Electronic Supplementary Material (ESI) for Organic & Biomolecular Chemistry.

Enantioselective copper catalysed intramolecular C–H insertion reactions of α-diazo-β-keto sulfones, α-diazo-β-keto phosphine oxides and 2-diazo-1,3-diketones; the influence of the carbene substituent.

Supporting Information

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1. Experimental:

1.1 Compound Characterisation:

Ethyl 4-phenylbutanoate[1] **8.** A solution of 4-phenylbutanoic acid (10.00 g, 0.0609 mol), and concentrated sulfuric acid (2 mL) in ethanol (100 mL) was heated under reflux while stirring for 24 h. The mixture was concentrated under reduced pressure and the resulting residue dissolved in DCM (70 mL) and stirred with anhydrous sodium carbonate (2.8011 g, 0.0264 mol) for 1 h. The mixture was then filtered and concentrated under reduced pressure to give the ester **8** (10.30 g, 88%) as a sweet-smelling, colourless oil which was used without further purification, ν_{max}(neat)/cm^{-1} 1733 (C=O), δ_H (400 MHz) 1.25 (3H, t, *J* 7.1, C*H*$_3$), 1.95 [2H, apparent qu, *J* 7.5, C(3)*H*$_2$], 2.32 [2H, t, *J* 7.5, C(2)*H*$_2$], 2.65 [2H, t, *J* 7.6, C(4)*H*$_2$], 4.12 (2H, q, *J* 7.2, C*H*$_2$CH$_3$), 7.16–7.21 (3H, m, aromatic *H*), 7.24–7.32 (2H, m, aromatic *H*). Spectral characteristics were consistent with previously reported data.[1]

4-Phenylbutan-1-ol[2] **22.** Borane-dimethylsulfide complex (3.75 mL, 0.0396 mol) was added over 15 min to a solution of phenylbutyric acid (5.00 g, 0.0305 mol) in dry tetrahydrofuran (30 mL) and the mixture was stirred at room temperature for 4 h. Methanol (20 mL) was then added to destroy any remaining borane. The solution was concentrated under reduced pressure and the crude residue dissolved in dichloromethane (30 mL) and extracted with water (30 mL). The aqueous layer was extracted with dichloromethane (2 x 20 mL) and the combined organic layers were washed with brine (1 x 30 mL), dried with magnesium sulfate and concentrated under reduced pressure to yield the alcohol **22** (4.07 g, 89%) as a clear oil which was used without further purification; ν_{max}(neat)/cm^{-1} 3326 (OH), 2934, 2860 (CH), 1059, 1029 (C-O); δ_H (400 MHz) 1.37 (1H, bs, O*H*), 1.54–1.78 [4H, m, C(2)*H*$_2$ and C(3)*H*$_2$], 2.64 [2H, t, *J* 7.5, C(4)*H*$_2$], 3.65 [2H, t, *J* 6.4, C(1)*H*$_2$], 7.13–7.22 (3H, m, aromatic *H*), 7.23–7.34 (2H, m, aromatic *H*). Spectral characteristics were consistent with previously reported data.[2]

4-Phenylbutanal 10[3] Celite® (2 g) was added to a solution of 4-phenylbutan-1ol **22** (2.00 g, 0.0133 mol) in dichloromethane (40 mL) followed by pyridinium chlorochromate (7.18 g, 0.0333 mol), the reaction mixture was stirred for 3 h at room temperature. The reaction mixture was filtered through a short plug of silica gel using dichloromethane to wash. The filtrate was concentrated under reduced pressure to yield the crude aldehyde **10** (1.52 g, 77%) as a yellow oil which was sufficiently pure to use in the next reaction. Purification by column

chromatography, employing 10% ethyl acetate in hexane as eluent, gave the analytically pure aldehyde **10** (0.48 g, 24%) as a colourless oil, δ_H (400 MHz) 1.97 [2H, apparent qu, *J* 7.4, C(3)H_2], 2.46 [2H, td, *J* 7.2, 1.7, C(4)H_2], 2.66 [2H, t, *J* 7.6, C(2)H_2], 7.14–7.24 (3H, m, aromatic *H*), 7.26–7.35 (2H, m, aromatic *H*), 9.76 (1H, s, C*H*O). Spectral characteristics were consistent with previously reported data.[3]

1.2 Compound Characterisation methyl sulfides:

4-Fluorophenyl methyl sulfide[4] **23b.** A solution of iodomethane (2.33 mL, 0.0375 mol) in DMF (5 mL) was added dropwise to a solution of 4-fluorobenzene thiol (3.33 mL, 0.0312 mol) in DMF (30 mL) while stirring at room temperature. To the resulting solution potassium carbonate (6.23 g, 0.0375 mol) was added. The reaction mixture was stirred for 5 h at room temperature and was then quenched with aqueous hydrochloric acid (1 x 50 mL) followed by the addition of DCM (50 mL). The organic layer was washed with aqueous hydrochloric acid (3 x 50 mL, 10%) and the organic layers were combined and washed with brine (1 x 50 mL), dried with magnesium sulfate, filtered and concentrated under reduced pressure to give the sulfide **23b** (3.98 g, 89%) as an orange oil, which was used without further purification; ν_{max}(neat)/cm^{-1} 1589 (C=C, Ar), 1488. 1228, 1155, 824 (CS); δ_H (400 MHz) 2.45 (3H, s, CH_3), 6.95–7.13 (2H, m, aromatic *H*), 7.21–7.28 (2H, m, aromatic *H*). Spectral characteristics were consistent with previously reported data.[4]

