Supporting Information Experimental

Phosphine-Catalyzed Asymmetric Synthesis of *β*-Lactones from Ketoketenes and Aromatic Aldehydes

Mukulesh Mondal[a], Ahmad A. Ibrahim[a], Kraig A. Wheeler[b] and Nessan J. Kerrigan[a]*

[a]Department of Chemistry, Oakland University, 2200 N. Squirrel Road, Rochester, MI 48309-4477, USA

[b]Department of Chemistry, Eastern Illinois University, 600 Lincoln Avenue, Charleston, IL 61920-3099, USA

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General Information.

Diethyl ether and THF were freshly distilled from benzophenone ketyl radical under nitrogen prior to use. Dichloromethane was dried using a calcium hydride stills and *N*,*N*-dimethylethylamine was distilled from calcium hydride under nitrogen.[1] Tri-*n*-butylphosphine, (*R*)-BINAPHANE, lithium iodide, benzaldehyde, 2-chlorobenzaldehyde, 4-chlorobenzaldehyde 4-nitrobenzaldehyde, pentanal, hydrocinnamaldehyde, cinnamaldehyde, potassium hydroxide and sodium azide were purchased from Aldrich Chemical Co. Iatrobeads (Bioscan, 6RS-8060, 60μM particle size). TLC plates (Sorbent Technologies, UV254, 250μM) were used as received. Methylphenylketene, ethylphenylketene, *n*-butylphenylketene, methyl-4-tolylketene, methyl-2-tolylketene diphenylketene, and ethyl-*N*-methylindolylketene were prepared according to literature procedures.[2-4]

NMR spectra were recorded on Bruker DPX Avance 200 spectrometer (200 MHz for ^{1}H and 50 MHz for ^{13}C) and on Bruker Biospin AG 400 spectrometer (400 MHz for ^{1}H and 100 MHz for ^{13}C). NMR chemical shifts were reported relative to TMS (0 ppm) for ^{1}H and to $CDCl_3$ (77.23 ppm) for ^{13}C spectra. High resolution mass spectra were obtained from the College of Sciences Major Instrumentation Cluster at Old Dominion University. Optical rotations were measured on Rudolph DigiPol 781 TDV automatic polarimeter. IR spectra were recorded on a Bio Rad FTS-175C spectrometer.

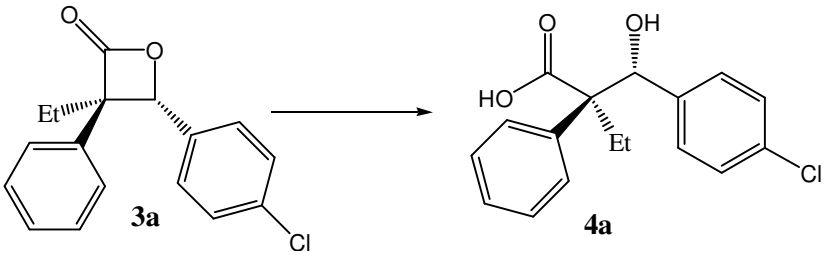
Analytical high performance liquid chromatography (HPLC) was performed using a Daicel Chiralpak AD column (0.46 cm x 25 cm) and an AS-H column (0.46 cm x 25 cm) (Daicel Chemical Ind., Ltd.) on a Perkin Elmer 235C instrument attached with diode array detector (deuterium lamp, 190-600 nm) with HPLC-grade isopropanol and hexanes as the eluting solvents.

Compound Characterization and Determination of Diastereomeric Ratios and Enantiomeric Excesses: Most of the *β*-lactones **3** appear to be unstable during attempted flash column chromatographic purification. The phosphine catalyst was removed by passing a dilute solution of the reaction mixture through a plug column of neutral silica (see procedure **A**), without causing decomposition of the *β*-lactones **3** (obtained in 70-99% purity). In order to provide characterization data for all compounds, the impure *β*-lactones (<95% purity) were converted into the corresponding stable *β*-hydroxyacids **4** by treatment with aqueous KOH in THF. The *β*-hydroxyacids **4** were purified by flash column chromatography to provide pure samples for full characterization (see procedure **B**). Diastereomeric ratios were determined for the crude *β*-lactones **3a-n** either by integrating the tertiary C**H** resonances in ^{1}H NMR or by comparing the peak areas of HPLC data. Enantiomeric excesses were determined by assaying the crude *β*-lactones **3a-n** using chiral HPLC analysis (at λ=225 nm; details given for each compound). Authentic racemic samples for chiral HPLC analysis were generated through the PBu_3-catalyzed reaction (Procedure **A**).

Procedure A for *β*-lactone synthesis: To a stirring solution of aldehyde (0.34-1.02 mmol, 1.0-3.0 equiv.) and phosphine catalyst (PBu_3 or BINAPHANE) (0.034 mmol, 0.1 equiv.) in dichloromethane (0.40 mL) at −78 °C under nitrogen atmosphere, was added a solution of ketoketene (0.34 mmol, 1.0 equiv.) in dichloromethane (0.40 mL) [overall ketene concentration 0.43M] over a period of 4 h using syringe pump and stirring was continued at −78 °C. After 4 h, the reaction was allowed to warm up to room temperature gradually over 4 h in the cooling bath (total reaction time = 12 h). The reaction was then quenched by addition of dilute H_2O_2 (0.002 mL, 0.038 mmol, 0.1 equiv), diluted with 10% EtOAc/hexane (10 mL) and dichloromethane (2.5 mL) [for ~100 mg reaction mixture] and the crude solution was passed through a plug column of

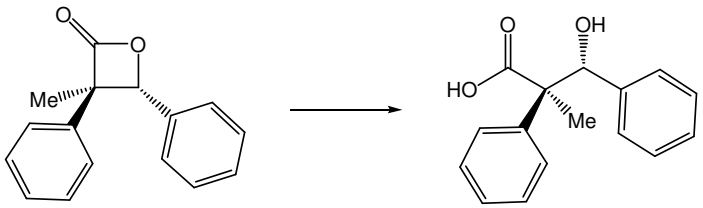
neutral silica (iatrobeads, 2 × 2 cm, 5 g) [50 x reaction mixture]. The plug column was eluted with 10% EtOAc/Hexane solvent system (100 mL), and the solvent was removed under vacuum to furnish the desired *β*-lactone **3a-n** with 70–>99% purity (as determined by GC-MS or ^{1}H NMR analysis).

Procedure B for *β*-hydroxyacid synthesis: A stirring mixture of *β*-lactone **3** (0.30 mmol, 1.0 equiv.) and aqueous KOH (1.0 N; 0.60 mL, 0.60 mmol, 2.0 equiv.) in THF (1.2 mL) was heated to 60 °C in a sealed tube for 6-12 h. After cooling, the reaction mixture was diluted with water (2 mL), extracted with dichloromethane (30 mL) to remove undesired product. The aqueous layer was acidified with HCl (10%), extracted with dichloromethane (20 mL x 3) and combined extracts were washed with brine and dried over Na_2SO_4. Removal of the solvent under vacuum followed by column chromatographic purification using hexane/EtOAc solvent system furnished the desired *β*-hydroxyacid. Isolated yields are determined for two steps from the relevant ketoketene.



(*3R,4R*)-4-(4-Chlorophenyl)-3-ethyl-3-phenyloxetan-2-one (3a): Following procedure **A**, ethylphenylketene (51 mg, 0.35 mmol) was added to 4-chlorobenzaldehyde (49 mg, 0.35 mmol) and (*R*)-BINAPHANE (25 mg, 0.035 mmol). **3a** was obtained as a colorless oil (94 mg, 94% yield, 96% purity by ^{1}H NMR), dr 93:7 (by HPLC); HPLC analysis: 64% ee [Daicel Chiralpak AS-H column; 0.5 mL/min; solvent system: 10% isopropanol in hexane; retention times: 11.6 min (major), 16.7 min (minor)]; $[\alpha]_D^{24}$ = −34.0 (c = 0.10, $CHCl_3$); IR (thin film): 2933, 1827, 1092 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$, TMS) δ 7.40-7.28 (m, 9H), 5.58 (s, 1H), 1.70-1.61 (m, 1H), 1.45-1.18 (m, 1H), 0.58 (t, J = 6.0 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 171.8, 137.5, 135.0, 133.6, 129.3, 129.3, 128.2, 127.4, 126.5, 82.3, 68.8, 27.4, 8.5; MS (EI 70 eV) m/z 242, 227, 192. Satisfactory HRMS data was not obtained for **3a**, so it was converted to **4a** to provide full characterization data.

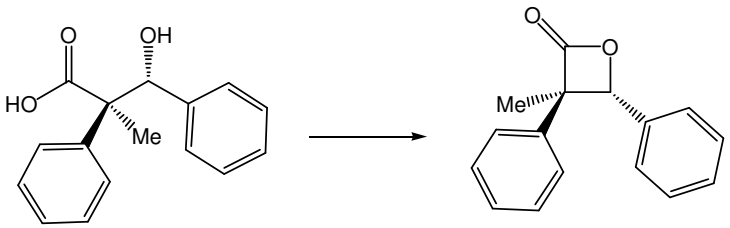
(*2R*)-2-((*R*)-(4-Chlorophenyl)hydroxymethyl)-2-phenylbutanoic acid (4a): Procedure **B** was followed employing **3a** (94 mg, 96% purity), aqueous KOH (0.63 mL, 0.63 mmol) and a reaction time of 6 hours. Elution with 25% EtOAc/hexane followed by solvent removal under reduced pressure yielded **4a** as a white gum (93 mg, 87% yield for two steps), dr 93:7 (by HPLC); $[\alpha]_D^{22}$ = −38.0 (c = 0.53, $CHCl_3$); IR (thin film): 2964, 2935, 1700 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$, TMS) δ 7.27-7.22 (m, 3H), 7.06-7.02 (m, 4H), 6.74-6.72 (d, J = 8.4 Hz, 2H), 5.26 (s, 1H), 2.11-2.02 (m, 1H), 1.90-1.80 (m, 1H), 0.98 (t, J = 7.4 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 179.9, 138.4, 137.2, 133.9, 129.2, 128.6, 128.1, 127.9, 127.9, 78.5, 60.7, 25.0, 10.1; (M^++Na) HRMS m/z calcd for $C_{17}H_{17}ClO_3Na$: 327.0758; Found: 327.0759.



3b **4b**

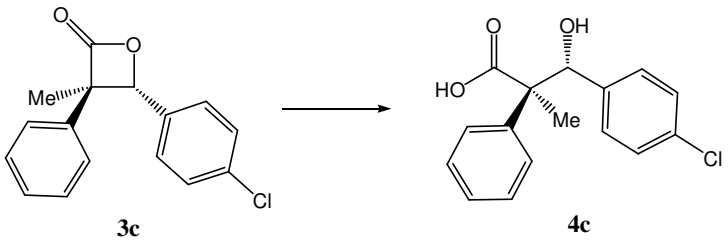
(3*R*,4*R*)-3-Methyl-3,4-diphenyloxetan-2-one (3b): Following procedure **A**, methylphenylketene (45 mg, 0.34 mmol) was added to benzaldehyde (36 mg, 0.34 mmol) and (*R*)-BINAPHANE (24 mg, 0.034 mmol). **3b** was obtained as colorless oil (80 mg, 90% purity by ^{1}H NMR), dr 96:4 (by ^{1}H NMR); HPLC analysis for **3b**: 79% ee [Daicel Chiralpak AS-H column; 0.5 mL/min; solvent system: 10% isopropanol in hexane; retention times: 12.7 min (major), 18.3 min (minor)].

