ELSEVIER

Journal of Molecular Catalysis A: Chemical 145 (1999) 139–146

JOURNAL OF MOLECULAR CATALYSIS A: CHEMICAL

www.elsevier.com/locate/molcata

Synthesis and characterization of chiral bis-ferrocenyl triphosphine Ni(II) and Rh(III) complexes and their use as catalyst precursors for acetalization reactions

Pierluigi Barbaro [a,*], Claudio Bianchini [a], Werner Oberhauser [a], Antonio Togni [b]

[a] *Istituto per lo Studio della Stereochimica ed Energetica dei Composti di Coordinazione, CNR, Via J. Nardi 39, I-50132 Firenze, Italy*
[b] *Laboratory of Inorganic Chemistry, Swiss Federal Institute of Technology, ETH-Zentrum, Universitätstrasse 6, CH-8092 Zürich, Switzerland*

Received 23 July 1998; accepted 15 December 1998

Abstract

The new metal complexes {[(*R*)-(*S*)-Pigiphos]Rh(CH_3CN)$_3$}Y_3 (Y = PF_6, (3a); OTf, (3b)) and {[(*R*)-(*S*)-Pigiphos]-Ni(CH_3CN)}(BF_4)$_2$ (4) containing the chiral bis-ferrocenyl triphosphine ligand (*R*)-(*S*)-Pigiphos have been synthesized and used as catalyst precursors for the acetalization of aldehydes and ketones with glycols. The reactions occur in mild conditions and require the presence of molecular sieves as drying agent. The yields are generally excellent, but no significant diastereo- or enantioselectivity is observed. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Chiral triphosphines; Acetalization; Rhodium; Nickel; Homogeneous catalysis; Asymmetric synthesis

1. Introduction

In recent years, several transition metal-catalyzed acetalization reactions have successfully been accomplished [1–7]. Although these reactions do not generally provide significant advantages over Lewis- or Brønsted-acid catalysis in terms of efficiency, the application of metal catalysts to acetalization reactions is still intensively pursued for stereochemical reasons. Metal complexes, better than inorganic and organic acids, can, in fact, finely be tuned to sterically control the reactions and, possibly, to transfer chiral information. Indeed, optically pure acetals and ketals are viable intermediates for the synthesis of various enantiomerically pure compounds [8–14].

Among the known metal catalysts for the acetalization of aldehydes and ketones, most efficient are those described by Venanzi et al. [15–17]. These contain Group VIII metals in their high oxidation states and polyphosphine ligands such as diphos [17] and triphos [15] together with labile ligands. Intrigued by the efficiency of Venanzi et al.'s catalysts, we decided to design Group VIII metal complexes with chiral polyphosphine ligands, and then test their catalytic activity in the acetalization of prochiral carbonyl compounds with alcohols.

* Corresponding author

1381-1169/99/$ - see front matter
PII: S1381-1169(99)00016-3

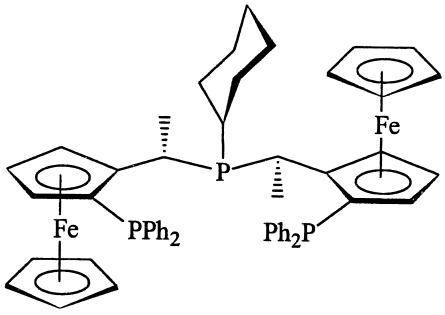


Fig. 1. A sketch of the ligand (*R*)-(*S*)-Pigiphos.

In this paper, we describe the synthesis of new Ni(II) and Rh(III) complex bearing labile acetonitrile ligands and stabilized by the chiral triphosphine ligand (*R*)-(*S*)-Pigiphos (Fig. 1) which has recently been prepared in our laboratory [18]. We also report a study in which the complexes {[(*R*)-(*S*)-Pigiphos]Rh$(CH_3CN)_3$}Y_3 (Y = PF_6, (3a); OTf, (3b)) and {[(*R*)-(*S*)-Pigiphos]Ni(CH_3CN)}$(BF_4)_2$ (4) have been employed as catalyst precursors for the acetalization of aromatic aldehydes and ketones with achiral and chiral glycols.

