4.84; Br, 31.94; N, 5.60. Found: C, 57.41; H, 4.77; Br, 31.85; N, 5.63.

Preparation of 9o from 1a and 7o in Solid K_2CO_3/C_6H_6/TBABr System. Powdered K_2CO_3 (2.5 g, 1.8 mmol), benzene (20 mL), TBABr (0.1 g, 0.31 mmol), dimethyl malonate (**7o**) (0.79 g, 6 mmol), and **1a** (0.85 g, 5 mmol) were stirred and refluxed for 5 h. The mixture was then cooled and filtered, and the solid was washed with benzene. The combined filtrates were concentrated, and the product **9o** was isolated by vacuum distillation (Table I): bp 105 °C (0.1 mm); ^1H NMR δ 0.50–1.43 (m, 3 H, CH_2 and CH of cyclopropane ring), 1.82–2.19 (m, 2 H, CH_2), 2.56–3.15 (m, 1 H, CHBr), 3.43–3.78 (m, 7 H, 2 CH_3 and CHCOO); IR (film) 3000, 2950, 1750–1730, 1440, 1345, 1250, 1150, 1040 cm^{-1}; MS *m/e* (relative intensity) 267 ($M^+ + 2$, 1), 266 ($M^+ + 1$, 10), 265 (M^+, 2), 264 ($M^+ - 1$, 8), 201 (21), 185 (37), 153 (35), 132 (100), 125 (40), 100 (23), 59 (17), 39 (10), 27 (8). Anal. Calcd for $C_9H_{13}BrO_4$: C, 40.78; H, 4.94; Br, 30.14. Found: C, 40.63; H, 4.81; Br, 29.89.

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Registry No. (*E*)-**1a**, 95896-07-4; (*Z*)-**1a**, 95896-06-3; **7a**, 71-36-3; **7b**, 111-27-3; **7c**, 112-30-1; **7d**, 108-93-0; **7e**, 100-51-6; **7f**, 636-72-6; **7g**, 108-95-2; **7h**, 106-48-9; **7i**, 150-76-5; **7j**, 108-98-5; **7k**, 1823-91-2; **7l**, 3333-14-0; **7**, 86-29-3; **7n**, 140-29-4; **7o**, 108-59-8; **8a**, 119819-25-9; **8b**, 119819-26-0; **8c**, 119819-27-1; **8d**, 119819-28-2; **8e**, 119819-29-3; **8f**, 119819-30-6; **8m**, 119819-37-3; (*E*)-**9g**, 119819-31-7; (*Z*)-**9g**, 119819-41-9; (*E*)-**9h**, 119819-32-8; (*Z*)-**9h**, 119819-42-0; (*E*)-**9i**, 119819-33-9; (*Z*)-**9i**, 119819-43-1; (*E*)-**9j**, 119819-34-0; (*Z*)-**9j**, 119819-44-2; (*E*)-**9k**, 119819-35-1; (*Z*)-**9K**, 119819-45-3; (*E*)-**9l**, 119819-36-2; (*Z*)-**9l**, 119819-46-4; (*E*)-**9m**, 119819-38-4; (*Z*)-**9m**, 119819-47-5; (*E*)-**9n**, 119819-39-5; (*Z*)-**9n**, 119819-48-6; (*E*)-**9o**, 119819-40-8; (*Z*)-**9o**, 119819-49-7; TEBACl, 56-37-1.

Enantioselective Preparation of Functionalized Cyclopentanoids via a Common Chiral (π-Allyl)palladium Complex[1]

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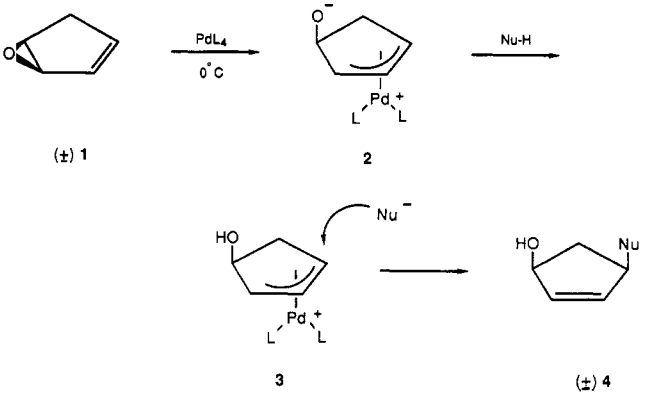
Functionalized cyclopentanoids have provided molecular foundations for the construction of biologically intriguing compounds of diverse medicinal interest.[2,3] The fact that pharmacological response often derives from a single enantiomorph underscores the need for the development of enantiospecific routes to these cyclopentyl backbones. Herein, we report the efficient preparation of potentially useful, optically active cyclopentanoids via a common chiral (π-allyl)palladium complex.