(2*R*,3*R*)-3-Hydroxy-2-methyl-2,3-diphenylpropanoic acid (4b): Procedure **B** was followed employing **3b** (80 mg, 90% purity), aqueous KOH (0.60 mL, 0.60 mmol) and a reaction time 4 h. Elution with 20% EtOAc/hexane followed by solvent removal under reduced pressure yielded **4b** as white gum (76 mg, 87% yield for two steps), dr >96:4 (by ^{1}H NMR); $[\alpha]_D^{23}$ = −130.3 (c = 0.76, EtOAc); IR ($CHCl_3$): 3569, 3491, 3022, 1699 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$, TMS): δ 7.34-7.29 (m, 3H), 7.26-7.09 (m, 5H), 6.84 (d, J = 7.2 Hz, 2H), 5.48 (s, 1H), 1.60 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 182.1, 139.3, 138.3, 128.6, 127.9, 127.7, 127.6, 127.4, 127.0, 78.4, 56.5, 15.2; (M^++Na) HRMS m/z calcd for $C_{16}H_{16}O_3Na$: 279.0992; Found: 279.0990.



4b **3b**

For ee determination of **4b**, **4b** was recyclized to **3b**. Experimental procedure: To an ice-cooled stirring solution of **4b** (26 mg, 0.10 mmol) and triethylamine (30 mg, 0.30 mmol) in CH_2Cl_2 (0.6 mL), benzoylchloride (28 mg, 0.20 mmol) was added dropwise and stirring was continued for 1 h at 0 °C. Then the reaction mixture was passed through a plug column of neutral silica (like general procedure A), and the solvent was removed under vacuum to furnish the desired β-lactone **3b** (>99% purity) as a colorless oil (9 mg, 37% yield), dr >99:1 (by ^{1}H NMR); HPLC analysis: 79% ee [Daicel Chiralpak AS-H column; 0.5 mL/min; solvent system: 10% isopropanol in hexane; retention times: 13.0 min (major), 18.9 min (minor)]; $[\alpha]_D^{23}$ = −19.3 (c = 0.07, EtOAc); IR (Neat): 2925, 1832 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$, TMS): δ 7.33-7.51 (m, 10H), 5.73 (s, 1H), 1.26 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 172.9, 139.9, 135.0, 129.5, 129.1, 129.0, 128.2, 125.7, 83.0, 64.7, 20.5; (M^++Na) HRMS m/z calcd for $C_{16}H_{14}O_2Na$: 261.0886; Found: 261.0887.

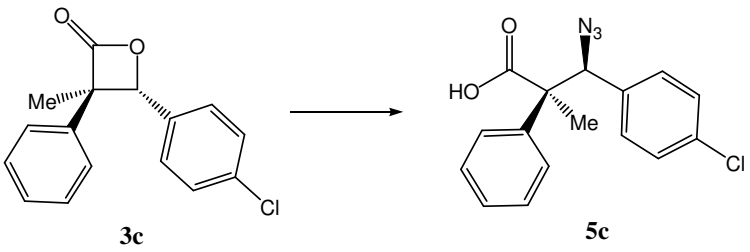


3c **4c**

(*3R,4R*)-4-(4-Chlorophenyl)-3-methyl-3-phenyloxetan-2-one (3c): Following procedure **A**, methylphenylketene (50 mg, 0.38 mmol) was added to 4-chlorobenzaldehyde (53 mg, 0.38 mmol) and (*R*)-BINAPHANE (25 mg, 0.038 mmol). **3c** was obtained as a colorless oil (80 mg, 90% purity by ^{1}H NMR), dr 95:5 (by ^{1}H NMR); HPLC analysis: 90% ee [Daicel Chiralpak AS-H column; 0.5 mL/min; solvent system: 10% isopropanol in hexane; retention times: 17.8 min (major), 27.1 min (minor)].

(2*R*,3*R*)-3-(4-Chloro-phenyl)-3-hydroxy-2-methyl-2-phenyl-propionic acid (4c): Procedure **B** was followed employing **3c** (80 mg, 90% purity), aqueous KOH (0.53 mL, 0.53 mmol) and a reaction time of 4 h. Elution with 25% EtOAc/hexane followed by solvent removal under reduced pressure yielded **4c** as a white gum (72 mg, 65% yield for two steps), dr 96:4 (by ^{1}H

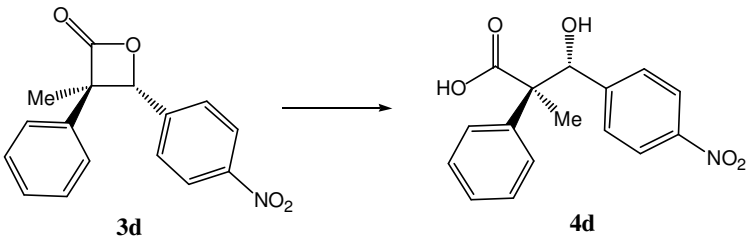
NMR); $[\alpha]_D^{23}$ = −130.0 (c = 0.42, $CHCl_3$); IR (thin film): 3441, 2631, 1699, 1090 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$, TMS) δ 7.28-7.22 (m, 3H), 7.13-7.09 (m, 2H), 6.97 (d, J = 12.0 Hz, 2H), 6.62 (d, J = 12.0 Hz, 2H), 5.36 (s, 1H), 1.47 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 181.8, 138.9, 136.8, 133.5, 129.0, 128.8, 128.2, 127.6, 127.0, 77.8, 56.5, 14.7; (M^++Na) HRMS m/z calcd for $C_{16}H_{15}ClO_3Na$: 313.0602; Found: 313.0600.



3c **5c**

(3*R*,4*R*)-4-(4-Chlorophenyl)-3-methyl-3-phenyloxetan-2-one (3c): Following procedure **A**, methylphenylketene (103 mg, 0.78 mmol) was added to 4-chlorobenzaldehyde 110 mg, 0.78 mmol) and (*R*)-BINAPHANE (55 mg, 0.078 mmol). **3c** was obtained as a colorless oil (202 mg, 90% purity by ^1H NMR), dr 95:5 (by ^1H NMR); HPLC analysis: 90% ee [Daicel Chiralpak AS-H column; 0.5 mL/min; solvent system: 10% isopropanol in hexane; retention times: 17.8 min (major), 27.1 min (minor)].

(2*R*,3*S*)-3-Azido-3-(4-Chlorophenyl)-3-methyl-2-phenylpropanoic acid (5c): Sodium azide (23 mg, 0.36 mmol) was added to a stirring solution of **3c** (50 mg, ~0.18 mmol) in DMSO (1.2 mL). The reaction vessel was sealed and heated to 65 °C for 48 h. After cooling, the reaction mixture was acidified with HCl (10%), and extracted with dichloromethane (20 mL x 3). The combined organics were washed with brine (20 mL x 3) and dried over Na_2SO_4. Removal of the solvent under vacuum followed by column chromatographic purification (15% EtOAc/ hexane) furnished the desired β-azido acid **5c** as a white gum (32 mg, 61% yield), dr >99:1 (by ^1H NMR); HPLC analysis: 90% ee [Daicel Chiralpak AD column; 0.5 mL/min; solvent system: 2% isopropanol in hexane; retention times: 27.3 min (major), 34.8 min (minor)]; $[\alpha]_D^{23}$ = −133.1 (c = 0.32, EtOAc); IR ($CHCl_3$): 3345, 3019, 2108, 1703, 1493, 1215 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$, TMS): δ 7.41-7.34 (m, 5H), 7.22 (d, J = 8.5 Hz, 2H), 6.96 (d, J = 8.5 Hz, 2H), 5.33 (s, 1H), 1.54 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 180.7, 137.4, 134.7, 134.4, 130.7, 128.4, 128.4, 128.3, 128.3, 70.8, 55.2, 19.2; (M^++Na) HRMS m/z calcd for $C_{16}H_{14}ClN_3O_2Na$: 338.0667; Found: 338.0665.

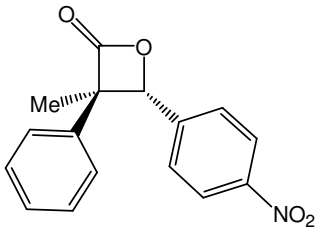


3d **4d**

(3*R*,4*R*)-3-Methyl-4-(4-nitrophenyl)-3-phenyloxetan-2-one (3d): Following procedure **A**, methylphenylketene (46 mg, 0.35 mmol) was added to 4-nitrobenzaldehyde (53 mg, 0.35 mmol) and (*R*)-BINAPHANE (24 mg, 0.035 mmol). Eluting with 20% EtOAc/hexane through a plug column of neutral silica followed by solvent removal under reduced pressure afforded **3d** as a colorless oil (90 mg, 80% purity by ^1H NMR), dr 95:5 (by ^1H NMR of **4d**); HPLC analysis: 92% ee [Daicel Chiralpak AS-H column; 1.0 mL/min; solvent system: 8% isopropanol in hexane; retention times: 22.4 min (major), 33.7 min (minor)].

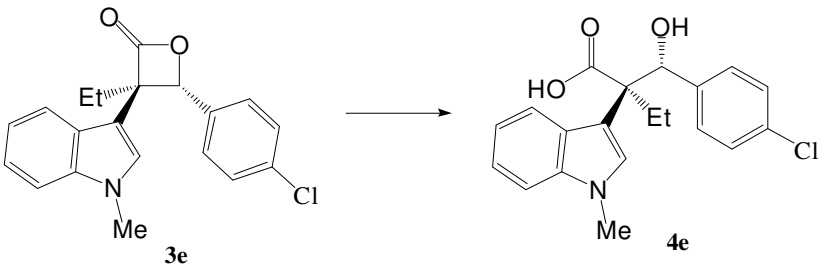
(2*R*,3*R*)-3-Hydroxy-2-methyl-3-(4-nitrophenyl)-2-phenylpropanoic acid (4d): Procedure **B** was followed employing **3d** (90 mg, 80% purity), aqueous KOH (0.51 mL, 0.51 mmol) and a reaction time 4 h. Elution with 20% EtOAc/hexane followed by solvent removal under reduced pressure yielded **4d** as a white gum (66 mg, 63% yield for two steps), dr 95:5 (by ^1H NMR); $[\alpha]_D^{25}$ = −126.0 (c = 0.44, EtOAc); IR ($CHCl_3$): 3553, 3021, 1695, 1521, 1349, 1216 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$, TMS): δ 7.91 (d, J = 8.8 Hz, 2H), 7.36-7.29 (m, 3H), 7.21-7.15 (m,

2H), 6.89 (d, J = 8.7 Hz, 2H), 5.56 (s, 1H), 1.56 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 182.0, 147.4, 145.8, 138.3, 129.1, 128.6, 128.5, 126.9, 122.4, 77.6, 56.4, 14.2; (M^++Na) HRMS m/z calcd for $C_{16}H_{15}NO_5Na$: 324.0842; Found: 324.0843.



