32 *Organometallics* **2006,** *25,* 32−34

# Rhodium Phosphinates as Catalysts for Metal-Stabilized Carbene Chemistry: Synthesis, Characterization, and Application of $Rh_2(O_2PMe_2)_4$

George M. Adjabeng,[§] David A. Gerritsma,[†] Hitesh Bhanabhai,[†]
Christopher S. Frampton,[‡] and Alfredo Capretta*[,†]

*GlaxoSmithKline, 5 Moore Drive, Research Triangle Park, North Carolina 27709, Department of Chemistry, McMaster University, Hamilton, Ontario, Canada L8S 4M1, and Pharmorphix Limited, 250 Cambridge Science Park, Milton Road, Cambridge, U.K. CB4 0WE*

*Received October 23, 2005*

*Summary: The first rhodium(II) phosphinate complex, $Rh_2(O_2PMe_2)_4$, is described and is shown to act as an effective catalyst for the decomposition of α-diazo compounds.*

Rhodium(II) salts have demonstrated their synthetic utility in the catalytic decomposition of diazo compounds over the last three decades, allowing for a number of transformations, including cyclopropanation, ylide generation, and carbon−hydrogen insertions among others.[1] These rhodium-mediated carbenoid reactions generally proceed under mild conditions with excellent efficiency and chemoselectivity, and their reactivity can be modulated via the utilization of an appropriate ligand. Since the pioneering work of Teyssié in 1973 with $Rh_2(OAc)_4$,[2] a variety of ligands have been introduced into dirhodium complexes, including a number of carboxylates (most notably trifluoroacetate, pivalate, or octanoate) and carboxamides.[3] To date, however, the introduction of phosphinate ligands has not been described in the literature.[4] Our interest in the preparation of Rh(II) phosphinates stems from chemistry developed in our laboratory that has allowed for the facile preparation of chiral phosphinates from readily available terpene starting materials.[5] Our ultimate goal is the preparation of Rh(II) phosphinates that will facilitate asymmetric transformations.[6] The present paper describes the synthesis and characterization of $Rh_2(O_2PMe_2)_4$ and shows that the complex is suitable for use in rhodium-mediated carbenoid reactions by facilitating a series of cyclopropanation reactions.

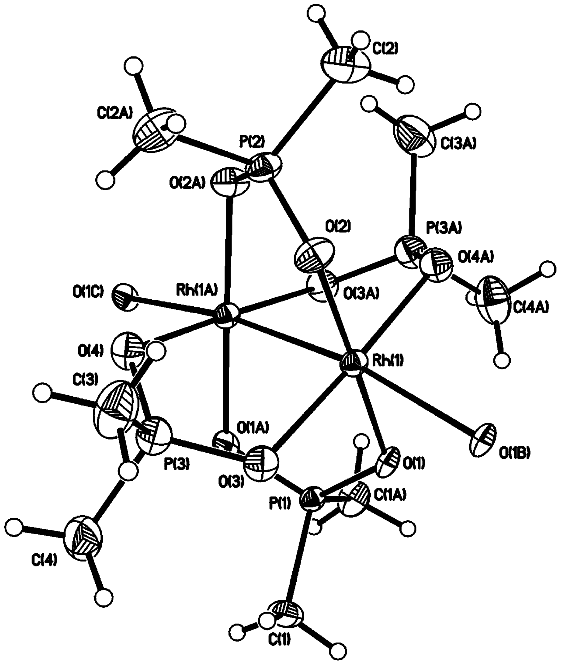


**Figure 1.** X-ray crystal structure of $Rh_2(O_2PMe_2)_4$.

The desired complex of $Rh_2(O_2PMe_2)_4$ was prepared via a standard ligand exchange process. In this way, commercially available dimethylphosphinic acid (5 equiv) and $Rh_2(OAc)_4$ (1 equiv) were introduced into a Soxhlet extractor containing chlorobenzene and $Na_2CO_3$ in the extractor thimble. The mixture was refluxed for 24 h, at which time the chlorobenzene was evaporated under reduced pressure and the residue crystallized from acetonitrile to give dark green crystals in 62% yield. The complex was characterized by MS and NMR.[8] Furthermore, additional recrystallization of $Rh_2(O_2PMe_2)_4$ from acetonitrile gave material suitable for X-ray crystallographic analysis.[9] The structure appears as shown in Figure 1.