2. Experimental

2.1. Materials and methods

All manipulations were performed under a pure argon atmosphere unless otherwise stated. Diethyl ether and THF were distilled over Na-benzophenone. CH_2Cl_2 and CH_3CN were dried over CaH_2. Toluene, benzene, methanol, *n*-pentane and *n*-hexane were distilled over sodium. (*R*)-(*S*)-PPFA [19] and (*R*)-(*S*)-Pigiphos (1) [18] were prepared following reported procedures. $[Ni(CH_3CN)_6](BF_4)_2 \cdot 0.5CH_3CN$, prepared with a slightly modified procedure [20], was recrystallized twice from CH_3CN/diethyl ether prior to use. All solid compounds were collected on sintered glass frits before being dried in a stream of nitrogen. Aldehydes were distilled twice under reduced pressure and stored at 4°C under Ar before being used. 1,2-Epoxy-2-methylpropane and 2-methyl-1,2-propanediol were prepared using a reported method [21]. The other products employed were used as received by commercial suppliers (> 99% purity) without further purification.

$^{31}P\{^1H\}$ NMR spectra were recorded on a Bruker Avance DRX-500 spectrometer operating at 202.47 MHz. Chemical shifts are relative to external 85% H_3PO_4 with downfield values reported as positive. ^1H and $^{13}C\{^1H\}$ NMR spectra were recorded at 500.132 and 125.76 MHz, respectively, on a Bruker Avance DRX-500 spectrometer equipped with a variable temperature control unit accurate to ± 0.1°C. Chemical shifts are relative to tetramethylsilane as external reference or calibrated against the solvent resonances. The assignments of the signals resulted from ^1H homonuclear decoupling experiments and proton detected $^1H,^{13}C$ correlations using degassed nonspinning samples. 2D NMR spectra were recorded using pulse sequences suitable for phase-sensitive representations using TPPI. The $^1H,^{13}C$ correlations [22] were recorded using the standard HMQC sequence with no decoupling during acquisition, 1024 increments of size 2K (with 64 scans each) were collected covering the full range in both dimensions (ca. 5000 Hz in F_2 and ca. 18000 Hz in F_1) with a relaxation delay of 0.8 s. The ^1H NOESY measurements were recorded with 1024 increments of size 2K (with 16 scans each) covering the full range in both dimensions and using a mixing time of 0.6 s [23]. Infrared spectra were recorded on a Perkin-Elmer 1600 Series FT-IR spectrometer using samples mulled in Nujol between KBr plates. Merck silica gel 60, 230–400 mesh ASTM was used for column chromatography. Thin-layer chromatography was performed with Macherey–Nagel Polygram SIL G/UV254 precoated plastic sheets. GC analyses were performed either on a Shimadzu GC-14A gas chromatograph equipped with a flame ionisation detector and a 30-m (0.25 mm i.d., 0.25 μm FT) SPB-1 Supelco fused silica capillary column and coupled with a C-R6A Chromatopac operating in the corrected area

method or with a Shimadzu GC-17A gas chromatograph equipped with a flame ionisation detector and a 40 m × 0.25 mm i.d. Chiraldex G-TA capillary column and coupled with a Shimadzu C-R7A Chromatopac. GC–MS analyses were performed on a Shimadzu QP 2000 apparatus equipped with a column identical to that used for GC analyses (SPB-1). The organic compounds were identified by their GC–MS, ^{1}H NMR and ^{1}H NOESY spectra.

2.2. Synthesis of the complexes

2.2.1. [(R)-(S)-Pigiphos]RhCl$_3$ (2)

Solid $RhCl_3 \cdot 3H_2O$ (0.09 g, 0.33 mmol) was added to a solution of 1 (0.30 g, 0.33 mmol) in ethanol (20 ml) and the mixture was refluxed with stirring for 4 h. After cooling to room temperature, the orange solid obtained was filtered off and washed with diethyl ether (30 ml). Yield 78%. ^{1}H NMR (CD_2Cl_2, 294 K): δ 5.04 (*dt*, 1H, C*H*′CH$_3$, $J_{HH} = 7.6$, $J_{HP} = 15.5$ Hz), 3.27 (*qnt*, 1H, C*H*″CH$_3$, $J_{HH} = J_{HP} = 7.2$ Hz), 1.74 (*dd*, 3H, CH′C*H*$_3$, $J_{HP} = 12.3$ Hz), 2.05 (*dd*, 3H, CH″C*H*$_3$, $J_{HP} = 10.9$ Hz), 4.61 (*s*, 1H, Cp*H*′), 4.59 (*s*, 1H, Cp*H*″), 4.37 (*s*, 1H, Cp*H*‴), 4.36 (*s*, 1H, Cp*H*^{IV}), 4.34 (*t*, 1H, Cp*H*^{V}) 3.25 (*s*, 1H, Cp*H*^{VI}), 4.28 (*s*, 5H, C$_5H_5'$), 3.63 (*s*, 5H, C$_5H_5''$). Anal. Calcd for $C_{54}H_{55}Cl_3Fe_2P_3Rh$: C, 58.02; H, 4.96. Found: C, 58.12; H, 5.01.