(±)-3d

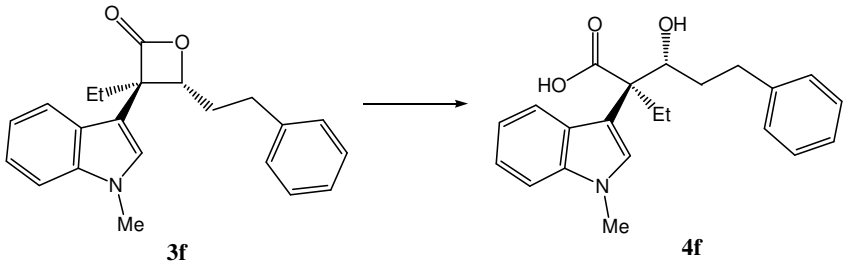
(±)-3-Methyl-4-(4-nitrophenyl)-3-phenyloxetan-2-one (3d): Following procedure **A**, methylphenylketene (44 mg, 0.33 mmol) was added to 4-nitrobenzaldehyde (50 mg, 0.33 mmol) and n-Bu_3P (7 mg, 0.033 mmol). Elution with 20% EtOAc/hexane through a plug column of neutral silica gel followed by recrystallization of the crude product from acetone/hexane afforded **(±)-3d** as a colorless solid (58 mg, 61% yield, >99% purity by ^{1}H NMR), dr >99:1 (by ^{1}H NMR); mp: 124-125 °C; IR ($CHCl_3$): 3021, 1835, 1526, 1350, 1216 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$, TMS): δ 8.36 (d, J = 8.5 Hz, 2H), 7.63 (d, J = 8.4 Hz, 2H), 7.51-7.44 (m, 4H), 7.43-7.37 (m, 1H), 5.80 (s, 1H), 1.27 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 171.7, 148.4, 142.2, 138.8, 129.7, 128.6, 126.7, 125.6, 124.4, 81.8, 65.5, 20.4.



3e **4e**

(*3R,4R*)-4-(4-Chlorophenyl)-3-ethyl-3-(1-methyl-1*H*-indol-3-yl)oxetan-2-one (3e): Folllowing procedure **A**, 1-methylindol-3-ylethylketene (72 mg, 0.36 mmol) was added to 4-chlorobenzaldehyde (50.6 mg, 0.36 mmol) and (*R*)-BINAPHANE (25 mg, 0.036 mmol). **3e** was obtained as a yellow oil (115 mg, 90% purity by ^{1}H NMR), dr 83:17 (by HPLC analysis); HPLC analysis: for major diastereoisomer >99% ee [Daicel Chiralpak AD column; 1 mL/min; solvent system: 2% isopropanol in hexane; retention times: 12.6 min (major), 14.0 min (minor)].

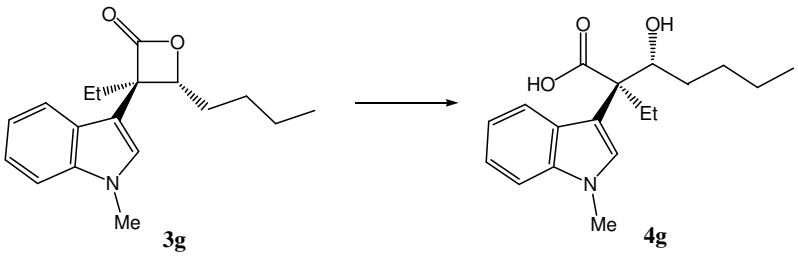
(*2R*)-2-((*R*)-(4-Chlorophenyl)hydroxymethyl)-2-(1-methyl-1*H*-indol-3-yl)butanoic acid (4e): Procedure **B** was followed employing **3e** (115 mg, 90% purity), aqueous KOH (0.61 mL, 0.61 mmol) and a reaction time of 11 hours. Elution with 25% EtOAc/hexane, followed by solvent removal under reduced pressure yielded **4e** as a yellow gum (97 mg, 75% yield for two steps), dr 83:17 (by ^{1}H NMR); $[\alpha]_D^{24} = -10.8$ (c = 0.06, $CHCl_3$); IR (thin film): 3420, 2918, 1646 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$, TMS) δ 7.56 (d, J = 8.0 Hz, 1H), 7.24 (d, J = 8Hz, 1H), 7.18 (s, 1H), 7.15 (d, J = 8.0 Hz, 1H), 7.03 (d, J = 8.0 Hz, 1H), 6.96 (d, J = 8.0 Hz, 2H), 6.57 (d, J = 8.0 Hz, 2H), 5.36 (s, 1H), 3.63 (s, 3H), 1.99-1.86 (m, 2H), 0.99 (t, J = 8.0 Hz , 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 180.2, 138.2, 137.3, 133.7, 129.7, 129.4, 127.7, 127.5, 122.2, 122.0, 119.4, 110.2, 109.8, 77.8, 57.5, 33.1, 27.0, 9.7; (M^++Na) HRMS m/z calcd for $C_{20}H_{20}ClNO_3Na$: 380.1024; Found: 380.1022.



3f **4f**

(3*R*,4*R*)-3-Ethyl-3-(1-methyl-1*H*-indol-3-yl)-4-(2-phenylethyl)-xetan-2-one (3f): Following procedure **A**, ethyl-*N*-methylindolylketene (45 mg, 0.23 mmol) was added to hydrocinnamaldehyde (93 mg, 0.69 mmol) and (*R*)-BINAPHANE (16 mg, 0.023 mmol). Eluting with 15% EtOAc/hexane through a plug column of neutral silica followed by solvent removal under reduced pressure afforded **3f** as a colorless oil (70 mg, 90% purity by ^{1}H NMR), dr >99:1 (by ^{1}H NMR); HPLC analysis: 97% ee [Daicel Chiralpak AS-H column; 0.5 mL/min; solvent system: 5% isopropanol in hexane; retention times: 19.8 min (minor), 21.0 min (major)].

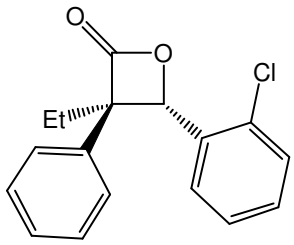
(2*R*,3*R*)-2-Ethyl-3-hydroxy-2-(1-methyl-1*H*-indol-3-yl)-5-phenylpentanoic acid (4f): Procedure **B** was followed employing **3f** (70 mg, 90% purity), aqueous KOH (0.38 mL, 0.38 mmol) and a reaction time of 17 h. Elution with 30% EtOAc/hexane followed by solvent removal under reduced pressure yielded **4f** as a light yellow gum (48 mg, 61% yield for two steps), dr >99:1 (by ^{1}H NMR); $[\alpha]_D^{25}$ = 2.4 (c = 0.19, EtOAc); IR ($CHCl_3$): 3457, 3018, 1704, 1217 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$, TMS): δ 7.61 (d, J = 8.0 Hz, 1H), 7.30-7.02 (m, 8H), 6.95 (s, 1H), 4.27 (dd, J = 10.6, 1.4 Hz, 1H), 3.72 (s, 3H), 2.87-2.77 (m, 1H), 2.65-2.53 (m, 1H), 2.35-2.09 (m, 2H), 1.87-1.76 (m, 1H), 1.49-1.37 (m, 1H), 0.86 (t, J = 7.5 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 180.1, 142.2, 137.4, 128.8, 128.7, 128.5, 127.0, 126.0, 121.8, 121.5, 119.6, 111.4, 109.7, 74.4, 56.7, 34.1, 33.1, 32.7, 28.0, 9.6; (M^++Na) HRMS m/z calcd for $C_{22}H_{25}NO_3Na$: 374.1727; Found: 374.1725.



3g **4g**

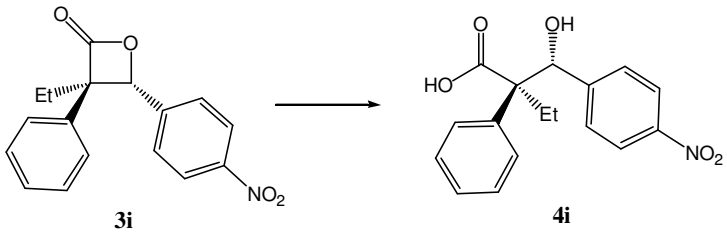
(3*R*,4*R*)-4-Butyl-3-ethyl-3-(1-methyl-1*H*-indol-3-yl) xetan-2-one (3g): Following procedure **A**, ethyl-*N*-methylindolylketene (46 mg, 0.23 mmol) was added to pentanal (60 mg, 0.69 mmol) and (*R*)-BINAPHANE (16 mg, 0.023 mmol). Eluting with 15% EtOAc/hexane through a plug column of neutral silica followed by solvent removal under reduced pressure afforded **3g** as a yellowish oil (62 mg, 90% purity by ^{1}H NMR), dr >99:1 (by ^{1}H NMR); HPLC analysis: 93% ee [Daicel Chiralpak AS-H column; 0.5 mL/min; solvent system: 5% isopropanol in hexane; retention times: 14.8 min (minor), 16.5 min (major)].

(2*R*,3*R*)-2-Ethyl-3-hydroxy-2-(1-methyl-1*H*-indol-3-yl)heptanoic acid (4g): Procedure **B** was followed employing **3g** (62 mg, 90% purity), aqueous KOH (0.40 mL, 0.40 mmol) and a reaction time of 20 h. Elution with 30% EtOAc/hexane followed by solvent removal under reduced pressure yielded **4g** as a light yellow gum (41 mg, 59% yield for two steps), dr >99:1 (by ^{1}H NMR); $[\alpha]_D^{24}$ = –2.7 (c = 0.09, EtOAc); IR ($CHCl_3$): 3535, 2957, 1702, 1216 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$, TMS): δ 7.67 (d, J = 8.2 Hz, 1H), 7.30 (d, J = 8.4 Hz, 1H), 7.21 (td, J = 8.2, 1.1 Hz, 1H), 7.16 (s, 1H), 7.07 (ddd, J = 8.1, 7.0, 1.0 Hz, 1H), 4.27 (dd, J = 10.5, 1.4 Hz, 1H), 3.78 (s, 3H), 2.40-2.19 (m, 2H), 1.56-1.40 (m, 2H), 1.34-1.05 (m, 4H), 0.94 (t, J = 7.2 Hz, 3H), 0.81 (t, J = 7.1 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 179.6, 137.5, 129.0, 127.0, 121.8, 121.6, 119.5, 111.5, 109.7, 75.7, 57.1, 33.1, 32.1, 28.8, 27.9, 22.7, 14.3, 9.8; (M^++Na) HRMS m/z calcd for $C_{18}H_{25}NO_3Na$: 326.1727; Found: 326.1726.



3h

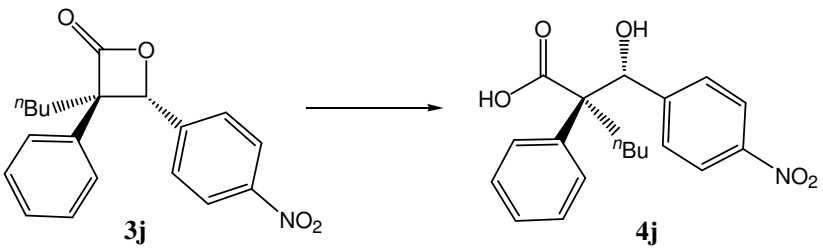
(*3R,4S*)-4-(2-Chlorophenyl)-3-ethyl-3-phenyloxetan-2-one (3h): Following procedure **A**, ethylphenylketene (57 mg, 0.39 mmol) was added to 2-chlorobenzaldehyde (55 mg, 0.39 mmol) and (*R*)-BINAPHANE (27 mg, 0.039 mmol). **3h** was obtained as a colorless oil (112 mg, >99%), dr 75:25 (by ^{1}H NMR); $[\alpha]_D^{24}$ = −84.0 (c = 0.15, $CHCl_3$); IR (thin film): 2973, 1829, 1109 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$, TMS) for the major diastereoisomer δ 7.58-6.92 (m, 9H), 5.91 (s, 1H), 2.42-2.30 (m, 2H), 1.02 (t, *J* = 14.8 Hz, 3H);); ^{13}C NMR (100 MHz, $CDCl_3$) for the major diastereoisomer δ 172.2, 134.5, 133.8, 132.0, 129.9, 129.5, 129.0, 128.5, 127.7, 127.6, 126.9, 79.5, 72.0, 30.4, 9.5; MS (EI=70 eV) m/z 242, 146, 117; (M^++Na) HRMS m/z calcd for $C_{17}H_{15}ClO_2Na$: 309.065; Found: 309.0657.



