Unexpectedly facile racemization of 8-diphenylphosphinoyl-8′-methoxy-1,1′-binaphthyl

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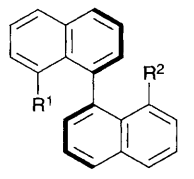
Optically active 8-diphenylphosphinoyl-8′-methoxy-1,1′-binaphthyl 7 racemizes very rapidly.

Optically active binaphthyls play an important role in asymmetric syntheses. 2,2′-Dihydroxy-1,1′-binaphthyl is frequently used as a chiral modifier both stoichiometrically[1] and catalytically.[2] In contrast, 8,8′-dihydroxy-1,1′-binaphthyl **1**[3] has received little attention as a chiral modifier. Recently, we reported the enantioselective protonation of enolates with (*R*)-**2** and the related carbamates.[4] To further extend the utility of this new chiral source **1**, we attempted to synthesize the optically active phosphine ligand **8** from **1**. Here we report the unexpectedly easy racemization of the phosphine oxides **5**–**7** we encountered in the synthesis of **8**.

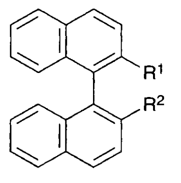
Recently, Hayashi *et al.* introduced chiral monodentate phosphine ligands, *e.g.* 2-diphenylphosphino-2′-methoxy-1,1′-binaphthyl **11**, for palladium-catalysed hydrosilylation,[5] hydroboration[6] and the reduction of allylic esters.[7] Switching the 2- and 2′-substituents of **11** to the 8- and 8′-positions, respectively, gives another phosphine **8**. Since the distance from the 8-phosphorus atom to the 2′-hydrogen in **8** should be the same as that from the 2-phosphorus atom to the 8′-hydrogen in **11**, each enantiomer should exist independently. Optically active **8** was expected to be easily prepared from optically active **1** without racemization according to a previously reported procedure.[8] The chiral environment of the diphenylphosphinoyl group in **8** is quite different from that in **11**. Another naphthyl ring located at the *peri*-position in **8** completely obstructs the approach from this side so that a higher selectivity may be expected for **8** than for **11**.[9] Extensive studies by Harris and co-workers[10] revealed that 1,1-binaphthyls with sp^3-substituents at the 8,8′-positions are optically more stable than those with sp^2-substituents.

Monophosphinoylation of optically pure monotriflate (*S*)-**3**, prepared from (*S*)-**1**,[4] proceeded smoothly under conditions similar to those reported for (*S*)-**9**,[8] to give the desired phosphine oxide **5** in 97% yield. Unexpectedly, the product **5** turned out to be a racemate. (*S*)-Ditriflate **4** also gave racemic **6**. To determine whether this racemization is based on some mechanistic constraint or on the thermal instability of the resulting phosphine oxide, the rate of racemization of (*S*)-8-diphenylphosphinoyl-8′-methoxy-1,1′-binaphthyl (**7**, 95% ee), prepared through the optical resolution of **5** followed by methylation, was determined in toluene. The half-life for the racemization of **7** was determined to be 130 min at 60 °C, which gave 110.5 ± 4 kJ mol^{-1} for the free energy of activation. On the other hand, no loss of optical purity of (*R*)-2-diphenylphosphinoyl-2′-methoxy-1,1′-binaphthyl **10** was observed at 100 °C, even after 64 h.

To explain why **7** is so easily racemized, the crystal structures of **7** and **10** were determined and are shown in Fig. 1.[‡] Torsion angles of the naphthyl ring with a diphenylphosphinoyl group



1 $R^1 = R^2 = OH$
2 $R^1 = OH$, $R^2 = OCONMe_2$
3 $R^1 = OH$, $R^2 = OTf$
4 $R^1 = R^2 = OTf$
5 $R^1 = OH$, $R^2 = P(O)Ph_2$
6 $R^1 = OTf$, $R^2 = P(O)Ph_2$
7 $R^1 = OMe$, $R^2 = P(O)Ph_2$
8 $R^1 = OMe$, $R^2 = PPh_2$



9 $R^1 = OTf$, $R^2 = P(O)Ph_2$
10 $R^1 = OMe$, $R^2 = P(O)Ph_2$
11 $R^1 = OMe$, $R^2 = PPh_2$

