the context of gilvocarcin synthesis.

Acknowledgment. This work was supported by the National Science Foundation (Grant No. 8705647), the National Institutes of Health (Grant No. CA50720), and Brown University.

Supplementary Material Available: Experimental procedures and spectroscopic data for **ii**, **iva,b**, **2a–e**, **6a,b**, **7a**, and **8–10** (6 pages). Ordering information is given on any current masthead page.

C_2-Symmetric Bis(phospholanes) and Their Use in Highly Enantioselective Hydrogenation Reactions†

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Received July 3, 1991

Asymmetric catalysis is one of the most powerful, economically feasible methods for the generation of enantiomerically enriched compounds. C_2-Symmetric chiral diphosphines have emerged as a valuable class of ligands in transition-metal-based asymmetric catalysis, and in certain cases, spectacular enantioselectivity has been observed.[1] We recently reported the preparation and use of a variety of new electron-rich chiral phospholane ligands.[2] We now describe a versatile synthetic route which allows ready access to a series of ethane-bridged bis(phospholanes) **1**, as well as the 1,2-bis(phospholano)benzene analogues **2**. High catalytic efficiencies and enantiomeric excesses (ee's) have been realized in the rhodium-catalyzed asymmetric hydrogenation of various olefinic substrates, including enol acetates where only limited success previously had been achieved.

The key intermediates in our current synthetic strategy are the 1,4-diol cyclic sulfates[3] (**4**), which were prepared from the readily available[2a,c] homochiral 1,4-diols **3** (R = Me, Et, *i*-Pr) by adaptation of a method described by Sharpless and co-workers[4] for the synthesis of 1,2-diol cyclic sulfates (Scheme I). Deprotonation of 1,2-bis(phosphino)ethane with *n*-BuLi (2 equiv) gave dilithium bis(phosphido)ethane,[5] which then was reacted with 1,4-diol cyclic sulfate **4** (2 equiv), followed, after 1 h, by a second addition of *n*-BuLi (Scheme I). Standard workup procedures directly afforded the pure 1,2-bis(phospholano)ethanes **1** in good yield (70–90%). In a similar fashion, the use of 1,2-bis(phosphino)benzene provided the 1,2-bis(phospholano)benzenes **2** (abbreviated Me-DuPHOS (R = Me); Et-DuPHOS (R = Et); *i*-Pr-DuPHOS (R = *i*-Pr)). Our interest in the DuPHOS ligands **2** derived from the expected greater rigidity of the 1,2-phenylene backbone relative to the ethano bridge of **1**. By this simple one-pot procedure, either antipode of **1** and **2** can be routinely prepared.

Scheme I

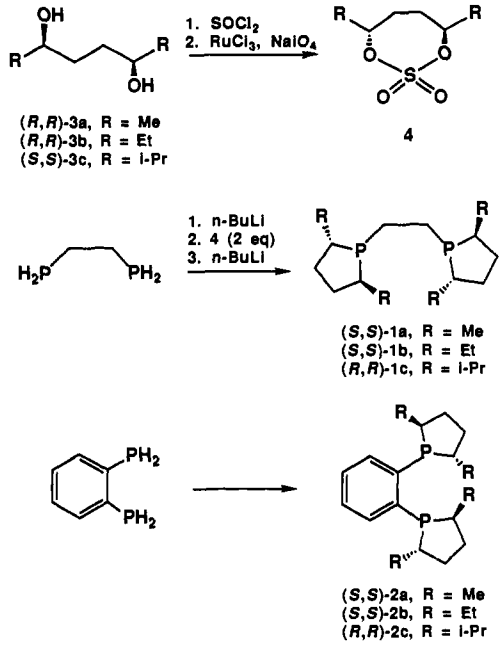

Table I. Asymmetric Hydrogenation of Acetamidoacrylates[a]

Ligand	(%ee)[b] Substrate: Ph, CO2Me, N(H)Ac	Substrate: i-Pr, CO2Me, N(H)Ac	Substrate: CO2Me, N(H)Ac
1a	85	64.4	91.4
1b	93	81.2	98.1
1c	93	98.8	96.4
2a	98	95.2	99.0
2b	99	99.0	99.4
2c	87	96.9	95.4

[a] Reactions were carried out at 20–25 °C and an initial H_2 pressure of 30 psi (2 atm) with 0.25–0.35 M methanol solutions of substrate and the catalyst precursors $[(COD)Rh(P_2)]^+OTf^-$ (0.1 mol %). Reaction time for complete (100%) conversion was 1–2 h. Product absolute configurations established by sign of optical rotations; for phosphines **1a**, **1b**, **2a**, and **2b**, *R,R* and *S,S* ligands afforded *R* and *S* products, respectively; *R,R*-**1c** and *R,R*-**2c** gave *S* products. Essentially identical results were obtained at 1 atm of H_2. [b] Enantiomeric excesses were determined by chiral HPLC (Daicel Chiralcel OJ, methyl acetamidophenylalanine) or capillary GC (Chrompack XE-60-*S*-Val, methyl acetamidoleucine and methyl acetamidoalanine) as described in the supplementary material.

For the purpose of comparison, we have examined the enantioselectivity associated with the series of ligands **1** and **2** in rhodium-catalyzed hydrogenations involving the much-studied acetamidoacrylate substrates **6** (Table I). With the homochiral series of ligands **1** and **2**, we are uniquely situated to *easily and systematically vary the steric environment imposed by the phosphines without significantly varying the electronic nature of the metal centers in a corresponding series of complexes.* Using this approach, it has been possible to optimize the enantioselectivity in hydrogenations by matching the steric demand of the ligands to the substrate of interest. We find that Et-DuPHOS (**2b**) is the ligand of choice for substrates **6**, and in general, enantioselectivities consistently approaching 100% were observed; the ee's listed are as high as or higher than any previously reported[1,6] for

† Dedicated to Professor K. Barry Sharpless on the occasion of his 50th birthday.