2.2.2. {[(R)-(S)-Pigiphos]Rh(CH$_3$CN)$_3$}Y$_3$ (Y = PF$_6$, (3a); OTf, (3b))

Solid $TlPF_6$ (0.45 g, 1.28 mmol) was added to a suspension of 2 (0.12 g, 0.11 mmol) in CH_3CN (30 ml) and the mixture was refluxed with stirring for 10 h. During this time, a purple–red solution and a white precipitate were obtained. After the solution was cooled to room temperature, the white precipitate was filtered off. The red solution was concentrated under reduced pressure until red–orange microcrystals began to precipitate out (ca. 1/4 volume). Diethyl ether (15 ml) was then added to complete the precipitation of the solid compound, which was filtered off, washed with diethyl ether (30 ml) and recrystallized twice from acetonitrile–diethyl ether to give pure 3a in 68% yield. ^{1}H NMR (CD_3COCD_3, 294 K): δ 5.27 (*dt*, 1H, C*H*′CH$_3$, $J_{HH} = 8.1$, $J_{HP} = 17.3$ Hz), 3.75 (*qnt*, 1H, C*H*″CH$_3$, $J_{HH} = J_{HP} = 6.8$ Hz), 2.15 (*dd*, 3H, CH′C*H*$_3$, $J_{HP} = 18.1$ Hz), 2.46 (*dd*, 3H, CH″C*H*$_3$, $J_{HP} = 13.0$ Hz), 5.34 (*s*, 1H, Cp*H*′), 5.24 (*s*, 1H, Cp*H*″), 4.98 (*m*, 1H, Cp*H*‴), 4.92 (*t*, 1H, Cp*H*^{IV}), 4.91 (*t*, 1H, Cp*H*^{V}) 3.79 (*s*, 1H, Cp*H*^{VI}), 4.73 (*s*, 5H, C$_5H_5'$), 3.92 (*s*, 5H, C$_5H_5''$), 2.46 (*s*, 3H, C*H*$_3$CN′), 2.23 (*s*, 3H, C*H*$_3$CN″), 1.69 (*s*, 3H, C*H*$_3$CN‴). ^{13}C NMR (CD_3COCD_3, 294 K): δ 4.43 (*s*, *C*H$_3$CN′, $^1J_{CH} = 138.8$ Hz), 1.66 (*s*, *C*H$_3$CN″, $^1J_{CH} = 132.4$ Hz), 4.57 (*s*, *C*H$_3$CN‴, $^1J_{CH} = 136.6$ Hz). Anal. Calcd for $C_{60}H_{64}N_3F_{18}Fe_2P_6Rh$: C, 45.91; H, 4.11; N, 2.68. Found: C, 45.79; H, 4.08; N, 2.73. IR: 2322, 2294 ν(C–N) cm^{-1}.

The trifluoromethanesulfonate salt {[(*R*)-(*S*)-Pigiphos]Rh(CH$_3$CN)$_3$}(OTf)$_3$ (3b) was obtained as follows. Solid AgOTf (0.35 g, 1.37 mmol) was added to a suspension of 2 (0.17 g, 0.15 mmol) in CH_3CN (15 ml) and the mixture was stirred at 75°C for 4 h. During this time, a purple–red solution and an AgCl precipitate were obtained. After the solution was cooled to room temperature, AgCl was filtered off. The solution was concentrated under reduced pressure until red microcrystals began to precipitate out (ca. 1/2 volume). Diethyl ether (15 ml) was then added and the solid compound obtained was separated by filtration, washed with diethyl ether (30 ml) and recrystallized twice from acetonitrile–diethyl ether to give pure 3b in 77% yield. Anal. Calcd for $C_{63}H_{64}N_3F_9Fe_2O_9P_3RhS_3$: C, 47.83; H, 4.08; N, 2.66. Found: C, 47.77; H, 4.09; N, 2.70.