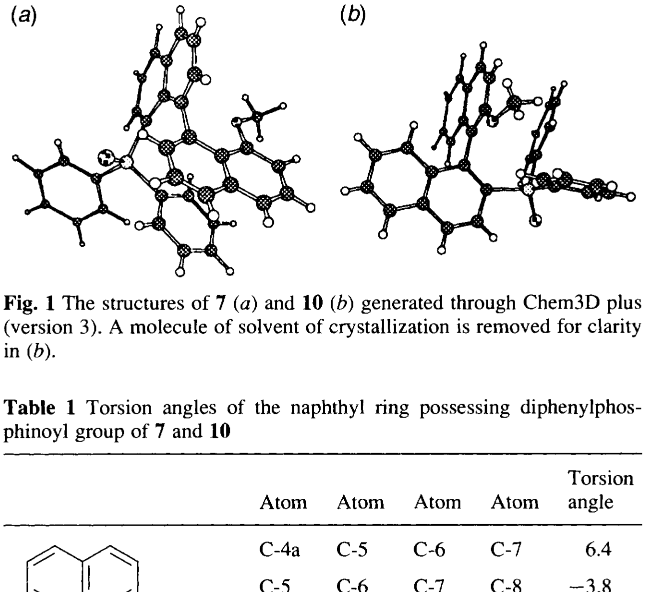
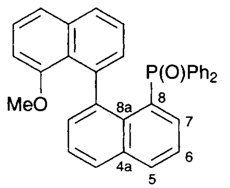
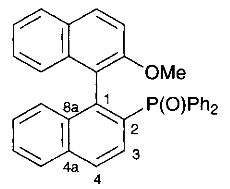


Fig. 1 The structures of **7** (*a*) and **10** (*b*) generated through Chem3D plus (version 3). A molecule of solvent of crystallization is removed for clarity in (*b*).

Table 1 Torsion angles of the naphthyl ring possessing diphenylphosphinoyl group of **7** and **10**

	Atom	Atom	Atom	Atom	Torsion angle
 **7**	C-4a	C-5	C-6	C-7	6.4
	C-5	C-6	C-7	C-8	−3.8
	C-6	C-7	C-8	C-8a	−4.4
	C-7	C-8	C-8a	C-4a	9.5
	C-8	C-8a	C-4a	C-5	−7.1
	C-8a	C-4a	C-5	C-6	−0.8
 **10**	C-1	C-2	C-3	C-4	2.6
	C-2	C-3	C-4	C-4a	0.5
	C-3	C-4	C-4a	C-8a	−2.9
	C-4	C-4a	C-8a	C-1	2.3
	C-4a	C-8a	C-1	C-2	0.7
	C-8a	C-1	C-2	C-3	−3.1

are given in Table 1. An interesting feature of the crystal structure of **7** is that C-8a, C-4a, C-5 and C-6 are located nearly on the same plane, while C-7 and C-8 are highly displaced from this plane such that the phenyl ring exists in a half-boat form which has a lower resonance energy than an aromatic ring. This striking distortion was not observed in the crystal structure of **10** (Table 1). These findings indicate that **7** is strongly destabilized in the ground state, which may explain its facile racemization. Semi-empirical molecular orbital calculations (PM3)[11] revealed that the heats of formation for **7** and **10** were 359.6 and 299.6 kJ mol^{-1}, respectively. The calculated enthalpy of activation for racemization of **7** and **10** was 88.7 and 174.1 kJ mol^{-1}, respectively. This large difference in the enthalpy of activation is mainly due to the destabilization of the ground state of **7**. It is worth noting that two substituents on C-8 and C-8′ are *anti* in the lowest-energy transition structure for racemization calculated for **7**, but *syn* for **10**.[§]

Footnotes

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[‡] *Crystal data* for **7**: monoclinic, space group $P2_1/c$, a = 11.782(7), b = 8.028(2), c = 26.59(2) Å, β = 97.86(4)°, V = 2491(6) Å^3, Z = 4, D_{calc} = 1.292 g cm^{-3}. The structure was refined to R = 0.042, Rw = 0.031 and S = 2.69.

For **10**, which contains a molecule of isopropanol as a solvent of crystallization; orthorhombic, space group $P2_12_12_1$, a = 12.292(5), b = 26.569(4), c = 9.042(1) Å, V = 2952(1) Å^3, Z = 4, D_{calc} = 1.225 g cm^{-3}. The structure was refined to R = 0.045, Rw = 0.038 and S = 3.01. Atomic coordinates, bond lengths and angles, and thermal parameters have been deposited at the Cambridge Crystallographic Data Centre (CCDC). See Information for Authors, Issue No. 1. Any request to the CCDC for this material should quote the full literature citation and the reference number 182/120.

[§] Harmonic vibrational frequency calculation gave only one imaginary frequency for the respective transition structures.

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