Recently, we[4] and others[5] described a highly direct, palladium-catalyzed route to (±)-*cis*-4-substituted-2-cyclopenten-1-ols (**4**) based on the reaction of mildly acidic nucleophiles with cyclopentadiene monoepoxide (**1**). The mechanism is outlined in Scheme I. The reaction's unusually high stereo- and regiospecificity appears to be governed by the unique structural characteristics of π-allyl complex **3**. The polar hydroxyl functionality maintains regiocontrol by directing the internally generated nucleophile toward the distal end of the π-allyl system[6] while the stereocontrol is regulated by the backside nucleophilic displacement of palladium.[7] Unfortunately, the reaction's usefulness in the preparation of optically active cyclopentanoids is constrained by the unavoidable racemic composition of epoxide **1**.[8] A desire to overcome this limitation coupled with the needs of a related project prompted our search for an optically active alternative to Scheme I.

Scheme I



We were keenly aware that if an enantioselective route to π-allyl **3** could be devised a virtually unlimited number of optically active cyclopentanoids would be potentially accessible from a single resolved source. Therefore, the preparation of enantiomerically pure **3** became the lodestar of our research program.

Several years ago it was discovered that palladium π-allyls could be prepared from allylic acetates and palladium(0) catalysts via a metal-induced ionization of the acetoxy moiety.[9] Subsequent reaction between these transient intermediates and externally generated nucleophiles was found to afford substitution products of predictable stereochemistry yet not always consistent regiochemistry. Since it was known[10] that palladium π-allyls derived from optically active allylic acetates were themselves optically active, we reasoned that exposure of enantiomerically pure allyl acetate **5** to palladium(0) catalyst ought to give rise to a single enantiomorph of (π-allyl)palladium complex **3**. Prompt nucleophile entrapment by this electrophilic species (**3**) was expected to yield substituted cyclopentanoids of homogeneous chirality. Problems associated with regiocontrol were not anticipated during this nucleophilic addition step since complex **3** was expected to deliver the externally generated nucleophiles to the same unhindered terminus of the π-allyl system that it had for the internally generated (Scheme I) counterparts. Thus, provided the starting allyl acetate **5** is enantiomerically enriched and that racemization mechanisms are

(1) Presented by R.G.L. at the annual Research Conference for Chemistry Undergraduates, April 25, 1987, Loyola Marymount University (sponsored by the Southern California Section of the American Chemical Society), and by D.R.D. at the 194th ACS National Meeting, August 30–September 4, 1987, New Orleans, LA.

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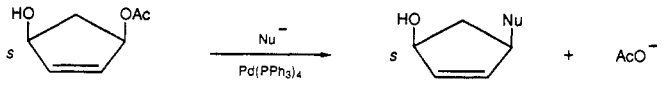
0022-3263/89/1954-2759$01.50/0

Table I. Palladium(0)-Catalyzed Substitution Reactions on (+)-Allyl Acetate 5

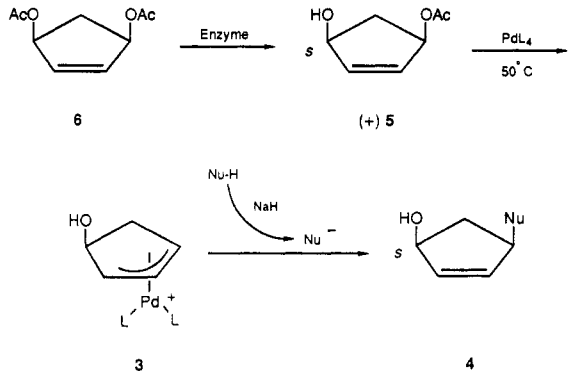


(+) 5 4

entry	nucleophile	nucleophile equiv[a]	NaH equiv[a]	$Pd(PPh_3)_4$,[a] mol %	PPh_3,[a] mol %	adduct	yield,[b] %
1	$CH_2(CO_2CH_3)_2$	2.0	2.0	5	15	**4a**	86
2	$CH_2(COCH_3)_2$	3.9	3.9	4.7	0	**4b**	78
3	$PhSO_2CH_2CO_2CH_3$	1.9	1.9	2.4	0	**4c**	97[c]
4	$CH_3COCH_2CO_2CH_3$	2.1	2.1	2.3	0	**4d**	91[c]
5	PhOH	2.2	2.2	2.9	0	**4e**	90
6	PhSH	1.8	1.8	3.1	9.3	**4f**	86
7	NaN_3	1.2	0	10	0	**4g**	44[d]
8	PthK[e]	1.5	0	15	15	**4h**	74

