The 10% Pd/C catalyst was of commercial origin (Engelhard, Ventron).

Identification of products was made by collection of samples using gas–liquid chromatography (15 ft × ¼ in. 152 DEGS or SE-30) and by IR and NMR spectra.

Benzyl Acetate by Transfer Reduction. Freshly distilled benzaldehyde (20 mL, 0.196 mol) was combined with 50 mL of cyclohexene, 2.0 g of 10% Pd/C, 20.45 mL of acetic anhydride, and 200 mg of $FeCl_3$ and refluxed for 4 h. The mixture was filtered to remove the catalyst and fractionally distilled to give 17.6 g (60%) of benzyl acetate, bp 104 °C (aspirator vacuum).

Transfer Reduction of (+)-α-Pinene. A mixture of 15.0 mL of (±)-α-pinene, 1.0 g of 10% Pd/C, and 15 mL of (+)-limonene (α^{24}_D +64.3°) was refluxed for 0.5 h. The mixture of pinanes and *p*-cymene obtained after filtration of the catalyst showed no detectable optical activity.

Transfer Reduction of Methyl *cis*-2-Phenyl-3-*p*-tolylpropenoate. Purified methyl *cis*-2-phenyl-3-*p*-tolylpropenoate (300 mg) was dissolved in 3.5 mL of purified (+)-limonene, α^{24}_D +106°, or (+)-1-*p*-menthene, α^{25}_D +70.5°. A 35-mg amount of 10% Pd/C was added, and the mixture was immersed in an oil bath at 195 °C for 6 min. These were the conditions found to be optimum for rapid quantitative reduction. After chromatography on 15 g of silica gel, 248 mg (82% yield) of methyl 2-phenyl-3-*p*-tolylpropanoate was obtained as a viscous liquid. GLC (10 ft 15% DEGS) indicated 100% purity, and NMR and IR data are in accord with the structure. No optical rotation was observed.

Transfer Reduction of α-Acetamidocinnamic Acid. α-Acetamidocinnamic acid (2.0 g) was dissolved in 90 mL of a 70:30 mixture of toluene/1-butanol, 15 mL of (+)-1-*p*-menthene (α^{25}_D +70.5°), and 250 mg of 10% Pd/C. The mixture was refluxed for 51 h at 116 °C. After removal of solvent and recrystallization, 640 mg (31%) of *N*-acetylphenylalanine, mp 140.5–141 °C, was obtained. The product exhibited no optical activity.

***N*-1,2,5,6-Tetrahydrophthalyl-L-leucine[5] (I).** L-Leucine (13.1 g), 15.2 g of 1,2,5,6-tetrahydrophthalic anhydride, 150 mL of toluene, and 1.3 mL of triethylamine were refluxed for 3 h in the presence of a Dean-Stark trap. The toluene was removed using a rotary evaporator, and the resulting semisolid was treated with 100 mL of distilled water and 2 mL of concentrated HCl. After washing with more water, filtration, and drying, 20.6 g (78% yield) of product was obtained. Recrystallization from ethanol saturated with water gave mp 137–138.5 °C. The NMR spectrum is in accord with the expected structure.

Transfer Reduction of Methyl *cis*-2-Phenyl-3-*p*-tolylpropenoate with I. Methyl *cis*-2-phenyl-3-*p*-tolylpropenoate (2.55 g) was combined with 3.0 g of I, 10 mL of toluene, and 500 mg of 10% Pd/C. The mixture was refluxed for 4 h, when NMR indicated complete reduction. After filtration, the solution was extracted with 6 M NaOH, dried, and evaporated to give 2.2 g of an oil which was chromatographed on alumina. Elution with 10% ether in pentane gave 1.3 g of pure methyl 2-phenyl-3-*p*-tolylpropanoate as an oil. No optical activity was observed.

Acknowledgment. The technical assistance of James W. Thill is greatly appreciated.

Registry No.—I, 69705-72-2; benzaldehyde, 100-52-7; acetic anhydride, 108-24-7; benzyl acetate, 140-11-4; (±)-α-pinene, 2437-95-8; methyl *cis*-2-phenyl-3-pitolylpropenoate, 42307-46-0; (+)-1-*p*-menthene, 1195-31-9; methyl 2-phenyl-3-*p*-tolylpropanoate, 69668-17-3; α-acetamidocinnamic acid, 69668-18-4; *N*-acetylphenylalanine, 69668-19-5; 1,2,5,6-tetrahydrophthalic anhydride, 4717-58-2; L-leucine, 61-90-5; *p*-anisaldehyde, 123-11-5; 2,6-dimethylbenzaldehyde, 1123-56-4; *p*-isopropylbenzaldehyde, 122-03-2; α-naphthaldehyde, 66-77-3; *p*-methoxybenzyl acetate, 104-21-2; 2,6-dimethylbenzyl acetate, 62346-87-6; *p*-isopropylbenzyl acetate, 59230-57-8; 1-naphthalenemethanol acetate, 13098-88-9; cyclopropyl phenyl ketone, 3481-02-5; 4-benzoylbutyric acid, 1501-05-9; *trans*-1,2-dibenzoylethylene, 959-28-4; 6-methoxytetralone, 1078-19-9; 4-chloroacetophenone, 99-91-2; *n*-butylbenzene, 104-51-8; 5-phenylpentanoic acid, 2270-20-4; 1,4-diphenylbutane, 1083-56-3; 6-methoxytetralin, 1730-48-9; 2-methoxynaphthalene, 93-04-9; ethylbenzene, 100-41-4; acetophenone, 98-86-2; 1-octene, 111-66-0; octane, 111-65-9; toluene, 108-88-3; α-phellandrene, 99-83-2; tetralin, 119-64-2; bicyclo[4.3.0]nona-3,7-diene, 3048-65-5; 4-vinylcyclohexene, 100-40-3; 9,10-dihydroanthracene, 613-31-0; isopulegol, 89-79-2; l-carvone, 99-49-0; *cis*-Δ⁴-tetrahydrophthalic anhydride, 935-79-5; (+)-limonene, 5989-27-5.