Dirhodium(II) complexes generally adopt the familiar “lantern” or “paddlewheel” structure, wherein the dirhodium core is surrounded by four negatively charged, three-center, bidentate bridging ligands. The vacant axial coordination site on the rhodium is often occupied by another ligand (in many instances solvent or water). The most striking feature of the $Rh_2(O_2PMe_2)_4$ structure, however, is its propeller shape. Crowding of methyl

---

* To whom correspondence should be addressed. Fax: +1-905-522-2509. Tel: +1-905-525-9140, ext. 27318. E-mail: capretta@mcmaster.ca.

[§] GlaxoSmithKline.

[†] McMaster University.

[‡] Pharmorphix Limited.

[1] Doyle, M. P.; McKervey, M. A.; Ye, T. *Modern Catalytic Methods for Organic Synthesis with Diazo Compounds: From Cyclopropanes to Ylides*; Wiley-Interscience: New York, 1998.

[2] Paulissen, R.; Reimlinger, H.; Hayez, E.; Hubert, A. J.; Teyssié, Ph. *Tetrahedron Lett.* **1973**, *14*, 2233.

[3] Padwa, A.; Austin, D. J. *Angew. Chem., Int. Ed. Engl.* **1994**, *33*, 1797. Doyle, M. P.; Ren, T. *Prog. Inorg. Chem.* **2001**, *49*, 113.

[4] Compounds containing phosphates (Dikareva, L. M.; Sadikov, G. G.; Porai-Koshits, M. A.; Baranovski, I. B.; Abullaev, S. S. *Russ. J. Inorg. Chem.* **1980**, *25*, 488. McCarthy, N.; McKervey, M. A.; Ye, T.; McCann, M.; Murphy, E.; Doyle, M. P. *Tetrahedron Lett.* **1992**, *33*, 5983. Pirrung, M. C.; Zhang, J. *Tetrahedron Lett.* **1992**, *33*, 5987) and closely related sulfates (Baranovski, I. B.; Chalisova, N. N.; Mazo, G. Y. *Russ. J. Inorg. Chem.* **1979**, *24*, 1893) have been described.

[5] Robertson, A.; Bradaric, C.; Frampton, C. S.; McNulty, J.; Capretta, A. *Tetrahedron Lett.* **2001**, *42*, 2609.

[6] Doyle, M. P.; Forbes, D. C. *Chem. Rev.* **1998**, *98*, 911. Davies, H. M. L.; Beckwith, R. E. J. *Chem. Rev.* **2003**, *103*, 2861.

[7] Doyle, M. P.; Bagheri, V.; Wandless, T. J.; Harn, N. K.; Brinker, D. A.; Eagle, C. T.; Loh, K. L. *J. Am. Chem. Soc.* **1990**, *112*, 1906.

[8] $^{1}$H NMR (200 MHz; $CD_3OD$): 1.11 ppm (d, $J_{H,P}$ = 11.83 Hz, $CH_3$). $^{13}$C NMR (50 MHz; $CD_3OD$): 19.9 ppm (d, $J_{C,P}$ = 93.35 Hz, $CH_3$). $^{31}$P NMR (81 MHz; $CD_3OD$; 85% $H_3PO_4$(aq)): 80.9 ppm (s, $PO_2Me_2$). HRMS (EI): calcd for $C_8H_{24}O_8P_4Rh_2$, 577.853 18; obsd, 577.583 10.

10.1021/om0509185 CCC: $33.50

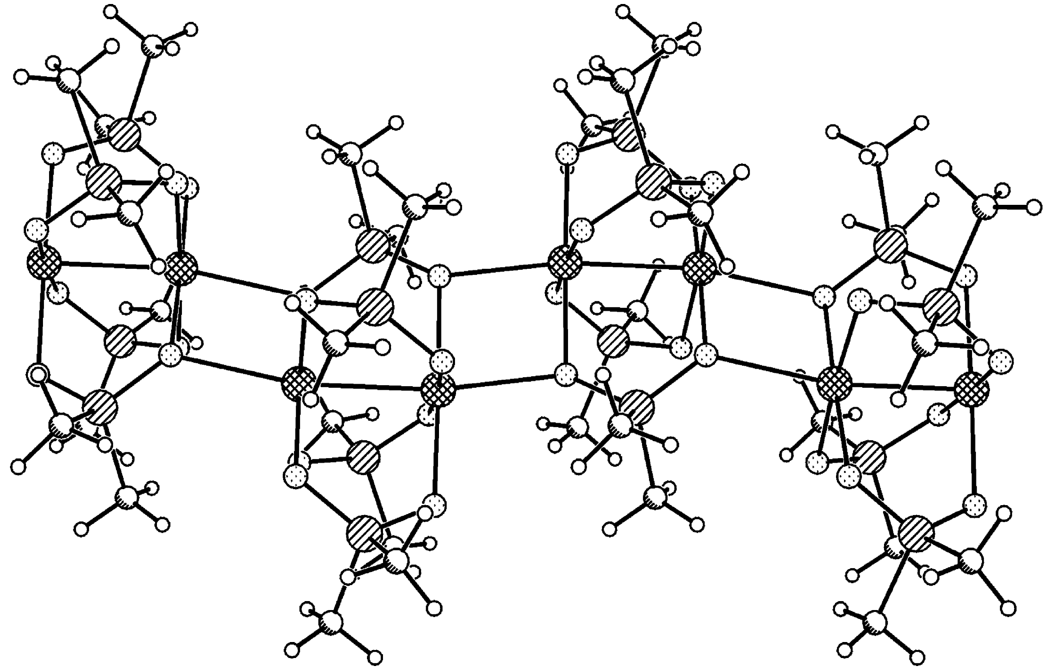
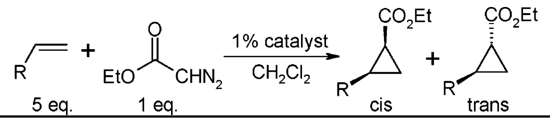