[a] Based on 5. [b] Yields refer to pure isolated products. [c] Mixture of diastereomers. [d] A 4:1 ratio of cis-1,4 and trans-1,4 adducts. [e] Potassium phthalimide.

Scheme II



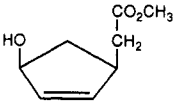
6 (+) 5 3 4

held in check, this palladium(0)-catalyzed substitution reaction ought to afford optically active *cis*-4-substituted-2-cyclopenten-1-ols (**4**) of deducible absolute configuration.

Indeed, it was found that substitution of the allylic acetoxy function occurred as predicted when optically active **5** reacted with catalytic tetrakis(triphenylphosphine)palladium(0) (2.3–15 mol %) and excess nucleophilic anion, which was prepared separately by prior treatment of the corresponding neutral species with sodium hydride. As Table I indicates, this stereospecific displacement reaction leading to optically active **4** appears to be quite general since it has been successfully carried out with carbon, oxygen, sulfur, and nitrogen nucleophiles. The yields range from fair to excellent. The cis-1,4 stereochemistry was assigned on the basis of distinctive ^1H NMR signals[11] and in two instances by comparison of (+)-**4a** and (+)-**4e** with their known[4,5] racemic counterparts. As expected, polarimetric measurement confirmed that all products were optically active.

The attractiveness of this procedure is enhanced by the ready availability of optically active starting material. Either antipodal form of **5** is procurable in gram quantities via a stereoselective enzymatic hydrolysis[12,13] of meso diester **6** (Scheme II). The (+)-rotomer of **5**, (1*S*,4*R*)-*cis*-4-acetoxy-1-hydroxycyclopent-2-ene, is secured in >99% ee by exposure of **6** to the electric eel enzyme acetyl cholinesterase,[12] while the (−)-rotomer is obtained in 98% ee by the action of pig liver esterase.[13] However, because our long-term goal remains the development of new routes to nucleoside analogues,[14] only the dextrorotomer of **5**, progenitor to (*S*)-hydroxy derivatives, was utilized in this investigation.

The introduction of a third stereogenic center in adducts **4c** and **4d** (entries 3 and 4) led to the expected mixture of diastereomers which were inseparable by column chromatography. These isomeric mixtures are still serviceable since by simple chemical manipulation they may be transformed into enantiomerically pure derivatives. For instance, diastereomers **4c** smoothly underwent reductive desulfonation[15] with sodium amalgam to afford in 68% yield the (+)-ester **7**, a useful cyclopentanoid[16] not directly available from **5**.



7

Of special note are adducts **4g,h** (entries 7 and 8), which are derived from sodium azide and potassium phthalimide, respectively. Since the two nitrogen nucleophiles are the synthetic equivalent of NH_2^-, their unmasking in **4g** and **4h** provides easy access to biologically important cyclopentylamines. The potassium phthalimide reaction[17] proved superior to sodium azide[18] both in terms of yield and stereocontrol. Whereas **4h** was homogeneous by ^1H NMR, **4g** was determined to be a 4:1 mixture of the cis-1,4 and trans-1,4 adducts. Interestingly, when the hydroxyl group on substrate **5** was replaced with a nitromethyl substituent, the analogous sodium azide reaction proceeded in good yield with high stereoselectivity.

Stereorandomization of allyl acetates is known[19] to occur in the presence of palladium(0) catalysts and may be responsible for the cis and trans isomers in **4g**. To insure

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against the remote possibility that (+)-**5** has undergone partial racemization, a chiral shift reagent study[20] on compound **4a** was undertaken. Treatment of racemic **4a** with tris[3-(heptafluoropropylhydroxymethylene)-(+)-camphorato]europium(III) (Eu(hfc)$_3$) caused the two absorptions ordinarily assigned to the diastereotopic carbomethoxy protons to split into four new peaks. In contrast, Eu(hfc)$_3$ complexation of (+)-**4a** under the identical conditions yielded no new absorptions. However, when racemic **4a** was added to the NMR tube containing the Eu(hfc)$_3$ and (+)-**4a** complex, multiple peaks were regenerated. It can be inferred from these data that the sample's optical purity is probably quite high.