3i **4i**

(3*R*,4*R*)-3-Ethyl-4-(4-nitrophenyl)-3-phenyloxetan-2-one (3i): Following procedure **A**, ethylphenylketene (50 mg, 0.34 mmol) was added to 4-nitrobenzaldehyde (52 mg, 0.34 mmol) and (*R*)-BINAPHANE (24 mg, 0.034 mmol). Eluting with 20% EtOAc/hexane through a plug column of neutral silica followed by solvent removal under reduced pressure afforded **3i** as a colorless oil (93 mg, 75% purity by ^{1}H NMR), dr 80:20 (by HPLC); HPLC analysis: 87% ee (major isomer) [Daicel Chiralpak AS-H column; 0.5 mL/min; solvent system: 10% isopropanol in hexane; retention times for major isomer: 27.9 min (minor), 40.1 min (major)].

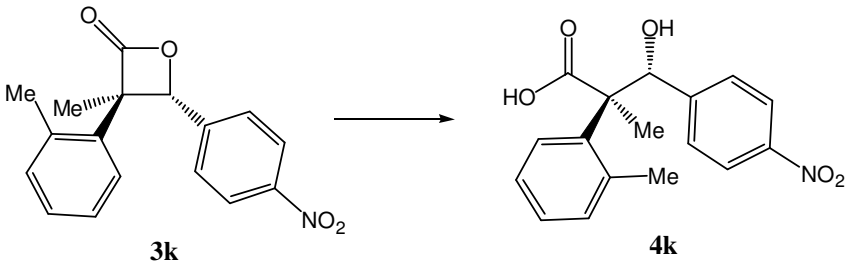
(2*R*)-2-((*R*)-(Hydroxy(4-nitrophenyl)methyl))-2-phenylbutanoic acid (4i): Procedure **B** was followed employing **3i** (93 mg, 75% purity), aqueous KOH (0.47 mL, 0.47 mmol) and a reaction time 4 of h. Elution with 20% EtOAc/hexane followed by solvent removal under reduced pressure yielded **4i** as a white gum (55 mg, 51% yield for two steps), dr >95:5 (by ^{1}H NMR); $[\alpha]_D^{24}$ = −47.5 (c = 0.32, EtOAc); IR ($CHCl_3$): 3522, 3025, 1703, 1522, 1349, 1218 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$, TMS): δ 7.95 (d, *J* = 9.0 Hz, 2H), 7.36-7.28 (m, 3H), 7.09-7.02 (m, 2H), 6.93 (d, *J* = 8.9 Hz, 2H), 5.45 (s, 1H), 2.22-1.91 (m, 2 H), 1.15 (t, *J* = 7.5 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 181.1, 147.5, 146.1, 138.1, 128.8, 128.7, 128.2, 128.0, 122.6, 78.7, 60.5, 24.1, 10.3; (M^++Na) HRMS m/z calcd for $C_{17}H_{17}NO_5Na$: 338.0999; Found: 338.0998.



3j **4j**

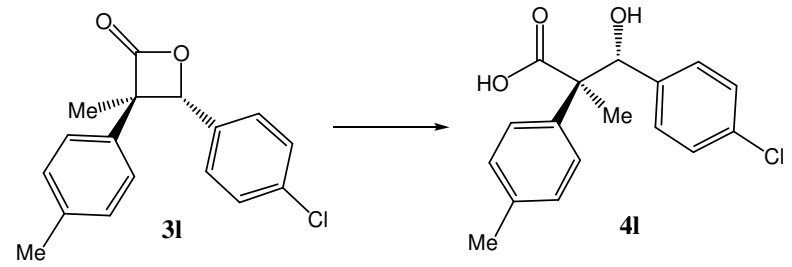
(3*R*,4*R*)-3-Butyl-4-(4-nitrophenyl)-3-phenyloxetan-2-one (3j): Following procedure **A**, *n*-butylphenylketene (62 mg, 0.35 mmol) was added to 4-nitrobenzaldehyde (54 mg, 0.35 mmol) and (*R*)-BINAPHANE (25 mg, 0.035 mmol). **3j** was obtained as a white solid (123 mg, 94% purity by GC/MS), dr 47:53 (by HPLC analysis); HPLC analysis: 61% ee for the major diastereoisomer [Daicel Chiralpak AS-H column; 0.5 mL/min; solvent system: 2% isopropanol in hexane; retention times: 20.8 min (major), 22.1 min (minor)] and 96% ee for the minor diastereoisomer [Daicel Chiralpak AS-H column; 0.5 mL/min; solvent system: 2% isopropanol in hexane; retention times: 25.5 min (minor), 29.8 min (major)].

(*2R*)-2-((*R*)-Hydroxy(4-nitrophenyl)methyl)-2-phenylhexanoic acid (4j): General procedure **B** was followed employing **3j** (123 mg, 94% purity), aqueous KOH (0.71 mL, 0.71 mmol) and a reaction time of 4 h. Elution with 30% EtOAc/hexane followed by solvent removal under reduced pressure yielded **4j** as a white gum (121 mg, 99% yield for two steps). **4j** was isolated in two fractions, the first fraction (105 mg) being a mixture of diastereoisomers and the second fraction (16 mg) being enriched with the major diastereoisomer. Fractions were characterized separately; IR (thin film): 3429, 2917, 1647 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$, TMS) for the mixture of diastereoisomers δ 7.89 (d, J = 8 Hz, 2H), 7.28-7.21 (m, 3H), 6.99-6.98 (m, 4H), 6.94 (d, J = 8.0 Hz, 2H), 6.84 (d, J = 8.0 Hz, 2H), 6.76 (d, J = 12.0 Hz, 2H), 5.40 (s, 1H), 5.38 (s, 1H), 2.08-1.06 (m, 12H), 1.60-0.90 (t, J = 6.0 Hz, 3H), 0.85 (t, J = 6.0 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) for the mixture of diastereoisomers δ 180.2, 179.1, 147.7, 147.5, 146.0, 145.9, 138.3, 135.8, 129.1, 129.1, 128.8, 128.3, 128.3, 128.1, 127.9, 127.8, 123.3, 122.6, 77.5, 75.7, 60.2, 60.1, 33.8, 30.9, 27.2, 26.2, 23.8, 23.4, 14.1, 14.1; ^1H NMR (400 MHz, $CDCl_3$, TMS) for the major diastereoisomer δ 7.89 (d, J = 8 Hz, 2H), 7.29-7.14 (m, 3H), 6.94 (d, J = 8.0 Hz, 2H), 6.76 (d, J = 12.0 Hz, 2H), 5.40 (s, 1H), 2.08-1.75 (m, 2H), 1.60-1.06 (m, 4H), 0.90 (t, J = 6.0 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) for the major diastereoisomer δ 180.2, 147.7, 145.9, 135.8, 129.1, 129.1, 128.3, 128.1, 122.6, 75.7, 60.2, 33.8, 27.2, 23.4, 14.1. (M^++Na) HRMS m/z calcd for $C_{16}H_{15}NO_5Na$: 366.1312; Found: 366.1310.



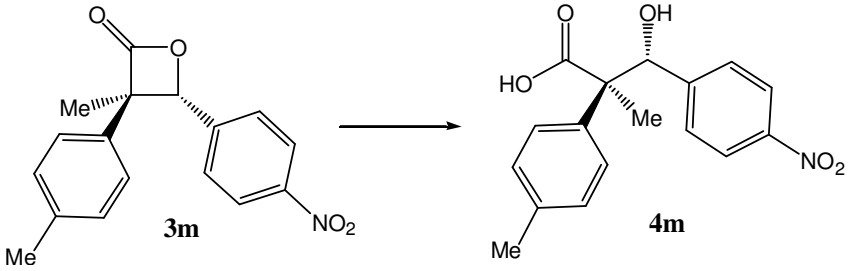
(3*R*,4*R*)-3-Methyl-4-(4-nitrophenyl)- 3-*o*-tolyloxetan-2-one (3k): Following procedure **A**, methyl-*o*-tolylketene (47 mg, 0.32 mmol) was added to 4-nitrobenzaldehyde (49 mg, 0.32 mmol) and (*R*)-BINAPHANE (22 mg, 0.032 mmol). Eluting with 20% EtOAc/hexane through a plug column of neutral silica followed by solvent removal under reduced pressure afforded **3k** as a light yellow oil (90 mg, 90% purity by ^1H NMR), dr 96:4 (by ^1H NMR); HPLC analysis: 54% ee [Daicel Chiralpak AS-H column; 1.0 mL/min; solvent system: 15% isopropanol in hexane; retention times: 19.3 min (minor), 36.0 min (major)].

(2*R*,3*R*)-3-Hydroxy-2-methyl-3-(4-nitrophenyl)-2-*p*-tolylpropanoic acid (4k): Procedure **B** was followed employing **3k** (90 mg, 90% purity), aqueous KOH (0.55 mL, 0.55 mmol) and a reaction time of 5 h. Elution with 30% EtOAc/hexane followed by solvent removal under reduced pressure yielded **4k** as a yellowish gum (73 mg, 72% yield for two steps), dr >99:1 (by ^1H NMR); $[\alpha]_D^{24}$ = 101.2 (c = 0.45, EtOAc); IR ($CHCl_3$): 3497, 3020, 1689, 1522, 1350 1216 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$, TMS): δ 7.88 (d, J = 8.8 Hz, 2H), 7.18-7.27 (m, 2H), 6.96 (t, J = 7.4 Hz, 1H), 6.85 (d, J = 8.8 Hz, 2H), 6.62 (d, J = 8.0 Hz, 1H), 5.59 (s, 1H), 2.50 (s, 3H), 1.66 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 184.3, 147.3, 145.6, 136.6, 136.0, 132.2, 128.7, 128.5, 127.6, 126.7, 122.3, 74.4, 54.8, 21.0, 17.7; (M^++Na) HRMS m/z calcd for $C_{17}H_{17}NO_5Na$: 338.0999; Found: 338.0998.



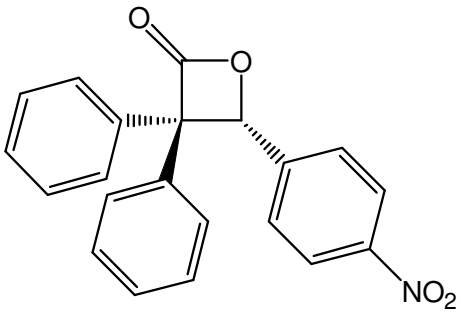
(3*R*,4*R*)-4-(4-Chlorophenyl)-3-methyl- 3-*p*-tolyloxetan-2-one (3l): Following procedure **A**, methyl-*p*-tolylketene (41 mg, 0.28 mmol) was added to 4-chlorobenzaldehyde (39 mg, 0.28 mmol) and (*R*)-BINAPHANE (20 mg, 0.028 mmol). **3l** was obtained as a colorless oil (80 mg, 85% purity by ^{1}H NMR), dr 92:8 (by ^{1}H NMR of **4l**); HPLC analysis: 84% ee [Daicel Chiralpak AS-H column; 0.5 mL/min; solvent system: 10% isopropanol in hexane; retention times: 14.8 min (major), 21.6 min (minor)].