2.2.3. {[(R)-(S)-Pigiphos]Ni(CH$_3$CN)}(BF$_4$)$_2$ (4)

Solid 1 (0.25 g, 0.26 mmol) was added to a solution of $[Ni(CH_3CN)_6](BF_4)_2 \cdot 0.5CH_3CN$ (0.12 g, 0.25 mmol) in CH_3CN (8 ml). The suspension was stirred at room temperature for 1 h. The violet solution obtained was concentrated in vacuo to half volume and diethyl ether

Table 1
$^{31}P\{^{1}H\}$ NMR data for the Rh complexes[a]

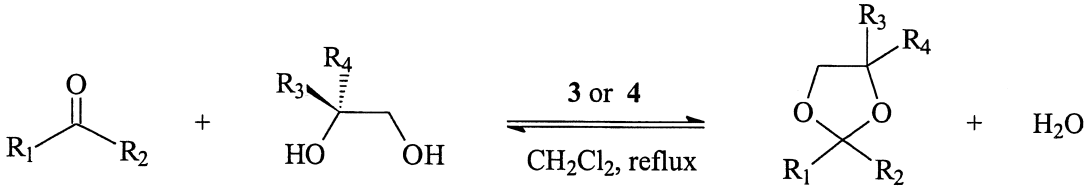
Complex	(Cy)P	$(Ph)P_A$	$(Ph)P_B$
[(*R*)-(*S*)-Pigiphos]$RhCl_3$ (2)	70.28 (*ddd*)	19.22 (*ddd*)	9.28 (*ddd*)
	J_{PPA} = 15.4, J_{PPB} = 31.3, J_{PRh} = 109.6	J_{PAPB} = 540.2, J_{PARh} = 85.8	J_{PBRh} = 86.6
{[(*R*)-(*S*)-Pigiphos]$Rh(CH_3CN)_3$}$^{3+}$ (3^{3+})	80.93 (*ddd*)	21.79 (*ddd*)	17.95 (*ddd*)
	J_{PPA} = 12.7, J_{PPB} = 27.5, J_{PRh} = 105.6	J_{PAPB} = 424.4, J_{PARh} = 74.6	J_{PBRh} = 75.5

[a]Chemical shifts in ppm, coupling constants in Hz. 202.47 MHz, 294 K. Abbreviations: *d*, doublet. 2 Solution in CD_2Cl_2, 3^{3+} solution in CD_3COCD_3.

(10 ml) was slowly added causing the precipitation of a violet solid. This was filtered off and recrystallized twice from acetonitrile–diethyl ether to give pure 4 in 78% yield. Anal. Calcd for $C_{56}H_{58}NB_2F_8Fe_2NiP_3$: C, 56.91; H, 4.95; N, 1.19. Found: C, 56.85; H, 4.88; N, 1.20. IR: 2290 ν(C–N) cm^{-1}. The $^{31}P\{^{1}H\}$ NMR and ^{1}H NMR data for the cation {[(*R*)-(*S*)-Pigiphos]-$Ni(CH_3CN)\}^+$ in 4 are identical with those reported for the perchlorate salt {[(*S*)-(*R*)-Pigiphos]$Ni(CH_3CN)\}(ClO_4)_2$ [18].

2.3. General procedure for the catalytic acetalization reactions

All operations were performed under an argon atmosphere. Three-angstrom molecular sieves (beads) were activated at 120°C for 48 h prior to use. The general procedure for the acetalization reactions is illustrated for the reaction of benzaldehyde with (*S*)-(+)-1,2-propandiol in the presence of {[(*R*)-(*S*)-Pigiphos]-$Rh(CH_3CN)_3\}(OTf)_3$ (3b). A three-necked flask was equipped with a condenser, a rubber septum and a magnetic bar. The molecular sieves (3 g) were placed in a cotton bag suspended above the liquid. The flask was charged with a solution of benzaldehyde (200 μl, 1.97 mmol) and (*S*)-(+)-1,2-propandiol (160 μl, 2.17 mmol) in CH_2Cl_2 (10 ml) to which solid 3b (1.6 mg, 0.98 μmol) was added under argon. The solution was quickly dipped in a thermostatized oil bath and refluxed with stirring for 1.5 h. The product formation was periodically monitored by GC. At the end of the reaction, the solution was quickly cooled to 0°C and filtered through an alumina column which was washed with diethyl ether (30 ml). The filtered solution and the ether washings were collected and the solvent was evaporated under reduced pressure. The organic products in the residue



R_1 = aryl, alkyl; R_2 = alkyl, H; R_3, R_4 = CH_3, H

Scheme 1. Substrates and products of acetalization reactions using 3a–b or 4.