Methyl 2-naphthyl sulfide[4] **23c.** Iodomethane (1.36 mL, 0.0225 mol) in DMF (5 mL), naphthalene-2-thiol (3.00 g, 0.0187 mol) in DMF (30 mL) and potassium carbonate (3.11 g, 0.0225 mol) were used following the procedure for **23b** to give the sulfide **23c** (3.04 g, 93%) as a cream solid, which was used without further purification; ν_{max}(neat)/cm^{-1} 1590 (C=C, Ar), 810, 741 (CS); δ_H (300 MHz) 2.58 (3H, s, CH_3), 7.33–7.50 (3H, m, aromatic *H*), 7.58–7.64 (1H, m, aromatic *H*), 7.69–7.82 (3H, m, aromatic *H*). Spectral characteristics were consistent with previously reported data.[4]

Methyl 1-naphthyl sulfide[4, 5] **23d.** Iodomethane (0.56 mL, 0.0090 mol) in DMF (5 mL), naphthalene-1-thiol (1.20 mL, 0.0075 mol) in DMF (30 mL) and potassium carbonate (1.44 g, 0.0090 mol) were used following the procedure for **23b** to give the sulfide **23d** (1.14 g, 87%) as a yellow oil, which was used without further purification; ν_{max}(neat)/cm^{-1} 1564 (C=C, Ar), 1382, 978, 786, 767 (CS); δ_H (400 MHz) 2.54 (3H, s, CH_3), 7.34–7.43 (2H, m, aromatic *H*), 7.45–

7.56 (2H, m, aromatic *H*), 7.65 (1H, d, *J* 7.7, aromatic *H*), 7.79–7.85 (1H, m, aromatic *H*), 8.25–8.33 (1H, dd, *J*8.1, 0.9, aromatic *H*). Spectral characteristics were consistent with previously reported data.[4, 5]

Mesityl methyl sulfide[6] **23e.** Iodomethane (1.47 mL, 0.0236 mol) in DMF (5 mL), 2,4,6-trimethylbenzenethiol (3.00 g, 0.0197 mol) in DMF (30 mL) and potassium carbonate (3.93 g, 0.0236 mol) were used following the procedure for **23b** to give the sulfide **23e** (3.03 g, 92%) as a yellow oil, which was used without further purification; ν_{max}(neat)/cm^{-1} 1603 (C=C, Ar), 1461, 1436, 966, 849 (CS); δ_H (300 MHz) 2.20 (3H, s, C*H*$_3$), 2.26 (3H, s, *p* C*H*$_3$), 2.51 (6H, s, *o*-CH$_3$), 6.92 (2H, s, aromatic *H*). Spectral characteristics were consistent with previously reported data.[6]

2-Ethylphenyl methyl sulfide[7] **23f.** Iodomethane (3.70 g, 0.0260 mol) in DMF (5 mL), 2-ethylbenzenethiol (3.00 g, 0.0217 mol) in DMF (30 mL) and potassium carbonate (3.60 g, 0.0260 mol) were used following the procedure for **23b** to give the sulfide **23f** (2.92 g, 88%) as an orange oil, which was used without further purification; ν_{max}(neat)/cm^{-1} 1589 (C=C, Ar), 1469, 1438, 744 (CS); δ_H (300 MHz) 1.24 (3H, t, *J* 7.5, CH$_2$C*H*$_3$), 2.45 (3H, s, C*H*$_3$), 2.73 (2H, q, *J* 7.6, C*H*2CH$_3$), 7.06-7.22 (4H, m, aromatic *H*). Spectral characteristics were consistent with previously reported data.[7]

4-Methoxyphenyl methyl sulfide[8] **23g.** Iodomethane (4.26 mL, 0.0685 mol) in DMF (30 mL), 4-methoxybenzenethiol (7.02 mL, 0.0571 mol) in DMF (30 mL) and potassium carbonate (11.38 g, 0.0685 mol) were used following the procedure for **23b** to give the sulfide **23g** (7.81 g, 89%) as a yellow oil, which was used without further purification; ν_{max}(neat)/cm^{-1} 1589 (C=C, Ar), 1492, 1438, 1239, 819 (CS); δ_H (300 MHz) 2.44 (3H, s, C*H*$_3$), 3.79 (3H, s, C*H*$_3$), 6.81–6.88 (2H, m, aromatic *H*), 7.23–7.30 (2H, m, aromatic *H*). Spectral characteristics were consistent with previously reported data.[8]

Cyclohexyl methyl sulfide[9] **23h.** Iodomethane (6.43 mL, 1.0325 mol) in DMF (50 mL), cyclohexanethiol (10.53 mL, 0.8604 mol) in DMF (10 mL) and potassium carbonate (17.17 g, 1.0325 mol) were used following the procedure for **23b** to give the sulfide **23h** (2.92 g, 88%) as an orange oil, which was used without further purification; δ_H (300 MHz) 1.15–1.40 (5H, m, cyclohexyl protons), 1.55–1.68 (1H, m, cyclohexyl proton), 1.70–1.85 (2H, m, cyclohexyl proton), 1.90–2.25 (2H, m, cyclohexyl proton), 2.09 (3H, s, C*H*$_3$), 2.47–2.62 (1H, m, cyclohexyl

proton. Further analysis not undertaken due to odour. Spectral characteristics were consistent with previously reported data.[9]

1.3 Compound Characterisation methyl sulfones:

1-Fluoro-4-(methylsulfonyl)benzene[10-12] **7b.** Aqueous hydrogen peroxide (11.78 mL, 0.1507 mol, 30%) was added over 5 min to a stirring solution of 4-fluorophenyl methyl sulfide **23b** (3.98 g, 0.0279 mol) in glacial acetic acid (15 mL). The reaction mixture was heated under reflux while stirring for 30 min then cooled by the addition of water (20mL) and extracted with DCM (3 x 30mL). The combined organic extracts were washed with saturated sodium bicarbonate solution (3 x 50mL) and brine (50 mL), dried with magnesium sulfate, filtered and concentrated under reduced pressure to give sulfone **7b** (2.28 g, 47%) as a white solid, mp 76–78°C (lit.,[10] 76–77 °C); ν_{max}(neat)/cm^{-1} 1285, 1144 (SO_2); δ_H (400 MHz) 3.06 (3H, s, C*H*$_3$), 7.21-7.31 (2H, m, aromatic *H*), 7.94-8.02 (2H, m, aromatic *H*). Spectral characteristics were consistent with previously reported data.[10-12]