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Asymmetric Chemistry. Comparison of Chiral Phosphines vs. Chiral Phosphinites in the Asymmetic Hydrogenation of Prochiral Olefins Containing a Carboxylic Acid or Ester Group

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The asymmetric hydrogenation of prochiral olefins has been an especially active field of research since Kagan's publication on the use of (−)-DIOP[1] in such reductions.[2,3] A common theme in these reactions has been the use of chiral phosphines as ligands in rhodium-catalyzed reductions. The substrates have frequently included carboxylic acid and/or acetamido groups attached to the olefin moiety. The reduction of olefins not having these groups often resulted in products of lower enantiomeric excess.[2,3]

Recently, Hayashi[4] published the results of asymmetric hydrogenations performed in the presence of a chiral phosphinite, *d-trans*-BDPCP,[5] rather than a chiral phosphine. Interestingly, the products obtained in the presence of this phosphinite proved to have greater enantiomeric excess, in many instances, than products obtained from (−)-DIOP reductions for substrates not containing carboxylic acid or acetamido groups. However, (−)-DIOP still proved to be superior to *d-trans*-BDPCP in the asymmetric reduction of prochiral olefins possessing carboxylic acid and/or acetamido groups. This raised the interesting speculation that chiral phosphines might be better than chiral phosphinites in the reduction of olefins containing a carboxylic acid moiety while the reverse may be true for olefins not containing an acid or acetamido group. Unfortunately, the Hayashi and Kagan ligands are too different in structure to relate their effects entirely to their differences in phosphorus groups.

We sought to determine if one could obtain better asymmetric induction for some substrates with chiral phosphines while the hydrogenation of other substrates may be influenced more by structurally similar phosphinites. Many chiral phosphine ligands have been synthesized by sequences which go through alcohol or diol intermediates. These are usually converted to tosylates or halides which, in turn, can be converted to the diphenylphosphino compounds. These same alcohol intermediates serve as ideal substrates for the preparation of phosphinites. Hence, the same synthetic sequence, with slight modifications, could be used to prepare structurally similar phosphines and phosphinites. The substrates we chose, to test our hypothesis, were olefins containing carboxylic acid moieties and their analogous methyl esters.[6]

For our phosphine–phosphinite pair we wanted to choose a chiral phosphine that had already been investigated in asymmetric hydrogenation. Unfortunately, attempts to prepare a bis(phosphinite) from the diol precursor of DIOP gave thermally unstable species. Likewise, it had been reported that the phosphinite derived from menthol was stable only below −20 °C.[7] Fortunately, the diol precursor of camphos[3e] did react with chlorodiphenylphosphine to produce a thermally

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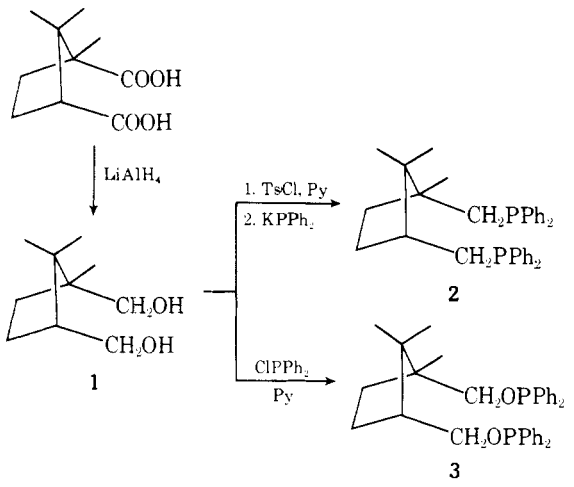

stable bis(phosphinite), **3**, which we shall refer to as camphinite. Camphos, **2**, was prepared according to literature procedures.[3e] While camphos was not as effective in enantiomeric selectivity as (−)-DIOP, it does have appreciable activity in asymmetric hydrogenations.