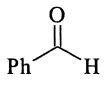
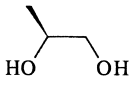
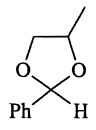
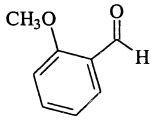
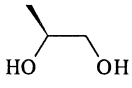
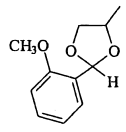
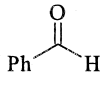
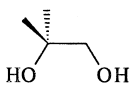
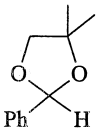
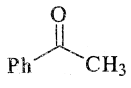
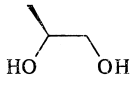
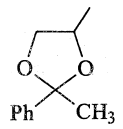
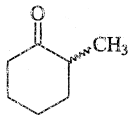
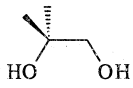
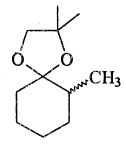
were identified by GC–MS analysis, ^{1}H NMR and ^{1}H NOESY spectroscopy.

3. Results and discussion

3.1. Synthesis and characterization of the Rh(III) complexes

The reaction of $RhCl_3 \cdot 3H_2O$ with Pigiphos in refluxing ethanol gives the Rh(III) complex [(*R*)-(*S*)-Pigiphos]$RhCl_3$ (2). By treatment of 2 with an excess of a chloride scavenger ($TlPF_6$ or AgOTf) in acetonitrile solution, the tris-acetonitrile Rh(III) complex {[(*R*)-(*S*)-Pigiphos]-$Rh(CH_3CN)_3$}$^{3+}$ (3^{3+}) can be isolated in the solid state as either PF_6^- (3a) or OTf^- (3b) salt. A similar synthetic route has previously been employed by Venanzi et al. to synthesize the complexes $[RhCl_x(CH_3CN)_{3-x}$(triphos)]-$(OTf)_{3-x}$ [15,16,24]. AgOTf proved to be more efficient than $TlPF_6$ to remove the chloride ligands from 2, but extreme care is required for the manipulation of the silver salt as the reactions must be performed in strictly anhydrous conditions. Unlike the parent trichloride complex 2, which is quite stable in common organic solvents, the tricationic complexes 3a–b are fully

Table 2
Acetalization reactions using {[(*R*)-(*S*)-Pigiphos]Ni(CH_3CN)}$(BF_4)_2$ (4)[a]

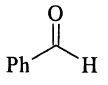
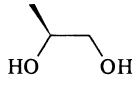
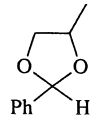
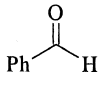
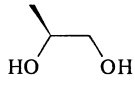
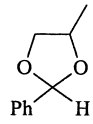
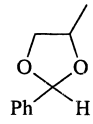
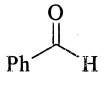
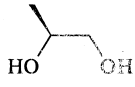
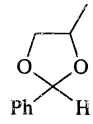
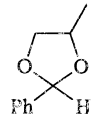
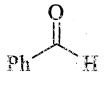
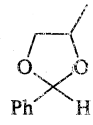
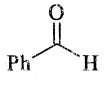
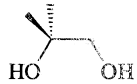
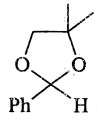
Entry	Carbonyl compound	Alcohol	Solvent	Time (h)	Product	Yield (%)[b]	cis/trans ratio[b,c]	ee (%)[d]
1			CH_2Cl_2	2		85.0	1.3	
2			CH_2Cl_2	1.5		89.4	1.4	
3			CH_2Cl_2	4		82.7		3.2
4			CH_2Cl_2	20		3.0	1.3	
5			CH_2Cl_2	4		62.7	1.3	

[a] General reaction conditions: carbonyl compound/catalyst mole ratio = 2000; alcohol/carbonyl compound mole ratio = 1.1; drying method: 3 Å molecular sieves placed in a cotton bag suspended above the liquid (10 ml); reflux temperature.
[b] Reaction mixture, GC.
[c] Products identified by ^{1}H NOESY spectroscopy on the isolated product.
[d] Isolated product, GC.

stable only in CH_3CN solutions. In acetone, they are enough stable to ensure a reliable spectroscopic characterisation, however. The solid-state IR spectra of 3a–b shows characteristic absorptions of coordinated CH_3CN molecules (2322, 2294 ν(C–N) cm^{-1}) [25–28]. The $^{31}P\{^1H\}$ NMR data for the Rh(III) complexes are listed in Table 1, while selected ^1H NMR data are reported in Section 2.

