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Enantioselective cross-coupling of vinyl-, aryl- and allyl-electrophiles catalyzed by nickel complexes containing (*R*,*R*)-1,2-cyclopentanediylbis(diphenylphosphine) and related ligands *

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Abstract

The cross-coupling of some electrophiles with Grignard reagents catalyzed by nickel complexes of (*R*,*R*)-cyclopentane-1,2-diylbis(diphenylphosphine) or the previously unknown enantiomerically pure *trans*-cyclopentane-1,2-diylbis(di-*p*-methoxyphenylphosphine) is described. In all reactions investigated the unsubstituted ligand gives better optical yields (up to 55%) than the substituted one.

Enantioselective cross-coupling reactions involving chiral racemic organometallic reagents of the Main Group elements in principle allow transformation of a racemic mixture into a single enantiomeric product [1]. Diphosphine nickel complexes have been mainly used in studies aimed at throwing light on the factors influencing the enantioselectivity in the coupling of sec-butyl magnesium halides with phenyl halides (reaction 1) [2]. Another approach, involving the use of nickel or palladium catalyst precursors containing phosphine ligands bearing groups able to interact with the Grignard reagent, has been used in the coupling of vinyl halides with 1-phenylethyl magnesium halides (reaction 2) [3]. Quite high optical yields were obtained in the synthesis of 3-phenyl-1-butene by this approach [4], whereas in the synthesis of 2-phenylbutane optical yields were low. The enantioselective allylation of chiral racemic Grignard reagents by allyl electrophiles (compare reaction 3) has been much less investigated [5,6].

$$C_2H_5CH(CH_3)MgX + C_6H_5X \xrightarrow{-MgX_2} C_2H_5CH(CH_3)C_6H_5 \quad (1)$$

$$C_6H_5CH(CH_3)MgX + CH_2{=}CHX \xrightarrow{-MgX_2} C_6H_5CH(CH_3)CH{=}CH_2 \quad (2)$$

$$C_6H_5CH(CH_3)MgX + CH_2{=}CHCH_2OC_6H_5 \xrightarrow{-MgXOC_6H_5} C_6H_5CH(CH_3)CH_2CH{=}CH_2 \quad (3)$$

* In memoriam Piero Pino (1921–1989).

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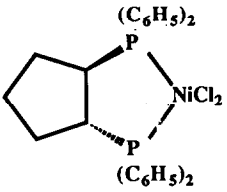

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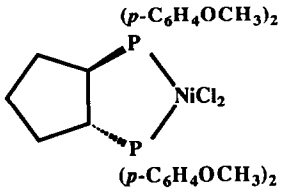

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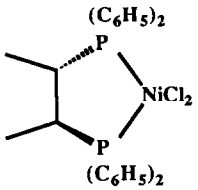

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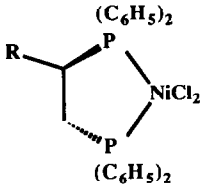

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The formation of the coupling product presumably involves reductive elimination of the two organic moieties from an intermediate metal bishydrocarbyl complex [7,8]. The possible intermediacy of radical anions has been also considered [9,10]. Reductive elimination is expected to be stereospecific [11–14]. Therefore, in the coupling reactions asymmetric induction must be determined at the level of the formation of that intermediate. Model studies of species related to that intermediate suggest that its diastereomeric composition is influenced by the rigidity of the chelate ring and that the use of ligands not having C_2 symmetry could reduce the enantiomeric excess [15]. With the aim of achieving a better understanding of this interesting reaction we decided to investigate the influence of the electronic factors on the activity and enantioselectivity of nickel catalysts containing rigid ligands, namely chiral ligands based on the *trans*-cyclopentane-1,2-diyl skeleton. We report here preliminary results obtained for the reactions **1**, **2** and **3** carried out with nickel catalysts **1** and **2**, and compare these results with those obtained with **3**, i.e., a catalyst containing the open chain diphosphine analogue (*S*,*S*)-1,2-dimethyl-1,2-ethanediylbis(diphenylphosphine), **3a**.