In summary, a generalized approach to the enantioselective preparation of various highly functionalized cyclopentanoids has been offered. We believe compounds **4a–h** will find their niche in organic synthesis. The scope and limitations of this methodology are still under investigation.

Experimental Section

Reactions were carried out in flame-dried glassware under a positive nitrogen pressure. Reagents and solvent transfers were made with oven-dried syringes, needles, and cannulas. Tetrahydrofuran was continuously distilled from a midnight blue solution of sodium benzophenone ketyl. With the exception of sodium azide (Sigma Chemical Co.) all reagents were purchased from Aldrich Chemical Co. Sodium hydride was used as a 60% dispersion in oil and washed three times with pentane prior to use. Dimethyl malonate, phenol, thiophenol, methyl (phenylsulfonyl)acetate, methyl acetoacetate, and 2,4-pentanedione were distilled under nitrogen. All chromatography solvents, tetrakis(triphenylphosphine)palladium(0), and triphenylphosphine were used as received. R_f values refer to the thin-layer chromatograms developed on Baker precoated silica gel Si 250F plates (0.25-mm thickness) visualized with ethanolic anisaldehyde reagent. Column chromatography separations were carried out on Baker silica gel (40–140 mesh). Chromatographed products were distilled bulb-to-bulb on a Büchi Kugelrohr apparatus and submitted to Desert Analytics, Tucson, AZ, for elemental analysis. Melting points were taken in open-ended capillary tubes on a Thomas-Hoover instrument and are uncorrected. The reported boiling points refer to air bath temperatures during bulb-to-bulb distillation.

Optical rotations at the sodium D line were measured in a 1-cm^3 water-jacketed microcell on a Perkin-Elmer Model 241 or JASCO DIP-360 digital polarimeter. The JASCO instrument was recently calibrated against NBS standard reference material 17d (sucrose) and was found to have an accuracy of 0.1%. The chloroform used as solvent for the optical rotation studies was first passed through a plug of aluminum oxide (neutral, activity grade I). Proton and carbon NMR spectra were obtained in $CDCl_3$ at 200.13 and 50.32 MHz, respectively. Infrared spectra were recorded as liquid films for oils and in KBr disks for solids on a Beckman Instruments FT 2100 spectrophotometer. High-resolution mass spectral determinations were performed by the Midwest Center for Mass Spectrometry.

General Procedure for the Preparation of Optically Active Cyclopentanoids. (+)-(1*R*,4*S*)-Dimethyl (4-Hydroxy-2-cyclopenten-1-yl)malonate (4a). To a room-temperature solution of (+)-(1*S*,4*R*)-*cis*-4-acetoxy-1-hydroxycyclopent-2-ene ((+)-**5**, >99% ee; 122 mg, 0.86 mmol), triphenylphosphine (35 mg, 15 mol %), and tetrakis(triphenylphosphine)palladium(0) (51 mg, 5 mol %) in dry THF (1.75 mL) was added a suspension of sodium dimethyl malonate previously prepared by reaction of dimethyl malonate (0.20 mL, 1.75 mmol) with 67.8 mg of 60% sodium hydride (40.7 mg, 1.7 mmol) in THF (3.8 mL). The flask was fitted with a cold finger condenser and purged with N_2. The flask was immediately immersed in an oil bath preheated to 50 °C and allowed to stir until the reaction was judged complete (usually under an hour) by TLC analysis (1:1 hexane–ethyl acetate, R_f 0.36). Next, the reaction mixture was passed through a SiO_2 plug (10 g) layered with anhydrous $MgSO_4$ (1 g) with purified ether (50 mL; this step removes suspended materials and some of the catalyst). After concentration of the filtrate under vacuum, the pale yellow residue was chromatographed over SiO_2 (57 g) with hexane–ethyl acetate (1:1; 600 mL) as the eluent. Solvent removal afforded 184 mg (86% yield) of the dimethyl malonate adduct **4a** as a clear colorless oil: $[\alpha]^{22}_D$ +18° (*c* 2.4, $CHCl_3$); bp (bulb-to-bulb) 90–98 °C at 0.15 mmHg; ^{1}H NMR δ 1.57 (dt, J = 14.5 and 3.6 Hz, 1 H, β-CH_2), 2.20 (br d, 1 H, O*H*), 2.55 (ddd, J = 14.5, 8.6, and 7.7 Hz, 1 H, α-CH_2), 3.25 (m, 1 H, C*H*CH(COOCH$_3$)$_2$), 3.49 (d, J = 7.3 Hz, 1 H, C*H*(COOCH$_3$)$_2$), 3.72 and 3.73 (2 s, 2 × 3 H, COOCH_3), 4.76 (m, 1 H, C*H*OH), 5.82 and 5.90 (2 m, 2 × 1 H, C*H*=C*H*); ^{13}C NMR δ 37.8, 44.1, 52.36, 52.39, 56.4, 76.8, 134.4, 135.9, 168.9, 169.1; IR (neat) 3409 (OH), 1736 (C=O), 758 cm^{-1}. Anal. Calcd for $C_{10}H_{14}O_5$: C, 56.07; H, 6.59. Found: C, 56.23; H, 6.79.