The spectral parameters are consistent with the presence of two diastereotopic 1,3-diphenylphosphino ferrocenyl units. The $J_{P_AP_B}$ coupling constants (540.2 and 424.4 Hz for 2 and 3^{3+}, respectively) are indicative of a *trans* disposi-

Table 3
Catalytic acetalization reactions using {[(*R*)-(*S*)-Pigiphos]Rh$(CH_3CN)_3$}$(PF_6)_3$ (3a) or {[(*R*)-(*S*)-Pigiphos]Rh$(CH_3CN)_3$}$(OTf)_3$ (3b)[a]

Entry	Carbonyl compound	Alcohol	Complex	Solvent	Time (h)	Product	Yield (%)[b]	cis/trans ratio[b,c]	ee (%)[d]
1			**3a**	THF	3.5		0.9	*e*	
2			**3a**	CH_2Cl_2	5		23.4	2.9	
					23		42.2	1.7	
3			**3b**	THF	1.2		77.7	1.8	
					1.9		85.9	1.3	
4			**3b**	CH_2Cl_2	1.2		97.1	1.2	
5			**3b**	CH_2Cl_2	3		77.8		0.6

[a]General reaction conditions: carbonyl compound/catalyst mole ratio = 2000; alcohol/carbonyl compound mole ratio = 1.1; drying method: 3 Å molecular sieves placed in a cotton bag suspended above the liquid (10 ml); reflux temperature.
[b]Reaction mixture, GC.
[c]Products identified by ^1H NOESY spectroscopy on the isolated product.
[d]Isolated product, GC.

tion of the two Ph_2P atoms, thus indicating a *mer* arrangement of the tridentate ligand in both complexes [29,30]. The $^1J_{RhP}$ coupling constant values are in line with the *trans*-influence of the coligands which decreases in the order $R_3P > CH_3CN > Cl$ [30–33]. Accordingly, in 2 and 3^{3+} the $^1J_{RhP}$ coupling constants of the two *trans* Ph_2P phosphorus atoms are smaller than the $^1J_{RhP}$ constant of the central CyP atom which, in turn, increases in going from 3^{3+} (105.6 Hz) to 2 (109.6 Hz). Consistent with the +3 oxidation state of the rhodium center, the $^1J_{RhP}$ values are smaller than the corresponding constants in related Rh(I) complexes such as [(*S*)-(*R*)-Pigiphos]RhCl and {[(*S*)-(*R*)-Pigiphos]Rh(CH_3CN)}$^+$ [31,34,35]. The ^1H and ^{13}C NMR resonances of the coordinated acetonitrile molecule in 3^{3+} can unambiguously be assigned by ^1H,^{13}C correlations recorded in acetone-d_6 solution. The observed ^1H chemical shifts for the CH_3CN protons are in the range 1.69–2.46 ppm, while the ^{13}C chemical shifts are in the range 1.66–4.57 ppm for the *C*H_3CN methyl group. On the basis of a previous report [27], the ^{13}C resonance at 1.66 ppm can be assigned to the acetonitrile molecule *trans* to the CyP group in 3^{3+}; consequently, the resonances at 4.53 and 4.47 ppm are attributed to the acetonitrile ligands *trans* to each other.

3.2. Catalytic acetalization reactions

The acetonitrile complexes 4 and 3a,b have been tested as catalyst precursors for the acetalization of simple carbonyl compounds with glycols under aprotic conditions (Scheme 1). Selected results are reported in Tables 2 and 3 for the Ni(II) and the Rh(III) complexes, respectively, together with the experimental conditions (carbonyl compound:catalyst mole ratio = 2000:1, alcohol:carbonyl compound mole ratio = 1.1:1). Among the several methods used to remove H_2O produced during the reactions, the use of 'suspended' 3 Å molecular sieves (see Section 2) proved to be the most efficient procedure. [1] The organic products were identified by their GC–MS and ^1H NMR spectra, while the stereochemistry was assigned on the basis of ^1H NOESY spectroscopy. [2] The enantiomeric excesses (ee) were determined by GC analysis.

