2_3/(*si*)-$COOR^1$ and (M)−PR^2_3/(*re*)-$COOR^1$ for complex **2**, etc.

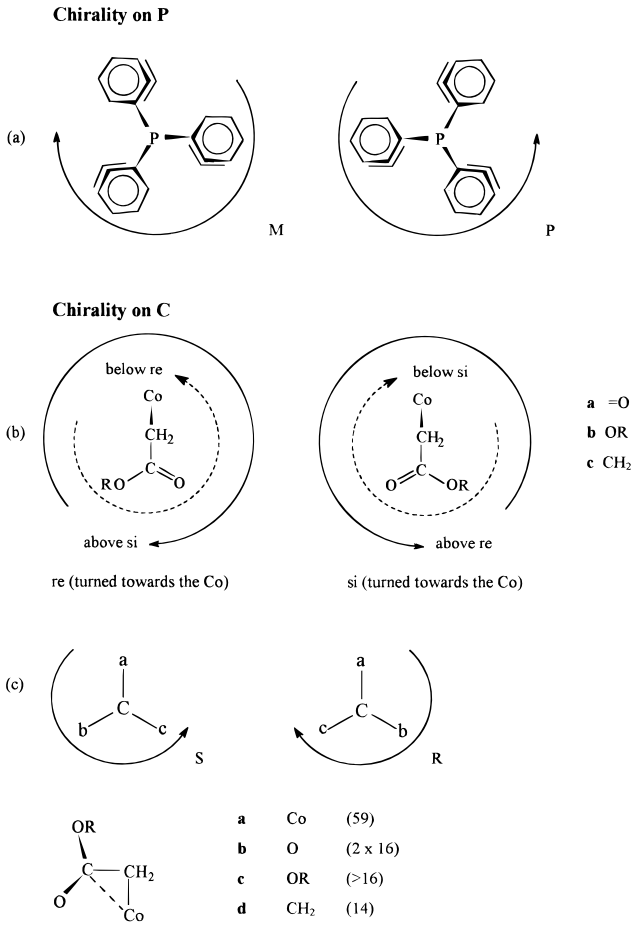

Figure 2. Notation of chirality of the conformers of complexes $R^1OC(O)CH_2Co(CO)_3(PPh_3)$.

(iv) The prevalence of "crystal field" (packing) forces in causing this self-organization can be excluded on the basis of the identical behavior of two different crystal forms of complex **7**.

(v) The presence of *one* stereogenic center in the ester group results in a corresponding single conformation of the PPh_3 ligand (**5, 9**), while at complexes **10** and **11** *more than one* stereogenic centers act in a more complex manner; the two conformers display also different ("opposing", rotated by ∼180°) orientations of the men-

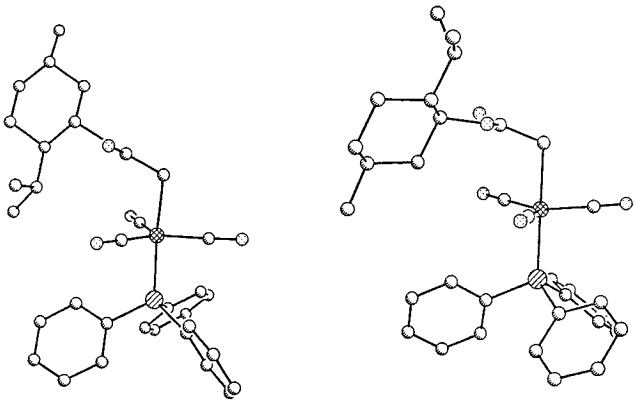

Figure 3. Schematic view of the pairs of independent molecules in the unit cell of (D-Menth)$OC(O)CH_2Co(CO)_3(PPh_3)$. Notation is as in Figure 1; H atoms are omitted.

thyl group (Figure 3 shows the conformers of **10**; in complex **11** the orientations of the L-menthyl group are opposite).

(vi) Introduction of a chiral group into the phosphine (**12**) causes the remaining two phenyl groups to stand concertedly into one (helical) direction. As a consequence of this, only one molecule, with one (chiral) conformation, was found in the unit cell, with only one conformer of the ester group.

In an attempt to rationalize these trends, the interpretation of the well-known[16] propeller chirality of PPh_3 complexes should be considered first. The most important feature of molecules **1** to **12** that one conformation of the PR^2_3 group is always accompanied by only one conformation of the ester group in a "concerted" manner.

A comparison of the conformations of complexes **1**, **2**, **4**, **7**, and **8** indicates alternating behavior (Table 2) caused by a systematic methyl perturbation.[17] This points at the possibility that this system does not seem to be controlled (as usual) by (linear) free energy changes[18,19] but rather by orbital (σ, π, d) symmetry effects. These are rarely realized in the chiral induction phenomena.[20,21]

Table 2. Alternating Phenomena in the Structures of $R^1OC(O)CH_2Co(CO)_3PR^2_3$ Compounds: Changes of the Conformation of the $COOR^1$ Group in Molecule 1 (Relative to Co) Caused by Changes in the R^1 Group

R^1 si(S)	parameter change	R^1 re(R)	parameter change	R^1 si(S)	parameter change	R^1 re(R)
	H/Me		H/Me			
			H/Et		open / cycle	
	H/Ph					

Some recent observations on self-organization of condensed matter[22−26] and solid-state chiral induction[27] as well as a speculative paper[28] on the possibilities of "absolute" enantioselective syntheses are complementary to our results.

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Supporting Information Available: Tables giving details of the crystal and molecular structure determination for **1**−**12** and spectroscopic and analytical data (143 pages). Ordering information is given on any current masthead page.

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