(2*R*,3*R*)-3-Hydroxy-2-methyl-3-(4-nitrophenyl)-2-*p*-tolylpropanoic acid (4l): Procedure **B** was followed employing **3l** (80 mg, 85% purity), aqueous KOH (0.47 mL, 0.47 mmol), and a reaction time of 6 h. Elution with 20% EtOAc/hexane followed by solvent removal under reduced pressure yielded **4l** as a white gum (62 mg, 72% yield for two steps), dr 92:8 (by ^{1}H NMR); $[\alpha]_D^{24}$ = −151.2 (c = 0.17, EtOAc); IR ($CHCl_3$): 3513, 3020, 1699, 1215 cm^{-1}; ^{1}H NMR [Major] (400 MHz, $CDCl_3$, TMS): δ 7.16-7.01 (m, 6H), 6.69 (d, J = 8.4 Hz, 2H), 5.39 (s, 1H), 2.33 (s, 3H), 1.49 (s, 3H); ^{13}C NMR [Major] (100 MHz, $CDCl_3$): δ 182.3, 137.9, 136.9, 135.9, 133.3, 129.5, 129.0, 127.5, 126.9, 77.7, 56.1, 21.2, 14.6; (M^++Na) HRMS m/z calcd for $C_{17}H_{17}ClO_3Na$: 327.0758; Found: 327.0756.



(3*R*,4*R*)-3-Methyl-4-(4-nitrophenyl)-3-*p*-tolyloxetan-2-one (3m): Following procedure **A**, methyl-*p*-tolylketene (45 mg, 0.31 mmol) was added to 4-nitrobenzaldehyde (47 mg, 0.31 mmol) and (*R*)-BINAPHANE (22 mg, 0.031 mmol). Eluting with 20% EtOAc/hexane through a plug column of neutral silica followed by solvent removal under reduced pressure afforded **3m** as a light yellow oil (85 mg, 70% purity by ^{1}H NMR), dr 90:10 (by ^{1}H NMR of **4m**); HPLC analysis: 85% ee [Daicel Chiralpak AS-H column; 1.0 mL/min; solvent system: 8% isopropanol in hexane; retention times: 20.5 min (major), 29.5 min (minor)].

(2*R*,3*R*)-3-Hydroxy-2-methyl-3-(4-nitrophenyl)-2-*p*-tolylpropanoic acid (4m): Procedure **B** was followed employing **3m** (85 mg, 70% purity), aqueous KOH (0.40 mL, 0.40 mmol) and a reaction time of 6 h. Elution with 25% EtOAc/hexane followed by solvent removal under reduced pressure yielded **4m** as a yellowish gum (53 mg, 55% yield for two steps), dr 90:10 (by ^{1}H NMR); $[\alpha]_D^{25}$ = −123.1 (c = 0.18, EtOAc); IR ($CHCl_3$): 3495, 3021, 1704, 1521, 1349 cm^{-1}; ^{1}H NMR [Major] (400 MHz, $CDCl_3$, TMS): δ 7.92 (d, J = 8.8 Hz, 2H), 7.19-7.03 (m, 4H), 6.92 (d, J = 8.8 Hz, 2H), 5.55 (s, 1H), 2.37 (s, 3H), 1.53 (s, 3H); ^{13}C NMR [Major] (100 MHz, $CDCl_3$): δ 182.2, 147.4, 145.9, 138.4, 135.3, 129.7, 128.6, 126.8, 122.4, 77.5, 56.1, 21.3, 14.3; (M^++Na) HRMS m/z calcd for $C_{17}H_{17}NO_5Na$: 338.0999; Found: 338.0997.



3n

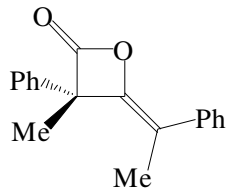
(4*R*)-4-(4-Nitrophenyl)-3,3-diphenyloxetan-2-one (3n): Following procedure **A**, diphenylketene (40 mg, 0.21 mmol) was added to 4-nitrobenzaldehyde (31 mg, 0.21 mmol) and (*R*)-BINAPHANE (15 mg, 0.021 mmol). Elution with 20% EtOAc/hexane through a plug column of neutral silica gel followed by recrystallization of the crude product from EtOAc/hexane afforded **3n** as a colorless crystalline solid (44 mg, 62% yield), HPLC analysis: 96% ee [Daicel Chiralpak AS-H column; 1.0 mL/min; solvent system: 15% isopropanol in hexane; retention times: 20.4 min (minor), 29.6 min (major)]; mp: 167-168 °C; $[\alpha]_D^{25}$ = 218.8 (c = 0.44, EtOAc); IR ($CHCl_3$): 3021, 1834, 1525, 1352, 1216 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$, TMS): δ 8.06 (dt, *J* = 8.7, 2.2 Hz, 2H), 7.56 (dt, *J* = 8.0, 2.3 Hz, 2H), 7.47 (tt, *J* = 7.9, 2.1 Hz, 2H), 7.38 (tt, *J* = 8.6, 2.2 Hz, 3H), 7.09-7.04 (m, 3H), 6.98-6.92 (m, 2H), 6.34 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 170.0, 148.0, 142.1, 137.9, 135.0, 129.5, 128.8, 128.7, 128.2, 127.7, 127.6, 127.1, 123.6, 81.7, 75.6; MS (EI 70 eV) m/z 301, 253, 165, 126, 91; (M^++Na) HRMS m/z calcd for $C_{21}H_{15}NO_4Na$: 368.0893; Found: 368.0894.

Control Reactions and Mechanistic Studies:

Quantitative Generation of phosphonium enolate from diphenyl ketene and reaction with 4-nitrobenzaldehyde: *n*-Bu_3P (89 mg, 0.46 mmol) was added to a solution of diphenylketene (98 mg, 0.46 mmol) in CH_2Cl_2 (0.92 mL) at −78 °C. ^{31}P NMR (162 MHz, 85% H_3PO_4) showed complete consumption of *n*-Bu_3P and gave a signal at 13.4 ppm, then 4-nitrobenzaldehyde (71 mg, 0.46 mmol) in CH_2Cl_2 (0.50 ml) was added to the phosphonium enolate solution at −78 °C and the reaction was allowed to warm up to room temperature in the cooling bath over five hours. GCMS analysis of the reaction showed no β-lactone formation.

^{31}P NMR study of the reaction of *n*-Bu_3P and 4-nitrobenzaldehyde: *n*-Bu_3P (17 mg, 0.084 mmol) was added to a solution of 4-nitrobenzaldehyde (127 mg, 0.84 mmol) in CH_2Cl_2 (1 mL) at −78 °C; ^{31}P NMR (162 MHz, 85% H_3PO_4) analysis of the reaction solution at −78 °C showed a signal for *n*-Bu_3P at δ -31 ppm.

^{31}P NMR study of the reaction of *n*-Bu_3P, 4-nitrobenzaldehyde and diphenylketene: *n*-Bu_3P (10 mg, 0.048 mmol) was added to a solution of diphenylketene (73 mg, 0.48 mmol) and 4-nitrobenzaldehyde (94 mg, 0.48 mmol) in CH_2Cl_2 (1.2 mL) at −78 °C; ^{31}P NMR (162 MHz, 85% H_3PO_4) analysis of the reaction solution at −78 °C: δ 13.4, 28.2 ppm, 34.2 ppm.[5,6,7]



10

(*S,Z*)-3-Methyl-3-phenyl-4-(1-phenylethylidene)oxetan-2-one: Methylphenylketene (57 mg, 0.39 mmol) was dissolved in CH_2Cl_2 (0.35 mL) and was cooled to −78 °C. (*R*)-BINAPHANE (27 mg, 0.04 mmol) was dissolved in CH_2Cl_2 (0.35 mL) and cooled to −78 °C. The phosphepine solution was then transferred via syringe to the flask containing the ketoketene solution. The reaction was stirred at −78 °C for 5 hours, after which the solvent was removed under reduced pressure. The crude material was dissolved in 10% EtOAc/hexane (12 mL) and CH_2Cl_2 (3 mL) and passed through a plug of neutral silica (6 g, 2×2 cm), eluting with 10% EtOAc/hexane (100 mL). The solvent was then removed under reduced pressure to yield **10** as a colorless oil (46 mg, 81%); HPLC analysis: 31% ee [Daicel Chiralpak AD column; 1 mL/min; λ=255 nm; solvent system: 2% isopropanol in

hexane; retention times: 4.8 min (minor), 6.7 min (major)]; $[\alpha]_D^{24} = -24.5$ (c = 0.30, $CHCl_3$)[7]; IR (thin film): 1881, 1844, 1699, 1140 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$, TMS): δ 7.52-7.16 (m, 10H), 1.92 (s, 3H), 1.86 (s, 3H); ^{13}C NMR (50 MHz, $CDCl_3$): δ 171.4, 146.9, 136.2, 135.2, 129.4, 128.6, 128.6, 127.6, 127.4, 126.3, 108.6, 64.4, 19.6, 15.6; MS (EI 70 eV): m/z 264, 132, 104, 78; (M^++Na) HRMS m/z calcd for $C_{18}H_{16}O_2Na$: 287.1043; found: 287.1039.

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2. Hodous, B. L.; Fu, G. C. *J. Am. Chem. Soc.* **2002**, *124*, 10006-10007.
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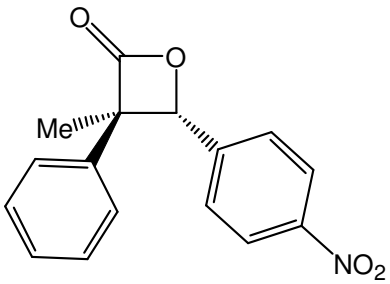
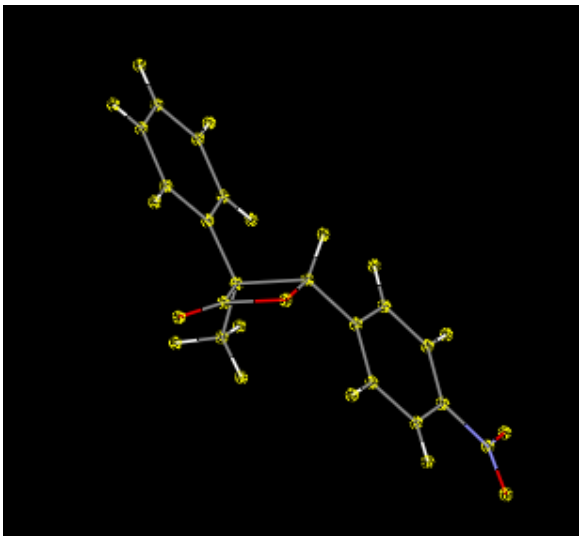
Determination of *trans* Relative Stereochemistry:

X-Ray Crystal Structure for Compound (±)-**3d**



(±) -3d



A colorless solution of crude (±)-**3d** in acetone/hexane (1:4) was prepared. Crystals suitable for X-ray structure analysis were obtained from this on standing.

A clear colourless plate-like specimen of $C_{16}H_{13}NO_4$, approximate dimensions 0.09 mm x 0.13 mm x 0.33 mm, was used for the X-ray crystallographic analysis. The X-ray intensity data were measured.

A total of 2668 frames were collected. The total exposure time was 7.41 hours. The frames were integrated with the Bruker SAINT software package using a narrow-frame algorithm. The integration of the data using an orthorhombic unit cell yielded a total of 14868 reflections to a maximum θ angle of 68.19° (0.83 Å resolution), of which 2392 were independent (average redundancy 6.216, completeness = 97.0%, R_{int} = 4.82%, R_{sig} = 3.01%) and 1843 (77.05%) were greater than $2\sigma(F^2)$. The final cell constants of a = 24.6054(4) Å, b = 7.01010(10) Å, c = 15.5516(2) Å, volume = 2682.44(7) $Å^3$, are based upon the refinement of the XYZ-centroids of 1166 reflections above 20 σ(I) with 7.183° < 2θ < 130.0°. Data were corrected for absorption effects using the multi-scan method (SADABS). The ratio of minimum to maximum apparent transmission was 0.781. The calculated minimum and maximum transmission coefficients (based on crystal size) are 0.7665 and 0.9278.