We explored the rhodium-catalyzed hydrogenations of olefinic acids with both camphos and camphinite. The results are given in Table I. Likewise, we examined the hydrogenations of the corresponding methyl esters with both ligands. The results are given in Table II. It would appear that the phosphine ligand, camphos, is better than or equal to the phosphinite ligand, camphinite, in the asymmetric reductions of olefinic acids. On the other hand, camphinite is the superior ligand when reducing olefinic esters unless an acetamido group is also present. These comparisons are pleasantly consistent with the extrapolations we made from Hayashi's study. There are a few inconsistencies which should be noted however. First, unlike DIOP, both camphos and camphinite gave better asymmetric reduction of methyl α-acetamidocinnamate than of the corresponding acid. Second, both camphos and camphinite gave poorer asymmetric reduction of the esters than of the corresponding acids with the exception noted above.

In summary, the phosphine analogue has proven to be an equal or better chiral ligand when a carboxylic acid or an acetamido group was present. When an ester group was present, the analogous phosphinite ligand gave greater asymmetric induction. As both types of ligands can be prepared from the same intermediate, both here and in general, it would appear that one has two different chiral ligands available from many synthetic schemes. The pattern that emerges from the direct comparison here and Hayashi's general comparison is that phosphines and phosphintes do have different abilities and limitations with respect to the type of substrate.

Table I. The Hydrogenation of Olefinic Acids with $Rh_2Cl_2(COD)_2$ in Benzene–Ethanol (1:1)

substrate	registry no.	enantiomeric excess, % camphos	enantiomeric excess, % camphinite
atropic acid	492-38-6	6.5 (6.0)[a]	2.0
α-acetamidocinnamic acid	5469-45-4	17.0	4.3
α-methylcinnamic acid	1199-77-5	15.4 (15.2)[a]	14.3
α-phenylcinnamic acid	3368-16-9	12.2 (11.8)[a]	12.0

[a] From ref 3e.

Table II. The Hydrogenation of Olefinic Esters with $Rh_2Cl_2(COD)_2$ in Benzene–Ethanol (1:1)

substrate	registry no.	enantiomeric excess, % camphos	enantiomeric excess, % camphinite
methyl atropate	1865-29-8	<1.0[a]	1.0
methyl α-acetamidocinnamate	52386-78-4	22.4	10.3
methyl α-methylcinnamate	25692-59-5	<1.0[a]	4.3
methyl α-phenylcinnamate	32892-18-5	<1.0[a]	4.6

[a] Only slight rotations were observed.

Experimental Section

The ^1H NMR spectra were obtained on a Varian T-60 spectrometer using tetramethylsilane as an internal standard in $CDCl_3$–Me_2SO-d_6 (1:1). Infrared spectra were recorded on a Perkin-Elmer 137 spectrometer. Optical rotations were obtained from an ETL-NPL 143A automatic polarimeter. Hydrogenations were performed in a Parr pressure hydrogenator. All of the carboxylic acid substrates were purchased and the methyl esters were prepared by standard diazomethane reactions on the acids. Camphos and diol 1 were prepared by literature procedures.[3e] The synthesis of camphinite and preparation of the hydrogenation mixtures were done in a Vacuum Atmospheres drybox. All solvents were distilled from sodium under a nitrogen atmosphere.

(+)-1,2,2-Trimethyl-1,3-bis(diphenylphosphinoxymethyl)cyclopentane (3, Camphinite). To a 500-mL erlenmeyer containing 160 mL of anhydrous THF, 13 g (0.075 mol) of diol **1**, 11.9 g of pyridine, and a magnetic stirring bar was added, dropwise, 33 g (0.15 mol) of chlorodiphenylphosphine. The reaction was stirred for 12 h, and then the precipitate was filtered. The filtrate was evaporated in vacuo and left a viscous oil. The oil slowly solidified after ca. 1 week. The crude yield was nearly quantitative and the product was used without further purification: mp 138–142 °C; $[\alpha]^{25}_D$ +93.8 (*c* 0.27, $CHCl_3$); ^1H NMR δ 0.78 (3 H, s), 1.00 (6 H, s), 1.15–2.30 (5 H, m), 3.45 (4 H, m), 7.38 (20 H, m); IR ($CHCl_3$) 1030, 1000 cm^{-1} (POC).

General Procedure for Reduction of the Olefinic Acids. To a Parr reaction vessel were added 200 mL of ethanol, 200 mL of benzene, 0.03 mol of the olefinic acid, 0.0003 mol of (cyclooctadiene)rhodium chloride dimer, 0.0018 mol of triethylamine, and 0.0009 mol of camphinte or camphos. The apparatus was sealed, heated to 60 °C and pressurized to 300 psi with hydrogen. After 24 h, the reaction was cooled, the solvent was evaporated, and the product was extracted by the procedure of Kagan.[2] Crude reaction yields were determined by ^1H NMR and were found to be quantitative.

General Procedure for the Reduction of the Olefinic Esters. The procedure was the same as for the acid except the reactions were run at 100 °C and 1000 psi of hydrogen for 48 h in the absence of triethylamine.[8] Crude reaction yields were determined by ^1H NMR and were found to be quantitative.

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Registry No.—**1**, 68510-42-9; **2**, 60989-76-6; **3**, 69631-82-9; chlorodiphenylphosphine, 1079-66-9.

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