The optically pure (*R*,*R*)-cyclopentane-1,2-diylbis(diphenylphosphine) **1a** was known previously [16]; the method of preparation (manual separation of enantiomorphic crystals containing the pure enantiomer of the corresponding nickel dibromide complex) was, however, impractical for obtaining relatively large amounts of the ligand. We made this ligand as well as the previously unknown optically active *trans*-cyclopentane-1,2-diylbis(*p*-methoxyphenylphosphine), in optically pure form by resolution into optical antipodes of the corresponding bisoxide derivatives by using 2,3-di-*O*-dibenzoyl tartaric acid as the resolution reagent [17]. The details of the resolution of these and related ligands will be described elsewhere. The results

Table 1

Nickel-catalyzed enantioselective cross-coupling reaction between Grignard reagents and unsaturated electrophiles

$RCH(CH_3)MgX$		$R'-X$		Chiral catalyst	Isomerization [a]	Chemical yield (%)	Enantiomeric excess (%)
R	X	R'	X				
C_6H_5	Br	CH_2=CH	Cl	**4** (*R*)	<1	85	2.0 (*S*)
C_6H_5	Cl	CH_2=CH	Cl	**3** (*S,S*)	~0	80	22.2 (*R*)
C_6H_5	Cl	CH_2=CH	Br	**3** (*S,S*)	~0	75	7.8 (*R*)
C_6H_5	Br	CH_2=CH	Cl	**3** (*S,S*)	~0	>95	18.1 (*R*)
C_6H_5	Br	CH_2=CH	Br	**3** (*S,S*)	~0	70	19.4 (*R*)
C_6H_5	Cl	CH_2=CH	Cl	**1** (*R,R*)	1	45	46.9 (*S*)
C_6H_5	Cl	CH_2=CH	Br	**1** (*R,R*)	2	55	30.3 (*S*)
C_6H_5	Br	CH_2=CH	Cl	**1** (*R,R*)	3	50	37.9 (*S*)
C_6H_5	Br	CH_2=CH	Br	**1** (*R,R*)	2	50	37.5 (*S*)
C_6H_5	Br	CH_2=CH	Cl	**2** (*R,R*) [b]	10	34	4.6 (*S*)
C_6H_5	Cl	CH_2=CH	Cl	**2** (*R,R*)	<1	>95	25.5 (*S*)
C_6H_5	Cl	CH_2=CH	Br	**2** (*R,R*)	<1	80	19.5 (*S*)
C_6H_5	Br	CH_2=$CHCH_2$	C_6H_5O	**1** (*R,R*)	~0	50	31.2 (*S*)
C_6H_5	Br	CH_2=$CHCH_2$	C_6H_5O	**2** (*R,R*)	~0	27	23.9 (*S*)
C_6H_5	Cl	CH_2=$CHCH_2$	C_6H_5O	**2** (*R,R*)	2	50	26.0 (*S*)
C_2H_5	Br	C_6H_5	Br	**3** (*S,S*)	<1	85	43.1 (*S*)
C_2H_5	Br	C_6H_5	Br	**1** (*R,R*)	7	50	54.8 (*R*)
C_2H_5	Cl	C_6H_5	Cl	**1** (*R,R*)	4	70	27.9 (*R*)
C_2H_5	Br	C_6H_5	Br	**2** (*R,R*)	–	~0	–
C_2H_5	Cl	C_6H_5	Cl	**2** (*R,R*)	–	~0	–

[a] Extent of formation of isomeric coupling product (i.e., 4-phenyl-1-butene, 5-phenyl-1-pentene and 1-phenylbutane, respectively). [b] See ref. 20.

obtained in some coupling reactions involving use of these ligands are shown in Table 1.