The structure was solved and refined using the Bruker SHELXTL Software Package, using the space group P c c n, with Z = 8 for the formula unit, $C_{16}H_{13}NO_4$. The final anisotropic full-matrix least-squares refinement on F^2 with 191 variables converged at R1 = 3.91%, for the observed data and wR2 = 10.37% for all data. The goodness-of-fit was 1.042. The largest peak in the final difference electron density synthesis was 0.229 $e^-/Å^3$ and the largest hole was -0.222 $e^-/Å^3$ with an RMS deviation of 0.042 $e^-/Å^3$. On the basis of the final model, the calculated density was 1.403 g/cm^3 and F(000), 1184 e^-.

Table 1. Sample and crystal data for 3d

Identification code	3d
Chemical formula	$C_{16}H_{13}NO_4$
Formula weight	283.27

Temperature	100(2) K	
Wavelength	1.54178 Å	
Crystal size	0.09 x 0.13 x 0.33 mm	
Crystal habit	clear colourless plate	
Crystal system	orthorhombic	
Space group	P c c n	
Unit cell dimensions	a = 24.6054(4) Å	α = 90°
	b = 7.01010(10) Å	β = 90°
	c = 15.5516(2) Å	γ = 90°
Volume	2682.44(7) $Å^3$	
Z	8	
Density (calculated)	1.403 Mg/cm^3	
Absorption coefficient	0.846 mm^{-1}	
F(000)	1184	

Table 2. Data collection and structure refinement for 3d

Theta range for data collection	3.59 to 68.19°	
Index ranges	-29<=h<=25, -7<=k<=6, -18<=l<=16	
Reflections collected	14868	
Independent reflections	2392 [R(int) = 0.0482]	
Coverage of independent reflections	97.0%	
Absorption correction	multi-scan	
Max. and min. transmission	0.9278 and 0.7665	
Structure solution technique	direct methods	
Structure solution program	SHELXS-97 (Sheldrick, 1990)	
Refinement method	Full-matrix least-squares on F^2	
Refinement program	SHELXL-97 (Sheldrick, 1997)	
Function minimized	$\Sigma w(F_o^2 - F_c^2)^2$	
Data / restraints / parameters	2392 / 0 / 191	
Goodness-of-fit on F^2	1.042	
Δ/σ_{max}	0.001	
Final R indices	1843 data; I>2σ(I)	R1 = 0.0391, wR2 = 0.0956
	all data	R1 = 0.0560, wR2 = 0.1037
Weighting scheme	$w=1/[\sigma^2(F_o^2)+(0.0533P)^2+0.7123P]$ where $P=(F_o^2+2F_c^2)/3$	
Largest diff. peak and hole	0.229 and -0.222 $eÅ^{-3}$	
R.M.S. deviation from mean	0.042 $eÅ^{-3}$	

Table 3. Atomic coordinates and equivalent isotropic atomic displacement parameters (Å^2) for 3d

U(eq) is defined as one third of the trace of the orthogonalized U_{ij} tensor.

	x/a	y/b	z/c	U(eq)
O1	0.59128(5)	0.20915(17)	0.88318(8)	0.0284(2)
O2	0.67093(6)	0.0511(2)	0.85968(8)	0.0358(2)
O3	0.52573(6)	0.7966(2)	0.22741(8)	0.0367(4)
O4	0.53880(6)	0.0483(2)	0.14947(8)	0.0348(2)
N1	0.53697(6)	0.8754(2)	0.15881(9)	0.0282(4)
C1	0.64462(8)	0.1946(2)	0.86051(11)	0.0284(4)
C2	0.65289(6)	0.4058(2)	0.84292(11)	0.0261(4)
C3	0.59127(6)	0.4173(2)	0.86756(11)	0.0256(4)
C4	0.69259(8)	0.4999(2)	0.90607(11)	0.0304(4)
C5	0.57547(6)	0.5306(2)	0.94534(10)	0.0243(4)
C6	0.56884(6)	0.4477(2)	0.02624(11)	0.0259(4)
C7	0.55498(6)	0.5591(2)	0.09655(11)	0.0263(4)
C8	0.54939(6)	0.7529(2)	0.08453(11)	0.0252(4)
C9	0.55623(6)	0.8396(2)	0.00524(11)	0.0260(4)
C10	0.56859(6)	0.7260(2)	0.93515(11)	0.0253(4)
C11	0.66617(6)	0.4588(2)	0.75036(11)	0.0267(4)
C12	0.66823(8)	0.6494(2)	0.72724(12)	0.0322(4)
C13	0.67970(8)	0.7022(2)	0.64314(12)	0.0361(5)
C14	0.68930(8)	0.5654(2)	0.58158(12)	0.0373(5)
C15	0.68727(10)	0.3773(2)	0.60407(12)	0.0468(5)
C16	0.67595(9)	0.3222(2)	0.68835(12)	0.0401(5)

Table 4. Bond lengths (Å) for 3d

O1-C1	1.363(2)	O1-C3	1.479(2)
O2-C1	1.196(2)	O3-N1	1.233(2)
O4-N1	1.221(2)	N1-C8	1.472(2)
C1-C2	1.520(3)	C2-C11	1.522(2)
C2-C4	1.534(2)	C2-C3	1.566(3)
C3-C5	1.498(2)	C3-H3	1.0
C4-H4A	0.98	C4-H4B	0.98
C4-H4C	0.98	C5-C10	1.390(3)
C5-C6	1.395(2)	C6-C7	1.386(2)
C6-H6	0.95	C7-C8	1.379(3)
C7-H7	0.95	C8-C9	1.385(2)
C9-C10	1.384(2)	C9-H9	0.95

C10-H10	0.95	C11-C16	1.381(3)
C11-C12	1.384(3)	C12-C13	1.388(3)
C12-H12	0.95	C13-C14	1.375(3)
C13-H13	0.95	C14-C15	1.365(3)
C14-H14	0.95	C15-C16	1.395(3)
C15-H15	0.95	C16-H16	0.95

Table 5. Bond angles (°) for 3d

C1-O1-C3	91.82(13)	O4-N1-O3	123.79(15)
O4-N1-C8	118.56(15)	O3-N1-C8	117.65(16)
O2-C1-O1	125.94(18)	O2-C1-C2	138.16(18)
O1-C1-C2	95.88(14)	C1-C2-C11	115.91(15)
C1-C2-C4	112.89(15)	C11-C2-C4	111.33(15)
C1-C2-C3	82.89(13)	C11-C2-C3	115.26(15)
C4-C2-C3	115.96(15)	O1-C3-C5	112.99(14)
O1-C3-C2	89.39(13)	C5-C3-C2	118.41(15)
O1-C3-H3	111.4	C5-C3-H3	111.4
C2-C3-H3	111.4	C2-C4-H4A	109.5
C2-C4-H4B	109.5	H4A-C4-H4B	109.5
C2-C4-H4C	109.5	H4A-C4-H4C	109.5
H4B-C4-H4C	109.5	C10-C5-C6	119.94(16)
C10-C5-C3	117.54(15)	C6-C5-C3	122.50(16)
C7-C6-C5	120.36(17)	C7-C6-H6	119.8
C5-C6-H6	119.8	C8-C7-C6	118.21(16)
C8-C7-H7	120.9	C6-C7-H7	120.9
C7-C8-C9	122.77(16)	C7-C8-N1	119.31(16)
C9-C8-N1	117.90(16)	C10-C9-C8	118.38(17)
C10-C9-H9	120.8	C8-C9-H9	120.8
C9-C10-C5	120.29(16)	C9-C10-H10	119.9
C5-C10-H10	119.9	C16-C11-C12	118.81(17)
C16-C11-C2	121.90(17)	C12-C11-C2	119.29(16)
C11-C12-C13	120.62(18)	C11-C12-H12	119.7
C13-C12-H12	119.7	C14-C13-C12	120.3(2)
C14-C13-H13	119.8	C12-C13-H13	119.8
C15-C14-C13	119.3(2)	C15-C14-H14	120.4
C13-C14-H14	120.4	C14-C15-C16	121.1(2)
C14-C15-H15	119.5	C16-C15-H15	119.5
C11-C16-C15	119.9(2)	C11-C16-H16	120.0
C15-C16-H16	120.0		

Table 6. Torsion angles (°) for 3d

C3-O1-C1-O2	179.90(18)	C3-O1-C1-C2	1.09(13)
O2-C1-C2-C11	65.7(3)	O1-C1-C2-C11	-115.71(16)
O2-C1-C2-C4	-64.4(3)	O1-C1-C2-C4	114.19(15)
O2-C1-C2-C3	-179.6(2)	O1-C1-C2-C3	-1.04(13)
C1-O1-C3-C5	-121.88(15)	C1-O1-C3-C2	-1.06(13)
C1-C2-C3-O1	0.95(12)	C11-C2-C3-O1	116.30(15)
C4-C2-C3-O1	-111.09(16)	C1-C2-C3-C5	116.95(16)
C11-C2-C3-C5	-127.70(17)	C4-C2-C3-C5	4.9(2)
O1-C3-C5-C10	-173.34(15)	C2-C3-C5-C10	84.2(2)
O1-C3-C5-C6	8.1(2)	C2-C3-C5-C6	-94.4(2)
C10-C5-C6-C7	0.5(3)	C3-C5-C6-C7	179.03(16)
C5-C6-C7-C8	-1.6(3)	C6-C7-C8-C9	1.0(3)
C6-C7-C8-N1	-177.45(15)	O4-N1-C8-C7	171.01(16)
O3-N1-C8-C7	-8.4(2)	O4-N1-C8-C9	-7.5(2)
O3-N1-C8-C9	173.12(16)	C7-C8-C9-C10	0.7(3)
N1-C8-C9-C10	179.21(16)	C8-C9-C10-C5	-1.9(3)
C6-C5-C10-C9	1.3(3)	C3-C5-C10-C9	-177.31(16)
C1-C2-C11-C16	-6.8(3)	C4-C2-C11-C16	124.0(2)
C3-C2-C11-C16	-101.3(2)	C1-C2-C11-C12	172.78(17)
C4-C2-C11-C12	-56.4(2)	C3-C2-C11-C12	78.4(2)
C16-C11-C12-C13	0.3(3)	C2-C11-C12-C13	-179.35(18)
C11-C12-C13-C14	-0.2(3)	C12-C13-C14-C15	0.2(3)
C13-C14-C15-C16	-0.4(3)	C12-C11-C16-C15	-0.5(3)
C2-C11-C16-C15	179.2(2)	C14-C15-C16-C11	0.5(4)

Table 7. Anisotropic atomic displacement parameters (Å^2) for 3d

The anisotropic atomic displacement factor exponent takes the form: $-2\pi^2[h^2 a^{*2} U_{11} + ... + 2 h k a^* b^* U_{12}]$