2-(Methylsulfonyl)naphthalene[13-15] **7c.** Aqueous hydrogen peroxide (4.86 mL, 0.0621 mol, 30%), methyl 2-naphthyl sulfide **23c** (2.00 g, 0.0115 mol) in glacial acetic acid (15 mL) were used following the procedure described for **7b** to give the sulfone **7c** (1.56 g, 66%) as a cream solid, mp 141–143 (lit.,[13] 142–143 °C); ν_{max}(neat)/cm^{-1} 1289, 1124 (SO_2); δ_H (400 MHz) 3.13 (3H, s, C*H*$_3$), 7.61-7.73 (2H, m, aromatic *H*), 7.88-8.06 (4H, m, aromatic *H*), 8.53 (1H, s, aromatic *H*). Spectral characteristics were consistent with previously reported data.[13-15]

1-(Methylsulfonyl)naphthalene[15, 16] **7d.** Aqueous hydrogen peroxide (3.67 mL, 0.0468 mol, 30%), methyl 1-naphthyl sulfide **23d** (1.51 g, 0.0087 mol) and glacial acetic acid (15 mL) were used following the procedure described for **7b** to give the sulfone **7d** (1.35 g, 76%) as a white solid, mp 101–103 °C (lit.,[15] 99–100 °C); ν_{max}(neat)/cm^{-1} 1297, 1122 (SO_2); δ_H (400 MHz) 3.22 (3H, s, C*H*$_3$), 7.57-7.68 (2H, m, aromatic *H*), 7.73 (1H, ddd, *J* 8.5, 6.9, 1.4, aromatic *H*), 7.99 (1H, d, *J* 8.0, aromatic *H*), 8.14 (1H, d, *J* 8.2, aromatic *H*), 8.35 (1H, dd, *J* 7.3, 1.2, aromatic *H*), 8.74 (1H, d, *J* 8.6, aromatic *H*). Spectral characteristics were consistent with previously reported data. [15, 16]

Mesityl methyl sulfone[17] **7e.** Aqueous hydrogen peroxide (7.68 mL, 0.0983 mol, 30%), mesityl methyl sulfide **23e** (3.03 g, 0.0182 mol) and glacial acetic acid (20 mL) were used following the procedure described for **7b** to give the sulfone **7e** (2.00 g, 55%) as a white solid, mp 121–

123 °C (lit.,[15] 122–124 °C); ν_{max}(neat)/cm^{-1} 1294, 1133 (SO_2); δ_H (300 MHz) 2.31 (3H, s, *p*-CH_3), 2.67 (6H, s, *o*-C*H*$_3$), 3.04 (3H, s, C*H*$_3$), 6.97 (2H, s, aromatic *H*). Spectral characteristics were consistent with previously reported data.[17]

1-Ethyl-2-(methylsulfonyl)benzene[18] **7f.** Aqueous hydrogen peroxide (8.06 mL, 0.1034 mol, 30%), 2-ethylphenyl methyl sulfide **23f** (2.92 g, 0.0191 mol) and glacial acetic acid (20 mL) were used following the procedure described for **7a** to give the sulfone **7f** (2.16 g, 61%) as a clear oil, δ_H (300 MHz) 1.34 (3H, t, *J* 7.5, CH_2CH_3), 3.04–3.15 (5H, m, CH_2CH_3 contains s at δ3.09 for C*H*$_3$), 7.33-7.45 (2H, m, aromatic *H*), 7.57 (1H, td, *J* 7.6, 1.4, aromatic *H*), 8.03 (1H, dd, *J* 8.0, 1.3, aromatic *H*). Spectral characteristics were consistent with previously reported data .[18]

1-Methoxy-4-(methylsulfonyl)benzene[19] **7g.** Aqueous hydrogen peroxide (21.35 mL, 0.2731 mol, 30%), 4-methoxyphenyl methyl sulfide **23g** (7.8 g, 0.0506 mol) and glacial acetic acid (70 mL) were used following the procedure for **7b** to give the sulfone **7g** (7.93 g, 84%) as a light yellow solid, mp 115–118 °C (lit.,[19] 102–110 °C); ν_{max}(neat)/cm^{-1} 1291, 1140 (SO_2); δ_H (300 MHz) 3.03 (3H, s, C*H*$_3$), 3.89 (3H, s, C*H*$_3$), 6.99–7.06 (2H, m, aromatic *H*), 7.83–7.91 (2H, m, aromatic *H*). Spectral characteristics were consistent with previously reported data.[19]

(Methylsulfonyl)cyclohexane[9] **7h.** Aqueous hydrogen peroxide (19.46 mL, 0.2488 mol, 30%), cyclohexyl methyl sulfide **23h** (6.00 g, 0.0461 mol) and glacial acetic acid (50 mL) were used following the procedure described for **7b** to give the sulfone **7h** (3.79 g, 51%) as a light yellow oil, ν_{max}(neat)/cm^{-1} 1295, 1111 (SO_2); δ_H (400 MHz) 1.15-1.42 (3H, m, 3 x cyclohexyl C*H*), 1.52 (2H, qd, *J* 12.4, 3.1, 2 x cyclohexyl C*H*), 1.70-1.80 (2H, m, 2 x cyclohexyl C*H*), 1.89-2.02 (2H, m, 2 x cyclohexyl C*H*), 2.15-2.77 (2H, m, 2 x cyclohexyl C*H*), 2.76-2.87 (1H, m, cyclohexyl C*H*), 2.81 (3H, s, C*H*$_3$). Spectral characteristics were consistent with previously reported data.[9]

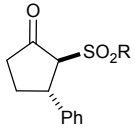
References:

1. D. A. Everson, R. Shrestha and D. J. Weix, *J. Am. Chem. Soc.,* 2010, **132**, 920-921.
2. P. Lu, T. Hou, X. Gu and P. Li, *Org. Lett.,* 2015, **17**, 1954-1957.
3. L. R. Jefferies and S. P. Cook, *Org. Lett.*, 2014, **16**, 2026-2029.
4. F. Luo, C. Pan, L. Li, F. Chen and J. Cheng, *Chem. Commun.*, 2011, **47**, 5304-5306.
5. L. C. Schmidt, V. Rey and A. B. Peñéñory, *Eur. J. Org. Chem.*, 2006, **2006**, 2210-2214.
6. M. Tudorache, S. Nica, E. Bartha, I. Lupan and V. I. Parvulescu, *Appl. Catal., A: General*, 2012, **441–442**, 42-46.
7. C. Bianchini, A. Meli, V. Patinec, V. Sernau and F. Vizza, *J. Am. Chem. Soc.*, 1997, **119**, 4945-4954.
8. X. Zhao, T. Li, L. Zhang and K. Lu, *Org. Biomol. Chem.*, 2016, **14**, 1131-1137.
9. E. L. Eliel and D. Kandasamy, *J. Org. Chem.*, 1976, **41**, 3899-3904.

10. J. Hirst and S. J. Una, *J. Chem. Soc. B*, 1971, 2221-2224.
11. T. Fujimoto and T. Ritter, *Org. Lett.*, 2015, **17**, 544-547.
12. C. Martin, F. Sandrinelli, C. Perrio, S. Perrio and M.-C. Lasne, *J. Org. Chem.*, 2006, **71**, 210-214.
13. B. L. a. K. Ankner, *Acta Chem. Scand.,* 1978, **32 B**, 264-268.
14. A. R. Katritzky, I. Takahashi and C. M. Marson, *J. Org. Chem.*, 1986, **51**, 4914-4920.
15. A. Kar, I. A. Sayyed, W. F. Lo, H. M. Kaiser, M. Beller and M. K. Tse, *Org. Lett.*, 2007, **9**, 3405-3408.
16. W. Zhu and D. Ma, *J. Org. Chem.*, 2005, **70**, 2696-2700.
17. R. P. Singh, R. M. Kamble, K. L. Chandra, P. Saravanan and V. K. Singh, *Tetrahedron*, 2001, **57**, 241-247.
18. G. Yuan, J. Zheng, X. Gao, X. Li, L. Huang, H. Chen and H. Jiang, *Chem. Commun.*, 2012, **48**, 7513-7515.
19. T. Okada, H. Matsumuro, S. Kitagawa, T. Iwai, K. Yamazaki, Y. Kinoshita, Y. Kimura and M. Kirihara, *Synlett*, 2015, **26**, 2547-2552.

2. HPLC data:

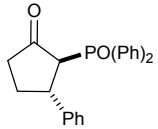
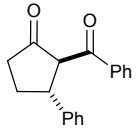
2.1 Table 1: HPLC conditions for the resolution of cyclopentanones **13a–k**

Figure	R	Compound	Column	UV (nm)	Eluent	Flow (mL/min)	Temp	Retention Time		Specific Rotation[a] $[\alpha]_D^{20}$
								Enantiomer	(min)	
	Phenyl	**13a**	Chiralpak OJ-H	217.0	Hexane : IPA 60 : 40	1.0	25 °C	(2*S*, 3*S*)	139	+19.1 (*c* 0.5, CH_2Cl_2, 23 %ee)[b]
								(2*R*, 3*R*)	84	−67.5 (*c* 0.5, CH_2Cl_2, 89 %ee) (**18**)
	4-Fluorophenyl	**13b**	LUX Cellulose-4	220.0	Hexane : IPA 95 : 05	1.0	25 °C	(2*S*, 3*S*)	91	+34.2 (*c* 0.25, CH_2Cl_2, 53 %ee) (**16**)
								(2*R*, 3*R*)	110	−75.2 (*c* 0.25, CH_2Cl_2, 86 %ee) (**18**)
	2-Naphthyl	**13c**	LUX Cellulose-2	228.1	Hexane : IPA 90 : 10	1.0	25 °C	(2*S*, 3*S*)	121	+27.3 (*c* 0.5, CH_2Cl_2, 47 %ee) (**16**)
								(2*R*, 3*R*)	129	−37.1 (*c* 0.5, CH_2Cl_2, 46 %ee) (**17**)
	1-Naphthyl	**13d**	LUX Cellulose-2	217.9	Hexane : IPA 90 : 10	1.0	25 °C	(2*S*, 3*S*)	125	+23.6 (*c* 0.25, CH_2Cl_2, 76 %ee) (**16**)
								(2*R*, 3*R*)	101	−120.4 (*c* 0.25, CH_2Cl_2, 81 %ee) (**18**)
	Mesityl	**13e**	LUX Cellulose-2	230.6	Hexane : IPA 90 : 10	1.0	25 °C	(2*S*, 3*S*)	54	+51.4 (*c* 0.25, CH_2Cl_2, 66 %ee)[c] (**15**)
								(2*R*, 3*R*)	33	−42.0 (*c* 0.25, CH_2Cl_2, 82 %ee)[d] (**18**)
	2-Ethylphenyl	**13f**	LUX Cellulose-2	215.0	Hexane : IPA 90 : 10	1.0	25 °C	(2*S*, 3*S*)	53	+ 62.2 (*c* 0.25, CH_2Cl_2, 78 %ee)[e] (**15**)
								(2*R*, 3*R*)	48	−53.2 (*c* 0.25, CH_2Cl_2, 87 %ee)[f] (**18**)