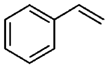
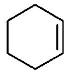
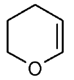
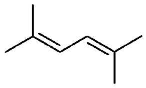
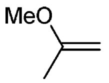
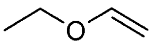
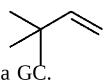
**Figure 2.** Lattice of $Rh_2(O_2PMe_2)_4$.

substituents or perhaps the larger distance between the oxygens of the dimethylphosphinate ligand results in a twisting of the dirhodium structure, preventing the paddlewheel geometry. This twist in the geometry is similar in nature to but significantly larger in magnitude than that in the $Rh_2(4S\text{-BNAZ})_4(CH_3CN)_2$ structure described by Doyle.[10] In addition, like Cotton's structures of $Rh_2(O_2CCF_3)_4$[11] and $Rh_2(O_2CC_3H_7)_4$,[12] oxygen atoms of the bridging dimethylphosphinate in $Rh_2(O_2PMe_2)_4$ form dative bonds at the axial positions of adjacent dirhodium units. Molecules of $Rh_2(O_2PMe_2)_4$ are, thereby, linked by axially ligating to each other to form long chains (Figure 2). Finally, the elongated Rh−Rh bond length of $Rh_2(O_2PMe_2)_4$ at 2.4379(7) Å (contrasted with 2.3813(8) Å for $Rh_2(O_2CCF_3)_4$ and 2.336(1) Å for $Rh_2(O_2CC_3H_7)_4$) may be a result of the twisted propeller geometry adopted by the complex, skewing the orbital overlap between the rhodium atoms.

With the $Rh_2(O_2PMe_2)_4$ in hand, the complex was tested for its ability to catalyze the cyclopropanation of various alkenes with diazo compounds. Dropwise addition of ethyl diazoacetate (1 equiv) to a solution of alkene (5 equiv) and 1% $Rh_2(O_2PMe_2)_4$ in $CH_2Cl_2$ over 18 h allowed for smooth formation of the cyclopropanes shown in Table 1. Yields and trans/cis ratios were determined via GC. Clearly, the phosphinate complex is a competent catalyst. Furthermore, if one compares the results with those obtained using $Rh_2(OAc)_4$,[13] $Rh_2(O_2PMe_2)_4$ shows a slightly different profile of activity. While yields are comparable with both $Rh_2(OAc)_4$ and $Rh_2(O_2PMe_2)_4$, in the cases of entries 5 and 6 the trans/cis ratios for the rhodium(II) phosphinate reaction are markedly better. The nature of the diazo compound has been shown to have a pronounced effect on diastereoselectivity,[14] and work involving cyclopropanation with phenyl and vinyl carbenoids is currently underway.

**Table 1. $Rh_2(O_2PMe_2)_4$-Mediated Cyclopropanations Using EDA**



| Entry | Alkene | Yield[a] | Trans/Cis ratio[a] |
|---|---|---|---|
| 1 |  | 88 | 1.8 |
| 2 |  | 83 | 3.0 |
| 3 |  | 80 | 5.6 |
| 4 |  | 84 | 1.3 |
| 5 |  MeO | 83 | 4.0 |
| 6 |  | 81 | 2.6 |
| 7 |  | 63 | 4.8 |

[a] Determined via GC.