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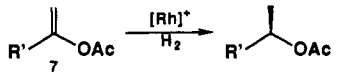
Table II. Asymmetric Hydrogenation of Enol Acetates 7[a]

R'	ligand	previous best[b]	% ee,[c] config[d]
C_6H_5	(S,S)-**2a**	64	89, (-)-*S*
p-$NO_2C_6H_4$	(R,R)-**1b**	65	90, (+)-*R*
m-ClC_6H_4	(R,R)-**2b**		91, (+)[e]
1-naphthyl	(R,R)-**1b**		94, (+)-*R*
1-naphthyl	(S,S)-**2a**		93, (-)-*S*
CO_2Et	(S,S)-**2a**	89	99, (-)-*S*
CO_2Et	(R,R)-**2b**	89	>99, (+)-*R*
CF_3	(S,S)-**2a**	77	94, (+)-*S*
CF_3	(R,R)-**1b**	77	>95, (-)-*R*

[a] Reaction conditions as in Table I. Reaction time for complete (100%) conversion was 2-12 h. [b] Values listed denote highest ee's previously reported for catalytic asymmetric hydrogenation of these substrates (see ref 8). [c] Enantiomeric excesses were determined as described in the supplementary material. [d] Product absolute configurations established by sign of optical rotations. [e] Absolute configuration not established.

these substrates (Table I). In addition, high catalytic rates and efficiencies (for methyl (*Z*)-α-acetamidocinnamate, S/C ratio = 10 000 with Et-DuPHOS) were demonstrated. Under the conditions described, methyl (*Z*)-α-benzamidocinnamate was hydrogenated to (*R*)-*N*-benzoylphenylalanine methyl ester in 98% ee and dimethyl itaconate was reduced to (*R*)-dimethyl 2-methylsuccinate in >95% ee with the Rh((*R*,*R*)-Et-DuPHOS) catalyst.

Substrate chelation through a secondary donor group (e.g., acetamido carbonyl oxygen) is thought to be crucial for the attainment of high enantiomeric excesses in many asymmetric hydrogenation reactions.[1,7] Efforts to identify other substrates which possess a similar grouping led us to examine the asymmetric hydrogenation of enol acetates **7** (Table II).[1c,8] These catalytic



7

enol acetate hydrogenations are synthetically equivalent to asymmetric keto group reductions. Good to excellent enantioselectivities have been observed, and in comparison with the best results previously reported[8] for these substrates, much higher selectivities are noted here. In contrast to the acetamidoacrylates (**6**), no one ligand consistently outperformed the others in the hydrogenation of enol acetates. For a given substrate, the highest ee's were obtained through systematic "steric matching", which demonstrates the potential power of this approach in optimizing enantioselectivities.

The presence of electron-withdrawing groups on an olefinic substrate is well-known to enhance late-transition-metal binding constants[9] and has been shown to result in higher rates and enantioselectivities in asymmetric hydrogenation reactions.[1,7] The high ee's we observe in hydrogenation reactions probably, in part, stem from the electron-rich nature of our phosphines, which increases electron density at the metal and leads to stronger olefin binding relative to most known asymmetric diphosphines which bear at least two aryl substituents on phosphorus.

The relative ease with which both antipodes of the new homochiral series of bis(phospholane) ligands **1** and **2** are prepared should lead to many applications in asymmetric catalysis; such studies are in progress.

Acknowledgment. The expert technical assistance of J. E. Feaster for synthetic work and J. Lazar for obtaining HRMS spectra and the invaluable advice obtained through insightful discussions with Drs. T. V. RajanBabu and W. A. Nugent (Du Pont CRD) are warmly acknowledged.

Supplementary Material Available: Experimental details including preparations and spectral and analytical data for phosphines **1** and **2**, cyclic sulfates **4**, and rhodium complexes **5** and enantiomeric excess determinations (17 pages). Ordering information is given on any current masthead page.

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Endohedral Complexes of Fullerene Radical Cations

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Received August 8, 1991

An interesting feature of the fullerenes[1] is the potential to confine atoms and atomic ions within their hollow center volume.[2-4] Such confinement of small species within larger cage molecules has been accomplished by synthesis in other areas of organic chemistry.[5]

One surprising method, however, of inserting the guest is by high-energy collisions of the C_{60} or C_{70} radical cations with helium target gas.[6] A series of even carbon number product ions[7] $C_n^{\bullet+}$ and $C_nHe^{\bullet+}$ (n = 48-58) were found, but the putative $C_{60}He^{\bullet+}$ precursor could not be seen. No other evidence for incorporation of other simple target gases (except ^3He) was reported,[6] although Ne uptake was mentioned in a note added in proof.[6]

We report the use of a new-design, four-sector tandem mass spectrometer[8] to expand the scope of fullerene endohedral complexes.[9] This instrument comprises two double-focusing mass spectrometers. The second stage, of reverse geometry design, possesses a planar rather than curved electrostatic analyzer (ESA),

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(8) This instrument was commissioned by the Midwest Center for Mass Spectrometry, a former NSF regional instrumentation facility (Grant No. CHE 8620177). It was designed by Robert Bateman and built by VG Analytical (now Fisons Instruments) for the MCMS. Although the spectrometer has not been completely evaluated, it was briefly described by Gross: Gross, M. L. In *Methods in Enzymology, Mass Spectrometry*; McCloskey, J. A., Ed.; Academic Press: New York, 1990; Vol. 193, pp 131-153.

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