	4-Methoxyphenyl	**13g**	LUX Amylose-1	209.8	Hexane : IPA 90 : 10	0.5	25 °C	(2*S*, 3*S*)	81	Not recorded
								(2*R*, 3*R*)	148	Not recorded
	Cyclohexyl	**13h**	LUX Cellulose-4	220.0	Hexane : IPA 70 : 30	1.0	25 °C	(2*S*, 3*S*)	17	−1.4 (*c* 0.5, CH_2Cl_2, 68 %ee) (**15**)
								(2*R*, 3*R*)	11	+2.4 (*c* 0.5, CH_2Cl_2, 78 %ee) (**18**)
	4-Methylphenyl	**13i**	LUX Cellulose-2	237.0	Hexane : IPA 80 : 20	1.0	25 °C	(2*S*, 3*S*)	61	+69.6 (*c* 0.5, CH_2Cl_2, 78 %ee) (**15**)
								(2*R*, 3*R*)	65	−73.6 (*c* 0.5, CH_2Cl_2, 91 %ee) (**18**)
	4-Bromophenyl	**13j**	Chiralpak OJ-H	230.6	Hexane : IPA 70 : 30	1.0	25 °C	(2*S*, 3*S*)	54	+54.0 (*c* 0.5, CH_2Cl_2, 72 %ee) (**15**)
								(2*R*, 3*R*)	46	−63.5 (*c* 0.5, CH_2Cl_2, 89 %ee) (**18**)
	Methyl	**13k**	LUX Cellulose-4	225.7	Hexane : IPA 70 : 30	1.0	25 °C	(2*S*, 3*S*)	21	+20.0 (*c* 0.25, CH_2Cl_2, 72 %ee) (**15**)
								(2*R*, 3*R*)	12	−20.7 (*c* 0.25, CH_2Cl_2, 52 %ee) (**18**)

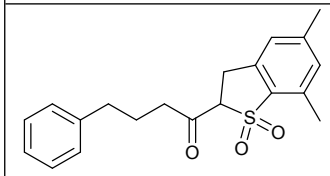
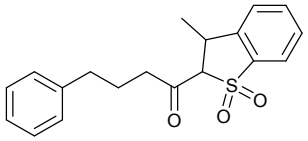
[a] Units for specific rotation are: 10^{-1} deg cm^2 g^{-1}. [b] Specific rotation of **13a** (2*R*, 3*R*) recorded from C–H insertion reaction using Rh_2(*S*-Phpa)$_4$.H_2O, Phpa = 2-phenylpropanoate. [c] Specific rotation of **13e** (2*S*, 3*S*) recorded from mix of **13e:19e**, 66:34. [d] Specific rotation of **13e** (2*R*, 3*R*) recorded from mix of **13e:19e**, 50:50. [e] Specific rotation of **13f** (2*S*, 3*S*) recorded from mix of **13f:19f**, 72:28. [f] Specific rotation of **13f** (2*R*, 3*R*) recorded from mix of **13f:19f**, 64:36.

2.2 Table 2: HPLC conditions for the resolution of cyclopentanones **20** and **21**

Figure	Compound	Column	UV (nm)	Eluent	Flow (mL/min)	Temp	Retention Time		Specific Rotation[a] $[\alpha]_D^{20}$
							Enantiomer	(min)	
	**20**	Chiralcel OD-H	237	Hexane : IPA 95 : 05	1.0	25 °C	(2*S*, 3*S*)[c]	40	+4.8 (*c* 0.06, CH_2Cl_2, 29 %ee) (**14**)
							(2*R*, 3*R*)	33	−18.2 (*c* 0.25, CH_2Cl_2, 53 %ee) (**18**)
	**21**	Chiralcel OD-H	300	Hexane : IPA 95 : 05	0.25	25 °C	(2*S*, 3*S*)[c]	28	Not recorded[b]
							(2*R*, 3*R*)[c]	37	Not recorded[b]

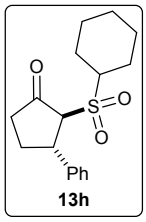
[a] Units for specific rotation are: 10^{-1} deg cm^2 g^{-1}. [b] Enantioenriched samples of **21** obtained from the copper catalysed reactions of **5** were of insufficient purity to obtain accurate rotation values. [c] The absolute stereochemistry of **20** or **21** have not been determined, assuming that the sense of enantioselection follows that seen in the sulfonyl derivatives.

2.3 Table 3: HPLC conditions for the resolution of fused sulfolanes **19e** and **19f**

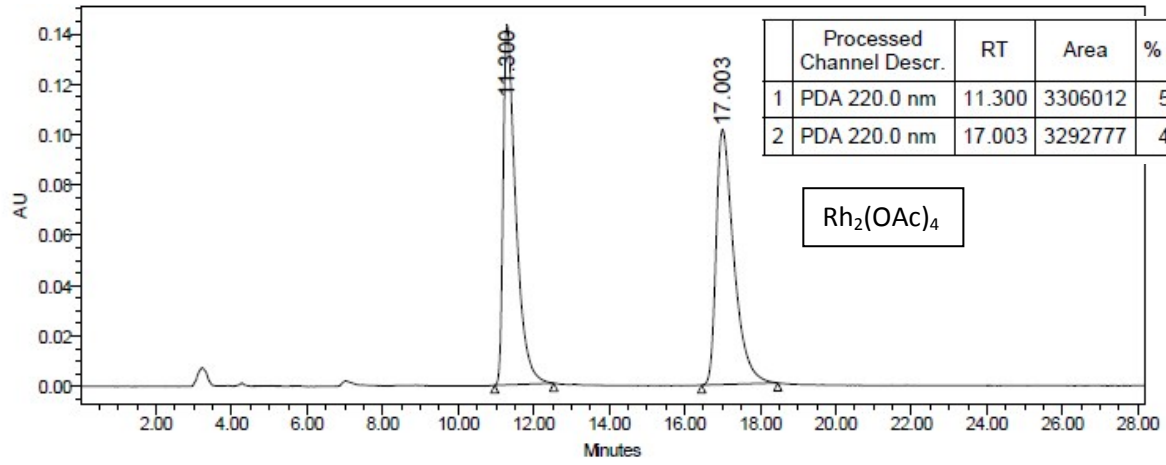
Figure	Compound	Column	UV (nm)	Eluent	Flow (mL/min)	Temp	Retention Time		Specific Rotation[a] $[\alpha]_D^{20}$
							Enantiomer	(min)	
	**19e**	Chiralpak OJ-H	230.6	Hexane : IPA 65 : 35	1.0	25 °C	(2*S*, 3*S*)[d]	29	Not recorded[b]
							(2*R*, 3*R*)[d]	19	Not recorded[b]
	**19f**	LUX Cellulose-2	215.0	Hexane : IPA 90 : 10	1.0	25 °C	(2*S*, 3*S*)[d]	23	−1.3 (*c* 0.8, CH_2Cl_2, 74 %ee) (**16**)
							(2*R*, 3*R*)[d]	20	Not recorded[c]