	U_{11}	U_{22}	U_{33}	U_{23}	U_{13}	U_{12}
O1	0.0310(8)	0.0242(7)	0.0299(5)	-0.0019(5)	0.0012(5)	-0.0007(5)
O2	0.0411(8)	0.0293(8)	0.0372(7)	-0.0009(5)	-0.0008(5)	0.0065(5)
O3	0.0476(9)	0.0415(9)	0.0209(5)	0.0006(5)	0.0059(5)	-0.0079(5)
O4	0.0457(9)	0.0289(9)	0.0297(7)	-0.0030(5)	0.0011(5)	0.0036(5)
N1	0.0281(9)	0.0316(11)	0.0248(8)	-0.0011(5)	0.0000(5)	-0.0008(5)
C1	0.0331(11)	0.0312(11)	0.0210(9)	-0.0029(8)	-0.0018(7)	0.0006(8)
C2	0.0261(10)	0.0264(10)	0.0257(9)	-0.0031(7)	-0.0001(7)	0.0012(7)
C3	0.0295(10)	0.0227(10)	0.0247(9)	-0.0002(7)	-0.0006(7)	-0.0008(7)

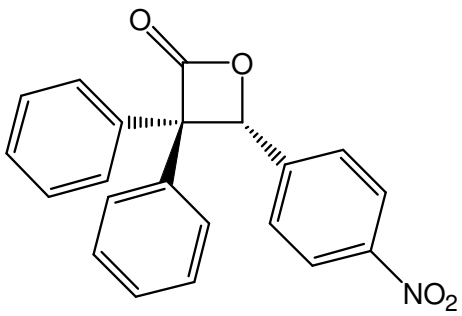
	U_{11}	U_{22}	U_{33}	U_{23}	U_{13}	U_{12}
C4	0.0296(11)	0.0343(11)	0.0273(10)	-0.0025(8)	-0.0012(8)	-0.0004(8)
C5	0.0205(10)	0.0289(10)	0.0234(9)	0.0001(7)	-0.0008(7)	-0.0010(7)
C6	0.0252(10)	0.0240(10)	0.0285(9)	0.0024(7)	-0.0011(7)	-0.0016(7)
C7	0.0264(10)	0.0310(11)	0.0216(9)	0.0029(7)	-0.0014(7)	-0.0040(7)
C8	0.0235(10)	0.0304(11)	0.0218(9)	-0.0029(7)	0.0001(7)	-0.0014(7)
C9	0.0260(10)	0.0249(10)	0.0272(9)	0.0008(7)	-0.0009(7)	-0.0005(7)
C10	0.0254(10)	0.0277(10)	0.0229(9)	0.0024(7)	0.0012(7)	-0.0012(7)
C11	0.0226(10)	0.0330(11)	0.0246(9)	-0.0031(7)	-0.0004(7)	-0.0010(7)
C12	0.0356(11)	0.0312(11)	0.0297(9)	-0.0027(8)	0.0060(8)	0.0002(8)
C13	0.0329(11)	0.0407(13)	0.0346(10)	0.0075(9)	0.0040(8)	0.0007(8)
C14	0.0311(11)	0.0548(14)	0.0260(10)	0.0005(9)	0.0030(8)	-0.0005(9)
C15	0.0621(16)	0.0504(15)	0.0279(10)	-0.0122(10)	0.0057(10)	-0.0002(11)
C16	0.0555(14)	0.0330(11)	0.0318(10)	-0.0046(9)	0.0028(9)	-0.0031(9)

Table 8. Hydrogen atomic coordinates and isotropic atomic displacement parameters ($Å^2$) for 3d

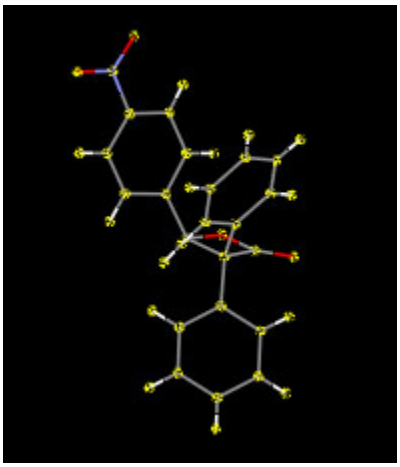
	x/a	y/b	z/c	U(eq)
H3	0.5683	0.4513	0.8167	0.031
H4A	0.6829	0.4640	0.9650	0.046
H4B	0.6906	0.6388	0.9000	0.046
H4C	0.7297	0.4569	0.8936	0.046
H6	0.5738	0.3142	1.0332	0.031
H7	0.5495	0.5033	1.1515	0.032
H9	0.5525	0.9738	0.9991	0.031
H10	0.5724	0.7819	0.8798	0.03
H12	0.6617	0.7449	0.7693	0.039
H13	0.6809	0.8334	0.6280	0.043
H14	0.6973	0.6015	0.5241	0.045
H15	0.6937	0.2825	0.5616	0.056
H16	0.6750	0.1907	0.7031	0.048

Determination of Absolute Stereochemistry:

X-Ray Crystal Structure for Compound **3n**



3n



A colorless solution of crude **3n** in EtOAc/hexane (2:3) was prepared. Crystals suitable for X-ray structure analysis were obtained from this on standing.

A clear colourless rod-like specimen of $C_{21}H_{15}NO_4$, approximate dimensions 0.28 mm x 0.34 mm x 0.39 mm, was used for the X-ray crystallographic analysis. The X-ray intensity data were measured.

A total of 3681 frames were collected. The total exposure time was 5.11 hours. The frames were integrated with the Bruker SAINT software package using a narrow-frame algorithm. The integration of the data using an orthorhombic unit cell yielded a total of 24408 reflections to a maximum θ angle of 71.71° (0.81 Å resolution), of which 3296 were independent (average redundancy 7.405, completeness = 99.9%, R_{int} = 2.49%, R_{sig} = 1.36%) and 3213 (97.48%) were greater than $2\sigma(F^2)$. The final cell constants of a = 9.51250(10) Å, b = 10.85260(10) Å, c = 16.4229(2) Å, volume = 1695.42(3) $Å^3$, are based upon the refinement of the XYZ-centroids of 7955 reflections above 20 σ(I) with 8.146° < 2θ < 142.1°. Data were corrected for absorption effects using the multi-scan method (SADABS). The ratio of minimum to maximum apparent transmission was 0.877. The calculated minimum and maximum transmission coefficients (based on crystal size) are 0.7534 and 0.8127.

Table 1. Sample and crystal data for 3n

Identification code	**3n**	
Chemical formula	$C_{21}H_{15}NO_4$	
Formula weight	345.34	
Temperature	100(2) K	
Wavelength	1.54178 Å	
Crystal size	0.28 x 0.34 x 0.39 mm	
Crystal habit	clear colourless rod	
Crystal system	orthorhombic	
Space group	P 21 21 21	
Unit cell dimensions	a = 9.51250(10) Å	α = 90°
	b = 10.85260(10) Å	β = 90°

	c = 16.4229(2) Å	γ = 90°
Volume	1695.42(3) $Å^3$	
Z	4	
Density (calculated)	1.353 Mg/cm^3	
Absorption coefficient	0.775 mm^{-1}	
F(000)	720	

Table 2. Data collection and structure refinement for 3n

Theta range for data collection	4.88 to 71.71°	
Index ranges	-11<=h<=11, -13<=k<=13, -19<=l<=20	
Reflections collected	24408	
Independent reflections	3296 [R(int) = 0.0249]	
Coverage of independent reflections	99.9%	
Absorption correction	multi-scan	
Max. and min. transmission	0.8127 and 0.7534	
Structure solution technique	direct methods	
Structure solution program	SHELXS-97 (Sheldrick, 1990)	
Refinement method	Full-matrix least-squares on F^2	
Refinement program	SHELXL-97 (Sheldrick, 1997)	
Function minimized	$\Sigma\, w(F_o^2 - F_c^2)^2$	
Data / restraints / parameters	3296 / 0 / 236	
Goodness-of-fit on F^2	1.065	
Δ/σ_{max}	0.013	
Final R indices	3213 data; I>2σ(I)	R1 = 0.0266, wR2 = 0.0687
	all data	R1 = 0.0274, wR2 = 0.0694
Weighting scheme	$w=1/[\sigma^2(F_o^2)+(0.0424P)^2+0.2177P]$ where $P=(F_o^2+2F_c^2)/3$	
Largest diff. peak and hole	0.174 and -0.176 $eÅ^{-3}$	
R.M.S. deviation from mean	0.037 $eÅ^{-3}$	

Table 3. Atomic coordinates and equivalent isotropic atomic displacement parameters ($Å^2$) for 3n

U(eq) is defined as one third of the trace of the orthogonalized U_{ij} tensor.

	x/a	y/b	z/c	U(eq)
O1	0.00270(9)	0.35799(8)	0.94346(5)	0.0279(2)
O2	0.78038(9)	0.30505(9)	0.90528(5)	0.0313(2)
O3	0.64386(9)	0.34257(9)	0.69770(6)	0.0350(2)

	x/a	y/b	z/c	U(eq)
O4	0.50517(10)	0.48149(10)	0.64865(6)	0.0429(2)
N1	0.53405(11)	0.40185(10)	0.69900(6)	0.0288(2)
C1	0.90298(12)	0.28308(11)	0.91095(6)	0.0253(2)
C2	0.00172(12)	0.17614(11)	0.89128(6)	0.0227(2)
C3	0.11489(12)	0.26539(11)	0.92984(6)	0.0242(2)
C4	0.22896(12)	0.31200(11)	0.87531(6)	0.0234(2)
C5	0.20635(12)	0.40996(11)	0.82228(6)	0.0277(2)
C6	0.30803(12)	0.44197(11)	0.76572(8)	0.0295(2)
C7	0.43069(12)	0.37435(11)	0.76315(6)	0.0254(2)
C8	0.45868(12)	0.27953(11)	0.81690(6)	0.0275(2)
C9	0.35665(12)	0.24922(11)	0.87344(6)	0.0272(2)
C10	0.02259(11)	0.15296(10)	0.80083(6)	0.0214(2)
C11	0.95137(12)	0.22179(11)	0.74232(6)	0.0252(2)
C12	0.98550(13)	0.20953(12)	0.66037(6)	0.0293(2)
C13	0.09129(12)	0.12980(12)	0.63652(6)	0.0290(2)
C14	0.16104(12)	0.05953(11)	0.69453(6)	0.0269(2)
C15	0.12604(12)	0.07027(11)	0.77628(6)	0.0246(2)
C16	0.96604(12)	0.06176(11)	0.94087(6)	0.0240(2)
C17	0.82716(12)	0.01986(12)	0.94124(6)	0.0291(2)
C18	0.78946(14)	0.91788(12)	0.98716(8)	0.0352(2)
C19	0.88887(17)	0.85661(12)	0.03338(8)	0.0374(2)
C20	0.02684(17)	0.89732(12)	0.03302(8)	0.0363(2)
C21	0.06575(13)	0.99934(11)	0.98698(6)	0.0301(2)

Table 5. Bond lengths (Å) for 3n

O1-C1	1.3585(16)	O1-C3	1.4828(14)
O2-C1	1.1940(15)	O3-N1	1.2270(14)
O4-N1	1.2273(15)	N1-C7	1.4715(16)
C1-C2	1.5276(17)	C2-C10	1.5197(16)
C2-C16	1.5229(15)	C2-C3	1.5805(16)
C3-C4	1.4951(17)	C3-H3	1.0
C4-C5	1.3910(17)	C4-C9	1.3930(17)
C5-C6	1.3854(18)	C5-H5	0.95
C6-C7	1.3790(17)	C6-H6	0.95
C7-C8	1.3817(17)	C8-C9	1.3830(18)
C8-H8	0.95	C9-H9	0.95
C10-C15	1.3915(17)	C10-C11	1.3929(17)
C11-C12	1.3908(17)	C11-H11	0.95
C12-C13	1.384(2)	C12-H12	0.95