Catalyst **4** ($R = CH_3$) was reported to show no enantioselectivity in the cross-coupling of vinyl bromide with 1-phenylethyl magnesium chloride (reaction 2). Similarly low enantioselectivities were recently observed for catalytic systems related to **4** (in which R was an alkyl group bearing different substituents potentially able to coordinate to the metal and therefore to avoid the formation of isomeric catalytic species due to the metal being a stereogenic center) [18]. The same effect of reducing the number of the possible catalytic species should be brought about by the use of a ligand having C_2 symmetry [5,19]. Better enantioselectivities were in fact obtained by using catalyst **3** (up to 22.2%). The optical yields were further improved (up to 46.9%) by using catalyst **1** with the more rigid ligand (*R,R*)-cyclopentane-1,2-diylbis(diphenylphosphine), **1a**. However, on going to catalyst **2** containing the more basic diphosphine ligand (*R,R*)-cyclopentane-1,2-diylbis(*p*-methoxyphenylphosphine) [20*], the enantioselectivity of the coupling reaction was again lowered. As previously observed for reaction 1 [2], the nature of the halide present on the two moieties to be coupled influences the enantioselectivity of the reaction. With one exception, the extent of formation of isomeric coupling product (i.e., 4-phenyl-1-butene) is low. The optical yield in the coupling reaction of the same Grignard

* Reference number with asterisk indicates a note in the list of references.

reagents with allyl phenyl ether (reaction 3) catalysed by **1** or **2** is comparable, and even a little higher for **1**. In this case also the extent of formation of isomeric coupling product is very low.

A fair optical yield (− 55%) was obtained in the synthesis of 2-phenylbutane (reaction 1) with **1** as the catalyst precursor; the optical yield previously observed in the same reaction in presence of **3** was lower (43.1%) [2]. Remarkably, complex **2** was found to be inactive in reaction 1.

The enantioselectivity displayed by the new ligands examined for coupling reaction 2 even in the best case is much lower than that when an aminophosphine is used as the ligand [3]. Optical yields are much better for **1** than for **2**, showing that enantiomer selection for this reaction is also influenced by a change in the basicity of the ligand.

The same enantiomer predominantly reacts in the coupling of the same 1-phenylethyl magnesium halide with either vinyl halides or allylphenylether; in the latter case, however, the effect of the substitution on the phosphorus phenyl substituents is smaller. It is noteworthy that for this reaction system **2** gives optical yields close to 60% [5].

In contrast with the previous reaction 2 a better enantioselectivity with respect to the sec-butyl Grignard reagents (reaction 1) is observed for **1** than for the aminophosphine ligands. This is particularly relevant in view of the smaller difference in size between an ethyl and a methyl group than between a phenyl and a methyl group. In both of these reaction use of the acyclic ligand in **3** gives lower optical yields than use of the cyclic ligand in **1**. Owing to the multistep character of the reaction it is difficult to suggest a satisfactory explanation of the absence of activity of catalyst **2** in coupling reaction 1. Preliminary experiments with racemic *trans*-cyclopentane-1,2-diylbis(*o*-methoxyphenylphosphine) show, that the latter system can be catalytically active.

References and notes

1 G. Consiglio and C. Botteghi, Helv. Chim. Acta, 56 (1973) 460.

2 G. Consiglio, F. Morandini and O. Piccolo, J. Organomet. Chem., 177 (1979) C13; G. Consiglio, F. Morandini and O. Piccolo, Tetrahedron, 39 (1983) 2707.

3 T. Hayashi, M. Tajika, K. Tamao and M. Kumada, J. Am. Chem. Soc., 98 (1976) 3718; T. Hayashi, M. Konishi, M. Fukushima, T. Mise, M. Kagotani, M. Tajika and M. Kumada, J. Am. Chem. Soc., 104 (1982) 180; T. Hayashi and M. Kumada, Acc. Chem. Res., 15 (1982) 395; T. Hayashi, M. Konishi, Y. Okamoto, K. Kabeta and M. Kumada, J. Org. Chem., 51 (1986) 3272; T. Hayashi, A. Yamamoto, M. Hojo and Y. Ito, J. Chem. Soc., Chem. Commun., (1989) 495; T. Hayashi, M. Fukushima, M. Konishi and M. Kumada, Tetrahedron Lett., 21 (1980) 79; T. Hayashi, M. Konishi, M. Fukushima, K. Kanehira, T. Hioki and M. Kumada, J. Org. Chem., 48 (1989) 2195.