---

(9) Crystal data and data collection and refinement details: $C_8H_{24}O_8P_4Rh_2$, $M_r = 577.97$, monoclinic, space group $C2/c$, $a = 17.7477(11)$ Å, $b = 11.4490(8)$ Å, $c = 9.3595(6)$ Å, $\beta = 99.246(3)°$, $U = 1877.1(2)$ Å$^3$, $Z = 4$, $D_c = 2.045$ g cm$^{-3}$, $\mu = 2.128$ mm$^{-1}$ (Mo Kα, $\lambda = 0.710\ 73$ Å), $F(000) = 1144$, $T = 120(1)$ K, data collected on a Enraf-Nonius Kappa CCD area-detector diffractometer equipped with an Oxford Cryosystems Cryostream cooler, crystal size 0.16 × 0.02 × 0.01 mm, $\theta_{max} = 26.37°$, 6443 reflections measured, 1877 unique ($R_{int} = 0.0747$), 97.6% complete, structure solution by direct methods, full-matrix least-squares refinement on $F^2$ with weighting $w^{-1} = \sigma^2(F_o^2) + (0.0320P)^2 + (0.0000P)$, where $P = (F_o^2 + 2F_c^2)/3$, anisotropic displacement parameters, riding hydrogen atoms, no absorption correction, final $R_w = \{\Sigma[w(F_o^2 - F_c^2)^2]/\Sigma[w(F_o^2)^2]^{1/2}\} = 0.0845$ for all data, conventional $R = 0.0375$ on $F$ values of 1381 reflections with $I > 2\sigma(I)$, $S = 1.001$ for all data and 105 parameters, final difference map between +0.74 and −0.99 e Å$^{-3}$, structure solved and refined using the SHELXTL suite of programs. The structure has been deposited with the CCDC (deposition number 283408).

(10) Doyle, M. P.; Zhou, Q.; Simonsen, S. H.; Lynch, V. *Synlett* **1996**, 697.

(11) Cotton, F. A.; Dikarev, E. V.; Feng, X. *Inorg. Chim. Acta* **1995**, *237*, 19.

(12) Cotton, F. A.; Shiu, K. *Rev. Chim. Miner.* **1986**, *23*, 14.

(13) Doyle, M. P.; Dorow, R. L.; Buhro, W. E.; Griffin, J. H.; Tamblyn, W. H.; Trudell, M. L. *Organometallics* **1984**, *3*, 44.

To establish the relative reactivity of $Rh_2(O_2PMe_2)_4$ with respect to that of other catalysts, a competitive cyclopropanation experiment, similar to the one described by Hubert and Noels, was undertaken.[15] Ethyl diazoacetate was added dropwise to a solution containing the catalyst under consideration and equimolar amounts of styrene and norbornene. The relative amounts of cyclopropanated styrene to cyclopropanated norbornene were then determined via GC and gave ratios of 1.8, 2.5, 3.4, and 3.8 for $Rh_2(tfa)_4$, $Rh_2(OAc)_4$, $Rh_2(S\text{-DOSP})_4$, and $Rh_2(O_2PMe_2)_4$, respectively. Given the differing electronic and steric properties of the alkene moieties of styrene and norbornene, catalysts giving higher ratios (i.e. greater amounts of cyclopropanated styrene) can be considered more selective, while those with lower ratios can be considered more indiscriminant. The experiment would seem to indicate that $Rh_2(O_2PMe_2)_4$ is less reactive and more selective than the other rhodium catalysts screened.

In conclusion, $Rh_2(O_2PMe_2)_4$ has been shown to be a viable catalyst for rhodium-mediated carbenoid chemistry and possesses a unique propeller structure. Unlike the carboxylate and carboxamide analogues, pendant substituents on the phosphinates occupy a different region of chemical space pointing toward the Rh metal. Ultimately, we wish to exploit these unique structural and electronic features in subsequent generations of Rh(II) phosphinate complexes.

**Acknowledgment.** We thank Materials and Manufacturing Ontario, Cytec Canada Inc., and the Natural Sciences and Engineering Research Council of Canada for financial support.

**Supporting Information Available:** Crystallographic data, given as a CIF file. This material is available free of charge via the Internet at http://pubs.acs.org. The CIF file has also been deposited with the Cambridge Crystallographic Database as CCDC 283408.

OM0509185

---

(14) Davies, H. M. L. *Aldrichim. Acta* **1997**, *30*, 107.

(15) Anciaux, A. J.; Hubert, A. J.; Noels, A. F.; Petiniot, N.; Teyssie, P. *J. Org. Chem.* **1980**, *45*, 695−702.