(−)-3-[(1*R*,4*S*)-4-Hydroxy-2-cyclopenten-1-yl]-2,4-pentanedione (4b): colorless oil; 78% yield; R_f 0.22 (1:1 hexane–ethyl acetate); $[\alpha]^{21}_D$ −0.52° (*c* 1.92, $CHCl_3$); bp (bulb-to-bulb) 105 °C at 0.15 mmHg; ^{1}H NMR δ 1.28 (dt, J = 14.0 and 4.1 Hz, 1 H, β-CH_2), 2.00 (br s, 1 H, O*H*), 2.18 and 2.19 (2 s, 2 × 3 H, COCH_3), 2.46 (ddd, J = 14.0, 8.0, and 7.4 Hz, 1 H, α-CH_2), 3.32 (m, 1 H, C*H*CH(COCH$_3$)$_2$), 3.70 (d, J = 9.8 Hz, 1 H, C*H*(COCH$_3$)$_2$), 4.80 (m, 1 H, C*H*OH), 5.71 and 5.88 (2 m, 2 × 1 H, C*H*=C*H*); IR (neat) 3391 (OH), 1719 (C=O), 725 cm^{-1}. Anal. Calcd for $C_{10}H_{14}O_3$: C, 65.92; H, 7.74. Found: C, 65.68; H, 7.79.

(+)-(2*R*,*S*)-Methyl 2-[(1*R*,4*S*)-4-Hydroxy-2-cyclopenten-1-yl]-2-(phenylsulfonyl)acetate (4c): pale yellow oil; 97% yield; R_f 0.22 (1:1 hexane–ethyl acetate); $[\alpha]^{21}_D$ +16.8° (*c* 1.19, $CHCl_3$); bp (bulb-to-bulb) 120–140 °C at 0.125 mmHg; ^{1}H NMR δ 1.68 (dt, J = 14.5 and 4.0 Hz, 0.5 H, β-CH_2), 1.80 (dt, J = 14.3 and 4.5 Hz, 0.5 H, β-CH_2) 1.91 (overlapping br s, 1 H, O*H*), 2.49 (ddd, J = 14.5, 8.8, and 8.5 Hz, 0.5 H, α-CH_2), 2.62 (ddd, J = 14.3, 8.1, and 8.0 Hz, 0.5 H, α-CH_2), 3.35 (m, 1 H, C*H*CHCO$_2$CH$_3$), 3.54 (s, 1.5 H, CO$_2$CH_3), 3.57 (s, 1.5 H, CO$_2$CH_3), 4.00 (d, J = 8.5 Hz, 0.5 H, C*H*SO$_2$Ph(*S**)), 4.10 (d, J = 7.3 Hz, 0.5 H, C*H*SO$_2$Ph(*R**)), 4.77 (m, 1 H, C*H*OH), 5.69 (m, 0.5 H, C=C*H*), 5.93 (m, 1 H, C=C*H*), 6.06 (m, 0.5 H, C=C*H*), 7.51–7.90 (m, 5 H, Ph); IR (neat) 3430 (OH), 1738 (C=O), 1311 and 1146 (SO$_2$) cm^{-1}; MS m/z (relative intensity) 155 (M$^+$ − SO$_2$Ph (23)), 137 (37), 77 (100); HRMS calcd for $C_{14}H_{15}O_4S$ (M$^+$ − OH) 279.0691, found 279.0696.