[a] Units for specific rotation are: 10^{-1} deg cm^2 g^{-1}. [b] **19e** was obtained exclusively as a racemate therefore no rotation value was obtained. [c] Enantioenriched sample of (2*R*, 3*R*)-**19f** obtained from reaction of **4f** in the presence of $CuCl_2$, (4*S*)-t-Bu-**17** was of insufficient purity to obtain an accurate rotation value. [d] The absolute stereochemistry of **19** has not been determined, assuming that the sense of enantioselection follows that seen in the sulfonyl derivatives.

2.4 Representative HPLC trace **13h**

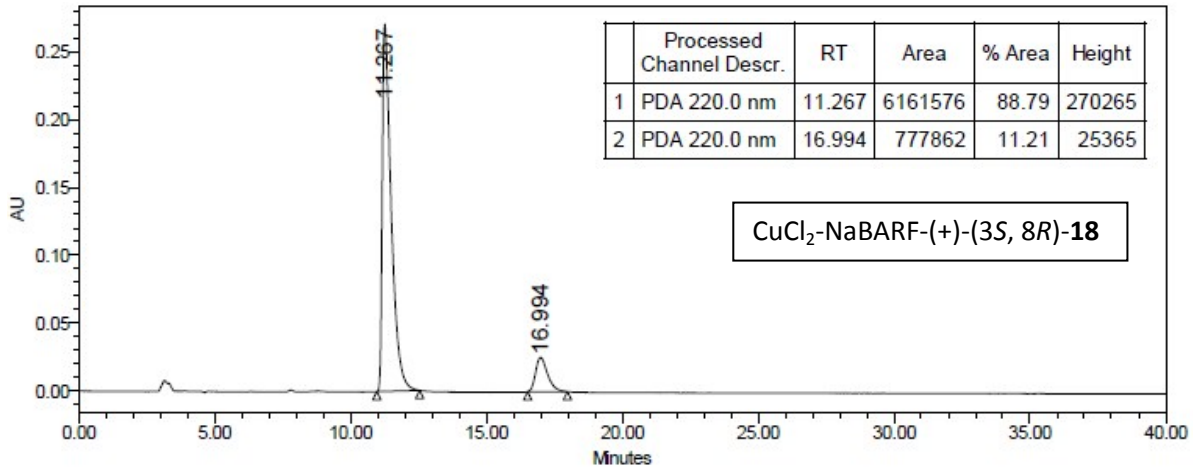


13h



	Processed Channel Descr.	RT	Area	% Area	Height
1	PDA 220.0 nm	11.300	3306012	50.10	142925
2	PDA 220.0 nm	17.003	3292777	49.90	101345