4 G. Cross, B.K. Vriesema, G. Boven, R.M. Kellogg and F. van Bolhuis, J. Organomet. Chem., 370 (1989) 357; G. Cross and R.M. Kellogg, J. Chem. Soc., Chem. Commun., (1987) 1746; B.K. Vriesema, M. Lemaire, J. Buter and R.M. Kellogg, J. Org. Chem., 51 (1986) 5169.

5 G. Consiglio, F. Morandini and O. Piccolo, Helv. Chim. Acta, 63 (1980) 987; G. Consiglio, F. Morandini and O. Piccolo, J. Chem. Soc., Chem. Commun., (1983) 112; G. Consiglio, O. Piccolo, L. Roncetti and F. Morandini, Tetrahedron, 42 (1986) 2043; G. Consiglio and R.M. Waymouth, Chem. Rev., 89 (1989) 257.

6 M. Chérest, H. Felkin, J.D. Umpleby and S.G. Davies, J. Chem. Soc., Chem. Commun., (1981) 681.

7 A. Yamamoto, T. Yamamoto, S. Komiya and F. Ozawa, Pure Appl. Chem., 56 (1984) 1621; S. Komiya, Y. Abe, A. Yamamoto and T. Yamamoto, Organometallics, 2 (1983) 1466; F. Ozawa, T. Hidaka, T. Yamamoto and A. Yamamoto, J. Organomet. Chem., 330 (1987) 53; F. Ozawa, K. Kurihare, M. Fujimori, T. Hidaka, T. Toyoshima and A. Yamamoto, Organometallics, 8 (1988) 180.

8 H. Kurosawa, H. Ohnishi, M. Emoto, N. Chatani, Y. Kawasaki, S. Murai and I. Ikeda, Organometallics, 9 (1990) 3038.
9 G.W. Parshall, W.A. Nugent, D.M.-T. Chan and W. Tam, Pure Appl. Chem., 57 (1985) 1809.
10 J.K. Kochi, Organometallic Mechanisms and Catalysis, Academic Press, New York, 1978, p. 395.
11 D. Milstein and J.K. Stille, J. Am. Chem. Soc., 101 (1979) 4981.
12 J.M. Brown and N.A. Cooley, Chem. Rev., 88 (1988) 1031.
13 T.C. Flood, in G. Geoffroy (Ed.), Topics in Inorganic and Organometallic Stereochemistry (Topics in Stereochemistry, Vol. 12), Wiley, New York, 1981, p. 37.
14 Y. Hatanaka and T. Hiyama, J. Am. Chem. Soc., 112 (1990) 7793.
15 K. Sano, T. Yamamoto and A. Yamamoto, Chem. Lett., (1984) 941; T. Yamamoto, K. Sano and A. Yamamoto, J. Am. Chem. Soc., 109 (1987) 1092.
16 D.L. Allen, V.C. Gibson, M.L.H. Green, J.F. Skinner, J. Bashkin and P.D. Grebenik, J. Chem. Soc., Chem. Commun., (1983) 895.
17 H. Brunner and W. Pieronczyk, Angew. Chem., 91 (1979) 655; H. Brunner, W. Pieronczyk, B. Schoenhammer, K. Streng, I. Bernal and J. Korp, Chem. Ber., 114 (1981) 1137; H. Takaya, K. Mashima, K. Koyano, M. Yagi, H. Kumobayashi, T. Taketomi, S. Akutagawa and R. Noyori, J. Org. Chem., 51 (1986) 629.
18 H. Brunner, H.-J. Lautenschlager, W.A. König and R. Krebber, Chem. Ber., 123 (1990) 847.
19 For a review see: J.K. Whitesell, Chem. Rev., 89 (1989) 1581.
20 The absolute configuration of this ligand was not unambiguously determined. We assume that the (−) enantiomer is homochiral with the (−) *trans*-cyclopentane-1,2-diylbis(diphenylphosphine) (*R*,*R*); this assignment is supported by comparison with the results obtained in the coupling reactions reported (cf. refs. 2, 5 and 21).
21 V.A. Pavlov, E. Yu. Zhorov, A.A. Voloboev and E.I. Klabunowski, J. Mol. Catal., 59 (1990) 119.