(+)-(2*R*,*S*)-Methyl 2-[(1*R*,4*S*)-4-Hydroxy-2-cyclopenten-1-yl]-3-oxobutanoate (4d): colorless oil; 91% yield; R_f 0.22 (1:1 hexane–ethyl acetate); $[\alpha]^{21}_D$ +18.4° (*c* 4.05, $CHCl_3$); bp (bulb-to-bulb) 90–120 °C at 0.125 mmHg; ^{1}H NMR δ 1.37 (dt, J = 14.3 and 3.8 Hz, 0.5 H, β-CH_2), 1.50 (dt, J = 14.3 and 3.7 Hz, 0.5 H, β-CH_2), 2.04 (br s, 1 H, O*H*), 2.24 (s, 3 H, Ac), 2.52 (ddd, J = 14.3, 8.3, and 7.7 Hz, 1 H, α-CH_2), 3.27 (m, 1 H, C*H*CHCO$_2$CH$_3$), 3.55 (overlapping d, J = 8.6 Hz, 0.5 H, CHC*H*CO$_2$CH$_3$), 3.57 (overlapping d, J = 8.6 Hz, 0.5 H, CHC*H*CO$_2$CH$_3$), 3.73 and 3.74 (2 s, 3 H, CO$_2$CH_3), 4.78 (m, 1 H, C*H*OH), 5.77–5.92 (m, 2 H, C*H*=C*H*); IR (neat) 3425 (OH), 1738 (C=O), 738 cm^{-1}. Anal. Calcd for $C_{10}H_{14}O_4$: C, 60.60; H, 7.12. Found: C, 60.60; H, 7.08.

(+)-(1*S*,4*R*)-4-Phenoxy-2-cyclopenten-1-ol (4e): colorless solid; 90% yield; R_f 0.50 (1:1 hexane–ethyl acetate); $[\alpha]^{21}_D$ +13.4° (*c* 2.26, $CHCl_3$); mp 45.7–46.3 °C; ^{1}H NMR δ 1.78 (dt, J = 14.3 and 3.8 Hz, 1 H, β-CH_2), 2.15 (br s, 1 H, O*H*), 2.86 (overlapping dt, J = 14.3 and 7.0 Hz, 1 H, α-CH_2), 4.75 (m, 1 H, C*H*OH), 5.10 (m, 1 H, C*H*OPh), 6.14 (br s, 2 H, C*H*=C*H*), 6.93 and 7.27 (2 m, 5 H, Ph); IR (KBr) 3345 (OH), 1239 (C–O–C), 753 cm^{-1}. Anal. Calcd for $C_{11}H_{12}O_2$: C, 74.98; H, 6.86. Found: C, 75.16; H, 6.82.

(+)-(1*S*,4*R*)-4-(Phenylthio)-2-cyclopenten-1-ol (4f): colorless oil; 86% yield; R_f 0.51 (1:1 hexane–ethyl acetate); $[\alpha]^{21}_D$ +99.0° (*c* 3.19, $CHCl_3$); bp (bulb-to-bulb) 85–90 °C at 0.10 mmHg; ^{1}H NMR δ 1.00 (br s, 1 H, O*H*), 1.80 (dt, J = 14.9 and 2.7 Hz, 1 H, β-CH_2), 2.70 (dt, J = 15.0 and 7.7 Hz, 1 H, α-CH_2), 4.08 (m, 1 H, C*H*SPh), 4.64 (m, 1 H, C*H*OH), 5.94 (m, 2 H, C*H*=C*H*), 7.31 (m, 5 H, Ph); ^{13}C NMR δ 41.2, 76.3, 127.5, 128.9, 132.7, 134.7, 135.2, and 135.4; IR (neat) 3366 (OH), 1479, 743 cm^{-1}. Anal. Calcd for $C_{11}H_{12}OS$: C, 68.71; H, 6.29; S, 16.67. Found: C, 68.72; H, 6.35; S, 16.45.

(+)-(1*S*,4*R*)-4-Azido-2-cyclopenten-1-ol (4g) was prepared by combining an aqueous solution (0.9 mL) of NaN_3 (56.7 mg, 0.87 mmol) with a solution of (+)-**5** (103 mg, 0.73 mmol) and

(20) Wenzel, T. J. *NMR Shift Reagents*; CRC Press: Boca Raton, FL, 1987; Chapter 3.