The reactions proceed efficiently in refluxing THF for the Rh complexes or in refluxing CH_2Cl_2 for both Ni and Rh complexes. Indeed, the choice of the solvent was seriously limited by the chemical and physical characteristics of the catalyst precursors which are practically insoluble in apolar solvents (hydrocarbons, C_6H_6), and easily decompose in THF (Ni) or CH_3NO_2 (Ni and Rh). Moreover, a solvent as weakly coordinating as possible is needed to avoid competition with the substrate (i.e., the reactions rates are very low in acetonitrile solutions), while alcohols or ketones cannot be used due to competitive acetalization reactions. The use of $C_2H_4Cl_2$ instead of CH_2Cl_2 did not appreciably affect either the reaction rates or the product composition.

The participation of residual protic acid in the acetalization reactions assisted by 3b (due to the excess of the silver salts used for its synthesis) can be ruled out as the metal complexes were repeatedly re-crystallized to give acid-free compounds. [3]

The conversions and the rate of the reactions were usually satisfactory using aldehydes, whereas they were lower for tertiary alcohols than for secondary alcohols (entries 1 and 3, Table 2; entries 4 and 5, Table 3) or using

[1] Although the reactions proceed also in the presence of activated Drierite or by introducing the molecular sieves directly into the reaction mixture, they are considerably slower in comparable experimental conditions. Azeotropic removal of water using C_6H_6 as solvent was unsuccessful due to the low solubility of the metal complexes. Use of trimethyl or tri(*iso*propyl) orthoformate was precluded by competitive reactions with methyl or isopropyl alcohol produced during the reaction.

[2] The *cis* and *trans* labels refer to the relative position of the hydrogen atoms or methyl groups with respect to the five-membered acetal ring.

[3] The presence of residual protic acid, even in trace amount, strongly increases the rate of the reaction also in C_6H_6 solutions.

ketones (Table 2, entries 1 and 4). This reactivity trend is quite common for proton-catalyzed acetalization reactions [36,37]. The *cis/trans* ratio of the acetal products does not seem to be significantly affected by the presence of the methoxy substituent in *ortho* position (Table 2, entry 2), and invariably decreases for increasing conversions (Table 3, entries 2 and 3). Unfortunately, in all the cases investigated, the acetalization reactions proceeded with no significant diastereo- or enantioselectivity (entry 3 Table 2, entry 5 Table 3).

Finally, it is worth mentioning that: (i) the presence of labile ligands in the catalyst precursors is of mandatory importance to promote the acetalization reaction (i.e., the reaction yields are much lower with the chloride complexes [(Pigiphos)NiCl]PF_6 or (Pigiphos)$RhCl_3$ in comparable experimental conditions); (ii) consistent with the general mechanism of acetalization reactions [17], the reaction rates increase with the charge of the catalyst precursor (i.e., the reaction is much slower with the monocationic complex {[(*S*)-(*R*)-Pigiphos]Rh(CH_3-CN)}OTf [35] than with the tricationic complex 3b); (iii) for the Rh(III) complexes, the catalyst efficiency is higher for the triflate salt than for the hexafluorophosphate salt (Table 3, entries 1 and 3; Table 3 entries 2 and 4). This counter-anion effect may be due to poisoning of the catalyst by fluoride ions released by PF_6^- during the reactions. Moreover, the present acetalization reactions show chemical characteristics that do not significantly differ from those described by Venanzi et al. [15–17].