C13-C14	1.3891(18)	C13-H13	0.95
C14-C15	1.3881(16)	C14-H14	0.95
C15-H15	0.95	C16-C21	1.3899(17)
C16-C17	1.3972(17)	C17-C18	1.386(2)
C17-H17	0.95	C18-C19	1.383(2)
C18-H18	0.95	C19-C20	1.385(2)
C19-H19	0.95	C20-C21	1.3908(18)
C20-H20	0.95	C21-H21	0.95

Table 6. Bond angles (°) for 3n

C1-O1-C3	92.16(8)	O3-N1-O4	123.22(11)
O3-N1-C7	118.36(11)	O4-N1-C7	118.40(10)
O2-C1-O1	126.38(12)	O2-C1-C2	137.37(12)
O1-C1-C2	96.22(9)	C10-C2-C16	114.64(9)
C10-C2-C1	114.38(9)	C16-C2-C1	111.66(9)
C10-C2-C3	113.84(9)	C16-C2-C3	115.91(9)
C1-C2-C3	82.44(9)	O1-C3-C4	112.54(9)
O1-C3-C2	89.17(8)	C4-C3-C2	117.50(9)
O1-C3-H3	111.9	C4-C3-H3	111.9
C2-C3-H3	111.9	C5-C4-C9	119.67(11)
C5-C4-C3	121.42(11)	C9-C4-C3	118.72(10)
C6-C5-C4	120.23(11)	C6-C5-H5	119.9
C4-C5-H5	119.9	C7-C6-C5	118.54(11)
C7-C6-H6	120.7	C5-C6-H6	120.7
C6-C7-C8	122.67(11)	C6-C7-N1	118.64(11)
C8-C7-N1	118.66(11)	C7-C8-C9	118.09(11)
C7-C8-H8	121.0	C9-C8-H8	121.0
C8-C9-C4	120.69(11)	C8-C9-H9	119.7
C4-C9-H9	119.7	C15-C10-C11	119.34(11)
C15-C10-C2	118.84(10)	C11-C10-C2	121.46(10)
C12-C11-C10	120.17(11)	C12-C11-H11	119.9
C10-C11-H11	119.9	C13-C12-C11	120.24(11)
C13-C12-H12	119.9	C11-C12-H12	119.9
C12-C13-C14	119.77(11)	C12-C13-H13	120.1
C14-C13-H13	120.1	C15-C14-C13	120.18(11)
C15-C14-H14	119.9	C13-C14-H14	119.9
C14-C15-C10	120.26(11)	C14-C15-H15	119.9
C10-C15-H15	119.9	C21-C16-C17	118.96(11)
C21-C16-C2	122.45(11)	C17-C16-C2	118.58(11)
C18-C17-C16	120.45(12)	C18-C17-H17	119.8

C16-C17-H17	119.8	C19-C18-C17	120.36(13)
C19-C18-H18	119.8	C17-C18-H18	119.8
C18-C19-C20	119.49(12)	C18-C19-H19	120.3
C20-C19-H19	120.3	C19-C20-C21	120.57(13)
C19-C20-H20	119.7	C21-C20-H20	119.7
C16-C21-C20	120.17(12)	C16-C21-H21	119.9
C20-C21-H21	119.9		

Table 7. Torsion angles (°) for 3n

C3-O1-C1-O2	178.29(12)	C3-O1-C1-C2	-0.26(8)
O2-C1-C2-C10	69.18(18)	O1-C1-C2-C10	-112.55(10)
O2-C1-C2-C16	-63.09(18)	O1-C1-C2-C16	115.19(10)
O2-C1-C2-C3	-178.03(15)	O1-C1-C2-C3	0.25(8)
C1-O1-C3-C4	119.85(10)	C1-O1-C3-C2	0.25(8)
C10-C2-C3-O1	113.14(10)	C16-C2-C3-O1	-110.68(10)
C1-C2-C3-O1	-0.22(7)	C10-C2-C3-C4	-1.99(15)
C16-C2-C3-C4	134.18(11)	C1-C2-C3-C4	-115.36(11)
O1-C3-C4-C5	-21.21(14)	C2-C3-C4-C5	80.23(14)
O1-C3-C4-C9	163.87(10)	C2-C3-C4-C9	-94.68(13)
C9-C4-C5-C6	2.52(17)	C3-C4-C5-C6	-172.35(11)
C4-C5-C6-C7	0.33(18)	C5-C6-C7-C8	-2.8(2)
C5-C6-C7-N1	175.27(11)	O3-N1-C7-C6	179.00(11)
O4-N1-C7-C6	-2.20(17)	O3-N1-C7-C8	-2.83(16)
O4-N1-C7-C8	175.97(11)	C6-C7-C8-C9	2.33(18)
N1-C7-C8-C9	-175.76(11)	C7-C8-C9-C4	0.64(17)
C5-C4-C9-C8	-3.03(17)	C3-C4-C9-C8	171.98(11)
C16-C2-C10-C15	-58.65(14)	C1-C2-C10-C15	170.52(10)
C3-C2-C10-C15	78.09(13)	C16-C2-C10-C11	128.25(12)
C1-C2-C10-C11	-2.58(15)	C3-C2-C10-C11	-95.00(13)
C15-C10-C11-C12	-1.26(17)	C2-C10-C11-C12	171.81(11)
C10-C11-C12-C13	-0.62(18)	C11-C12-C13-C14	1.65(18)
C12-C13-C14-C15	-0.79(18)	C13-C14-C15-C10	-1.10(18)
C11-C10-C15-C14	2.11(17)	C2-C10-C15-C14	-171.13(11)
C10-C2-C16-C21	100.44(13)	C1-C2-C16-C21	-127.42(12)
C3-C2-C16-C21	-35.38(15)	C10-C2-C16-C17	-80.95(13)
C1-C2-C16-C17	51.19(14)	C3-C2-C16-C17	143.22(11)
C21-C16-C17-C18	0.24(18)	C2-C16-C17-C18	-178.41(11)
C16-C17-C18-C19	0.2(2)	C17-C18-C19-C20	-0.5(2)
C18-C19-C20-C21	0.3(2)	C17-C16-C21-C20	-0.41(18)
C2-C16-C21-C20	178.19(11)	C19-C20-C21-C16	0.1(2)

Table 8. Anisotropic atomic displacement parameters (Å^2) for 3n

The anisotropic atomic displacement factor exponent takes the form: $-2\pi^2[h^2 a^{*2} U_{11} + ... + 2 h k a^* b^* U_{12}]$

	U_{11}	U_{22}	U_{33}	U_{23}	U_{13}	U_{12}
O1	0.0303(4)	0.0265(4)	0.0270(4)	-0.0023(2)	0.0064(2)	0.0016(4)
O2	0.0263(5)	0.0365(5)	0.0310(4)	0.0072(4)	0.0088(4)	0.0058(4)
O3	0.0219(4)	0.0430(5)	0.0401(5)	-0.0053(4)	0.0023(4)	0.0003(4)
O4	0.0347(5)	0.0448(5)	0.0494(5)	0.0164(5)	0.0098(4)	0.0001(5)
N1	0.0221(5)	0.0307(5)	0.0336(5)	-0.0042(4)	0.0006(4)	-0.0052(4)
C1	0.0277(5)	0.0288(5)	0.0194(5)	0.0041(4)	0.0048(4)	0.0010(5)
C2	0.0202(5)	0.0260(5)	0.0219(5)	0.0010(4)	-0.0007(4)	0.0006(5)
C3	0.0275(5)	0.0240(5)	0.0211(5)	-0.0009(4)	-0.0022(5)	0.0005(5)
C4	0.0241(5)	0.0242(5)	0.0220(5)	-0.0034(4)	-0.0034(4)	-0.0026(5)
C5	0.0233(5)	0.0266(5)	0.0330(5)	0.0021(5)	0.0004(5)	0.0021(5)
C6	0.0268(5)	0.0267(5)	0.0351(5)	0.0065(5)	0.0003(5)	-0.0009(5)
C7	0.0214(5)	0.0274(5)	0.0274(5)	-0.0034(5)	-0.0010(5)	-0.0057(5)
C8	0.0212(5)	0.0307(5)	0.0305(5)	-0.0038(5)	-0.0050(5)	0.0032(5)
C9	0.0282(5)	0.0280(5)	0.0255(5)	0.0018(5)	-0.0056(5)	0.0016(5)
C10	0.0196(5)	0.0231(5)	0.0216(5)	-0.0010(4)	0.0002(4)	-0.0035(4)
C11	0.0242(5)	0.0257(5)	0.0257(5)	-0.0003(4)	-0.0007(5)	-0.0004(5)
C12	0.0353(7)	0.0292(5)	0.0235(5)	0.0029(5)	-0.0046(5)	-0.0019(5)
C13	0.0342(5)	0.0312(5)	0.0217(5)	-0.0020(5)	0.0033(5)	-0.0086(5)
C14	0.0237(5)	0.0281(5)	0.0290(5)	-0.0057(5)	0.0032(5)	-0.0030(5)
C15	0.0233(5)	0.0251(5)	0.0255(5)	-0.0004(4)	-0.0018(4)	-0.0015(5)
C16	0.0288(5)	0.0254(5)	0.0179(5)	-0.0008(4)	0.0021(5)	-0.0014(5)
C17	0.0296(5)	0.0309(5)	0.0267(5)	-0.0016(5)	0.0016(5)	-0.0013(5)
C18	0.0362(7)	0.0353(7)	0.0342(7)	-0.0017(5)	0.0086(5)	-0.0079(5)
C19	0.0566(9)	0.0290(7)	0.0265(5)	0.0040(5)	0.0053(5)	-0.0097(5)
C20	0.0527(9)	0.0291(5)	0.0270(5)	0.0031(5)	-0.0083(5)	-0.0013(5)
C21	0.0333(5)	0.0277(5)	0.0293(5)	0.0005(5)	-0.0058(5)	-0.0014(5)

Table 9. Hydrogen atomic coordinates and isotropic atomic displacement parameters (Å^2) for 3n

	x/a	y/b	z/c	U(eq)
H3	0.1530	0.2325	0.9823	0.029
H5	0.1209	0.4551	0.8249	0.033
H6	0.2936	0.5090	0.7295	0.035
H8	0.5455	0.2364	0.8151	0.033

	x/a	y/b	z/c	U(eq)
H9	0.3738	0.1849	0.9114	0.033
H11	-0.1207	0.2773	0.7584	0.03
H12	-0.0640	0.2561	0.6206	0.035
H13	0.1161	0.1232	0.5807	0.035
H14	0.2329	0.0040	0.6782	0.032
H15	0.1729	0.0210	0.8156	0.03
H17	-0.2419	0.0615	0.9098	0.035
H18	-0.3052	-0.1101	0.9869	0.042
H19	-0.1373	-0.2129	1.0651	0.045
H20	0.0955	-0.1448	1.0645	0.044
H21	0.1607	0.0264	0.9871	0.036

The structure was solved and refined using the Bruker SHELXTL Software Package, using the space group P 21 21 21, with Z = 4 for the formula unit, $C_{21}H_{15}NO_4$. The final anisotropic full-matrix least-squares refinement on F^2 with 236 variables converged at R1 = 2.66%, for the observed data and wR2 = 6.94% for all data. The goodness-of-fit was 1.065. The largest peak in the final difference electron density synthesis was 0.174 $e^-/Å^3$ and the largest hole was -0.176 $e^-/Å^3$ with an RMS deviation of 0.037 $e^-/Å^3$. On the basis of the final model, the calculated density was 1.353 g/cm^3 and F(000), 720 e^-.