$Pd(PPh_3)_4$ (84 mg, 0.073 mmol) in THF (1.5 mL) and heating for 50 min in a 45 °C oil bath. The reaction was quenched by the addition of brine. The aqueous phase was repeatedly extracted with ether, and the combined organic phase was dried over $MgSO_4$, filtered, and concentrated under reduced pressure. The crude material (96 mg) was chromatographed over SiO_2 (14 g) with hexane–ethyl acetate (2:1) to provide a 4:1 ratio of adduct **4g** and its trans-1,4 isomer (40 mg, 44% yield). Although the dark yellow oil is unstable, it tolerates bulb-to-bulb distillation temperatures of 40–58 °C at 0.10 mmHg: R_f 0.31 (2:1 hexane–ethyl acetate); $[\alpha]^{26}_D$ +146.4° (*c* 1.725, $CHCl_3$); ^1H NMR δ 1.66 (dt, *J* = 14.6 and 3.9 Hz, 1 H, β-CH_2), 1.70 (overlapping br s, 1 H, O*H*), 2.72 (overlapping dt, *J* = 14.6 and 7.3 Hz, 1 H, α-CH_2), 4.22 (m, 1 H, C*H*N_3), 4.74 (m, 1 H, C*H*OH), 5.92 and 6.09 (2 m, 2 × 1 H, C*H*=C*H*); ^{13}C NMR δ 40.0, 64.6, 75.0, 132.1, 138.0; IR (neat) 3327 (OH), 2947, 2108 (N_3) cm^{-1}.

(+)-(1*S*,4*R*)-4-Phthalimido-2-cyclopenten-1-ol (4h) was prepared from the commercially available potassium phthalimide salt. The crude product was chromatographed over SiO_2 with methylene chloride–methanol–ammonium hydroxide (82:15:3) to provide a colorless solid in 74% yield. Recrystallization from ether afforded crystals of uniform melting point: mp 69–71 °C; R_f 0.47 (1:1 hexane–ethyl acetate); $[\alpha]^{26}_D$ +276° (*c* 1.03, $CHCl_3$); ^1H NMR δ 1.97 (br d, *J* = 15.4 Hz, 1 H, β-CH_2), 2.82 (ddd, *J* = 15.4, 9.6 and 7.8 Hz, 1 H, α-CH_2), 4.07 (br s, 1 H, O*H*), 4.74 (m, 1 H, C*H*OH), 5.23 (m, *J* = 9.6 and 2.2 Hz, 1 H, C*H*-N), 5.72 (dd, *J* = 5.5 and 2.5 Hz, 1 H, C=C*H*), 6.22 (m, *J* = 5.5, 1 H, C=C*H*), 7.65–7.90 (m, 4 H, Ar); ^{13}C NMR δ 38.2, 53.0, 75.8, 123.3, 130.1, 131.8, 134.2, 138.4, 168.4; IR (KBr) 3398 (OH), 1697 (C=O), 1380, 720 cm^{-1}. Anal. Calcd for $C_{13}H_{11}O_3N$: C, 68.12; H, 4.84; N, 6.11. Found: C, 67.81; H, 4.81; N, 6.31.

(+)-(1*S*,4*S*)-Methyl (4-Hydroxy-2-cyclopenten-1-yl)acetate (7). To an ice-cold suspension of anhydrous Na_2HPO_4 (42 mg) and adduct **4c** (421 mg, 1.42 mmol) in dry MeOH (8.0 mL) was added approximately 0.5% Na(Hg) previously prepared by mixing mercury (10 g) with sodium (50 mg, 2.17 mmol). The stirred reaction mixture was held at 0 °C until TLC analysis (R_f 0.22; 1:1 hexane–ethyl acetate) indicated the starting material was consumed (1.5 h). The methanolic solution was transferred to a separatory funnel, diluted with ether, and washed with water. The aqueous phase was sequentially extracted with ether until no product remained (TLC) in the water layer. The combined organic extracts were dried over $MgSO_4$, filtered, and concentrated under reduced pressure. The crude residue was chromatographed over SiO_2 (50 g, 1.5:1 hexane–ethyl acetate). Evaporation of solvent under vacuum provided 150 mg (67% yield) of oil. Subsequent bulb-to-bulb distillation between 80 and 100 °C at 0.15 mmHg afforded 128 mg of colorless material for analysis: R_f 0.40 (1:1 hexane–ethyl acetate); $[\alpha]^{22}_D$ +15.3° (*c* 2.29, $CHCl_3$); ^1H NMR δ 1.36 (dt, *J* = 13.9 and 7.8 Hz, 1 H, β-CH_2), 2.49 (m, *J* = 6.4 Hz, 2 H, CHCH_2CO_2), 2.53 (overlapping m, *J* = 13.9 and 4.8 Hz, 1 H, α-CH_2), 2.57 (overlapping br s, 1 H, O*H*), 2.95 (m, 1 H, C*H*CH_2CO_2), 3.65 (s, 3 H, CH_3), 4.78 (m, 1 H, C*H*OH), 5.79 (br s, 2 H, C*H*=C*H*); IR (neat) 3425 (OH), 2954, 1718 (C=O), 1439 cm^{-1}; MS *m/z* (relative intensity) 156 (M^+, 0.2), 138 (18), 96 (33), 83 (80), 79 (100); HRMS calcd for $C_8H_{12}O_3$ (M^+) 156.0786, found 156.0784.