References

[1] Chem. Abstr. 98 (1983) 215321q.
[2] Chem. Abstr. 108 (1988) 21098b.
[3] Chem. Abstr. 109 (1988) 109880g.
[4] Chem. Abstr. 100 (1984) 85265w.
[5] R.V. Hoffman, Tetrahedron Lett. 15 (1974) 2415.
[6] W. Voelter, C. Djerassi, Chem. Ber. 101 (1968) 1154.
[7] B.H. Lipshutz, D. Pollart, J. Monforte, H. Kotsuki, Tetrahedron Lett. 26 (1985) 705.
[8] A. Alexakis, P. Mangeney, Tetrahedron Asymmetry 1 (1990) 477.
[9] W.S. Johnson, C.A. Harbert, B.E. Ratcliffe, R.D. Stipanovic, J. Am. Chem. Soc. 98 (1976) 6188.
[10] W.S. Johnson, C.A. Harbert, R.D. Stipanovic, J. Am. Chem. Soc. 90 (1968) 5279.
[11] A. Mori, H. Yamamoto, J. Org. Chem. 50 (1985) 5444.
[12] P.A. Bartlett, W.S. Johnson, J.D. Elliott, J. Am. Chem. Soc. 105 (1983) 2088.
[13] K. Narasaka, M. Inoue, T. Yamada, J. Sugimori, N. Iwasawa, Chem. Lett. (1987) 2049.
[14] D. Seebach, R. Imwinkelried, T. Weber, in: R. Scheffold (Ed.), Modern Synthetic Methods, Vol. 4, Springer Verlag, Berlin, 1986.
[15] J. Ott, B. Schmid, L.M. Venanzi, G. Wang, T.R. Ward, G.M. Ramos Tombo, New J. Chem. 14 (1990) 495.
[16] J. Ott, G.M. Ramos Tombo, B. Schmid, L.M. Venanzi, G. Wang, T.R. Ward, Tetrahedron Lett. 30 (1989) 6151.
[17] F. Gorla, L.M. Venanzi, Helv. Chim. Acta 73 (1990) 690.
[18] P. Barbaro, A. Togni, Organometallics 14 (1995) 3570.
[19] T. Hayashi, T. Mise, M. Fukushima, M. Kagotani, N. Nagashima, Y. Hamada, A. Matsumoto, S. Kawakami, M. Konishi, K. Yamamoto, M. Kumada, Bull. Chem. Soc. Jpn. 53 (1980) 1138.
[20] B.J. Hathaway, D.G. Holah, A.E. Underhill, J. Chem. Soc. (1962) 2444.
[21] C.E. Wilson, H.J. Lucas, J. Am. Chem. Soc. 58 (1936) 2396.
[22] M.F. Summers, L.G. Marzilli, A. Bax, J. Am. Chem. Soc. 108 (1986) 4285.
[23] V. Sklener, H. Miyashiro, G. Zon, H.T. Miles, A. Bax, FEBS Lett. 208 (1986) 94.
[24] M. Sülü, Dissertation, Nr. 10648, ETH, Zürich, 1994.
[25] K. Nakamoto, Infrared and Raman Spectra of Inorganic and Coordination Compounds, Wiley, New York, 1986.
[26] M. Sekine, W.D. Harman, H. Taube, Inorg. Chem. 27 (1988) 3604.
[27] P. Barbaro, C. Bianchini, A. Togni, Organometallics 16 (1997) 3004.
[28] A. Albinati, Q. Jiang, H. Rügger, L.M. Venanzi, Inorg. Chem. 32 (1993) 4940.
[29] A.L. Crumbliss, R.J. Topping, in: J.G. Verkade, L.D. Quin (Eds.), Phosphorus-31 NMR Spectroscopy in Stereochemical Analysis, Methods in Stereochemical Analysis 8, Chap. 15, VCH, Weinheim, Germany, 1987, p. 531.
[30] P.S. Pregosin, R.W. Kunz, in: P. Diehl, E. Fluck, R. Kosfeld (Eds.), ^{31}P and ^{13}C NMR of Transition Metal Phosphine Complexes, Springer-Verlag, Berlin, 1979.
[31] D.W. Meek, T. Mazanec, J. Acc. Chem. Res. 14 (1981) 266.
[32] T.G. Appleton, H.C. Clark, L.E. Manzer, Coord. Chem. Rev. 10 (1973) 335.
[33] J.G. Verkade, J.A. Mosbo, in: J.G. Verkade, L.D. Quin (Eds.), Phosphorus-31 NMR Spectroscopy in Stereochemical Analysis, Methods in Stereochemical Analysis 8, Chap. 13, VCH, Weinheim, Germany, 1987, p. 432.
[34] P.S. Pregosin, L.M. Venanzi, Chem. Br. 14 (1978) 276.
[35] P. Barbaro, C. Bianchini, A. Togni, in preparation.
[36] F.A. Meskens, J. Synthesis (1981) 501.
[37] T.W. Greene, Protective Groups in Organic Synthesis, Wiley, New York, 1981.