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Note Added in Proof: A recent paper by Oppolzer et al. (*Tetrahedron Lett.* **1988**, *29*, 4705) reports a palladium-catalyzed substitution reaction on (1*R*,4*R*)-*trans*-1-acetoxy-4-chlorocyclopent-2-ene by the anion of a substituted malonate. Replacement of the allylic chloride proceeds with retention.

Registry No. **4a**, 120052-50-8; **4b**, 119971-14-1; **4c** (isomer 1), 119971-15-2; **4c** (isomer 2), 120052-52-0; **4d** (isomer 1), 119971-16-3; **4d** (isomer 2), 120052-53-1; **4e**, 120052-51-9; **4f**, 119971-17-4; (1*S*,4*R*)-**4g**, 120056-07-7; (1*S*,4*S*)-**4g**, 120056-08-8; **4h**, 119971-18-5; (+)-**5**, 60410-16-4; **7**, 120052-54-2; $CH_2(COCH_3)_2$, 123-54-6; $PhSO_2CH_2CO_2CH_3$, 34097-60-4; $CH_3COCH_2CO_2CH_3$, 105-45-3; PhOH, 108-95-2; PhSH, 108-98-5; PthK, 1074-82-4; sodium dimethyl malonate, 18424-76-5.

Low Temperature Nuclear Magnetic Resonance Study of the Acylation of a Stabilized Ylide: C- vs O-Acylation

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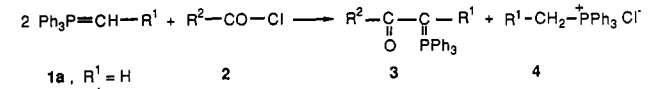
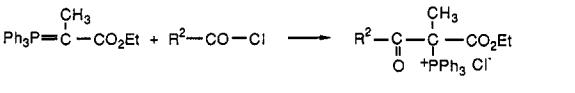
Acyl phosphoranes[1-4] and acyl phosphonium salts[4,5] produced from the reaction of an acid chloride with a phosphorus ylide continue to find use in organic synthesis. When ylides of the type **1** are used, a transylidation reaction occurs to produce the phosphonium salt **4** together with the synthetically useful acyl phosphorane **3**. Alternatively, the transylidation step can be suppressed by using low temperatures or by using substituted ylides, e.g., **5** and the thus-obtained phosphonium salts, e.g., **6a**, can be isolated.[4]



1a, R^1 = H; **1b**, R^1 = CH_3; **1c**, R^1 = Ph; **1d**, R^1 = CO_2Et

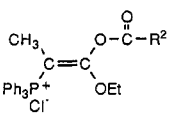
2 **3** **4**

We now show by low-temperature NMR that the reaction of ylide **5** with an acid chloride, e.g., acetyl chloride, initially yields the unexpected and labile *O*-acyl phosphonium salt, e.g., **7a**, which readily rearranges to the corresponding *C*-acyl phosphonium salt, e.g., **6a**, on standing. Treatment of the latter phosphonium salt with either a second equivalent of ylide[4] or triethylamine[5] then yields the expected allene product.



5

6a, R^2 = CH_3; **6b**, R^2 = $CH_2CH_2CO_2Me$; **6c**, R^2 = $CH_2CH_2CO_2CH_2Ph$



7a, R^2 = CH_3; **7b**, R^2 = $CH_2CH_2CO_2Me$; **7c**, R^2 = $CH_2CH_2CO_2CH_2Ph$

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