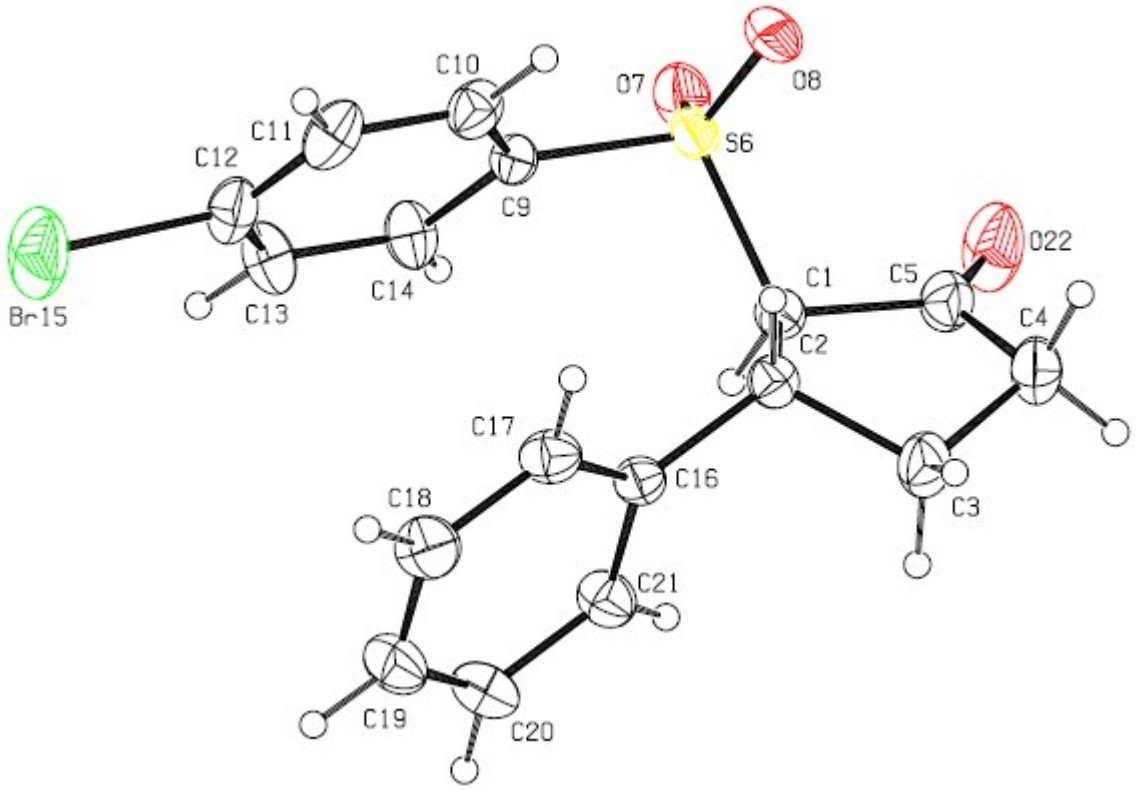
$Rh_2(OAc)_4$



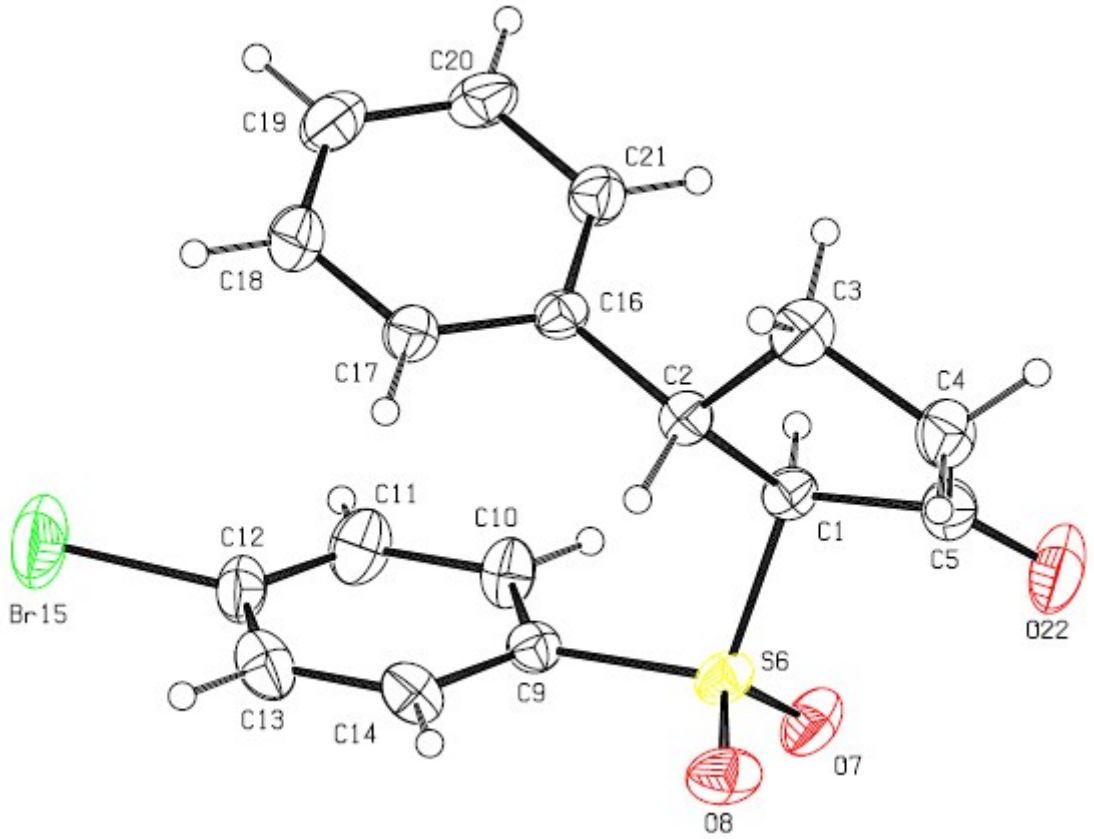
	Processed Channel Descr.	RT	Area	% Area	Height
1	PDA 220.0 nm	11.267	6161576	88.79	270265
2	PDA 220.0 nm	16.994	777862	11.21	25365

$CuCl_2$-NaBARF-(+)-(3*S*, 8*R*)-**18**

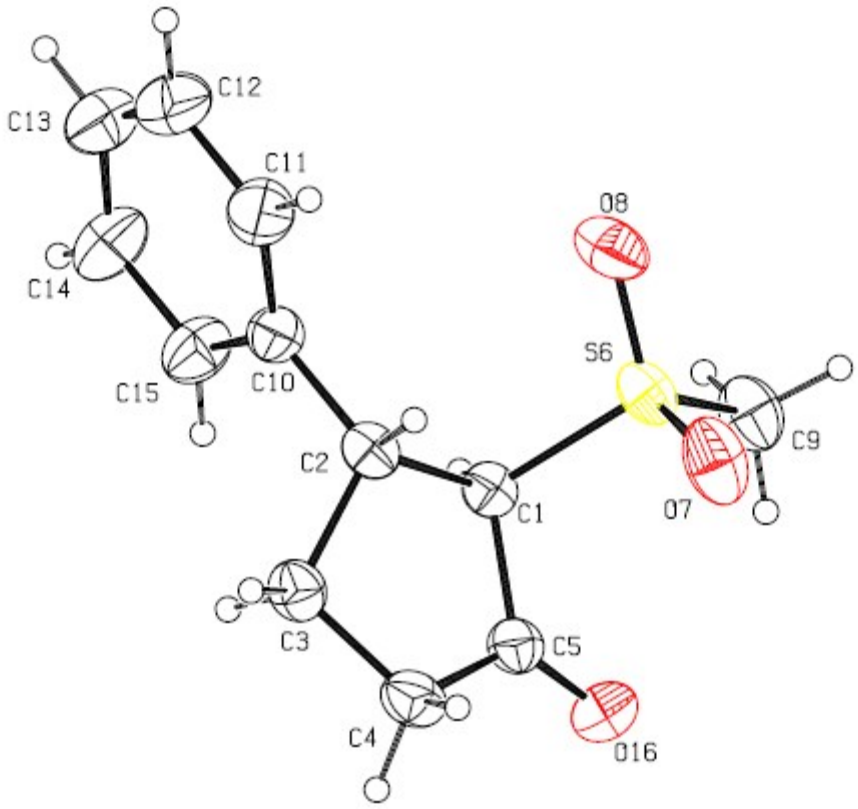
3. Crystallographic Data:



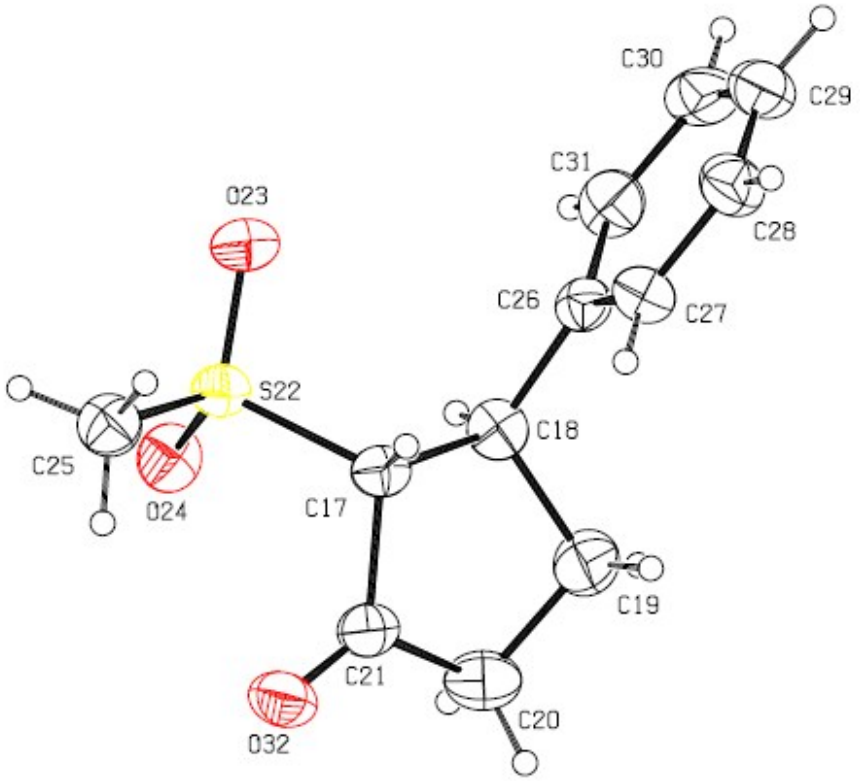
An ORTEP view of **(2*R*, 3*R*)-13j** showing the numbering scheme and relative stereochemistry. Anisotropic displacement parameters are drawn at the 30% probability level.



An ORTEP view of **(2*S*, 3*S*)-13j** showing the numbering scheme and relative stereochemistry. Anisotropic displacement parameters are drawn at the 30% probability level



An ORTEP view of **(2*R*, 3*R*)-13k** showing the numbering scheme and relative stereochemistry. Anisotropic displacement parameters are drawn at the 30% probability level

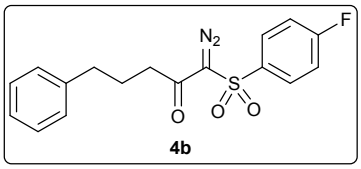


An ORTEP view of **(2*R*, 3*R*)-13k** showing the numbering scheme and relative stereochemistry. Anisotropic displacement parameters are drawn at the 30% probability level

CCDC 1529448 (2*R*, 3*R*)-**13j**, 1529449 (2*S*, 3*S*)-**13j** and 1529450 (2*R*, 3*R*)-**13k** contain the crystallographic data for this paper. This data can be obtained free of charge from The Cambridge Crystallographic Data Centre *via* www.ccdc.cam.ac.uk/data_request/cif

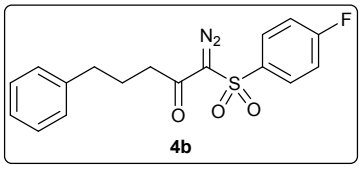
4. NMR Spectra (**4**, **9**, **11–13**, **19**, **20**, **21** and **24**) (All in $CDCl_3$):

^1H



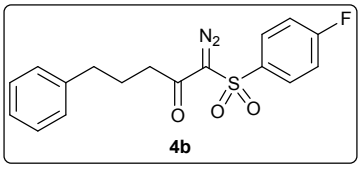
4b

^{13}C



4b

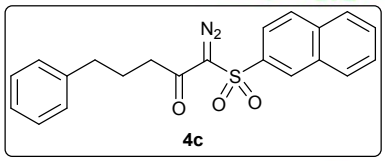
^{19}F


N2
F
S
O
O
O

4b

-15
-20
-25
-30
-35
-40
-45
-50
-55
-60
-65
-70
-75
-80
-85
-90
-95
-100
-105
-110
-115
-120
-125
ppm

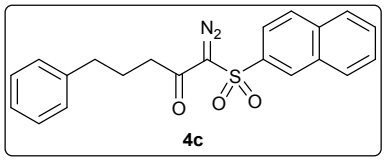
^{1}H


N2
S
O
O
O

4c

10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 ppm

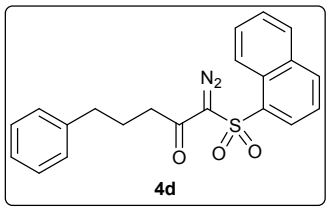
^{13}C


N2
S
O
O
O

4c

200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 ppm

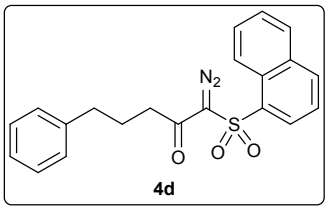
^{1}H


N2
S
O
O
O

4d

10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 ppm
0.96
0.94
1.01
1.02
1.04
1.05
1.02
3.35
2.04
4.16
2.00

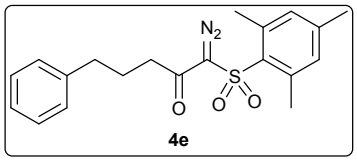
^{13}C


N2
S
O
O
O

4d

200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 ppm

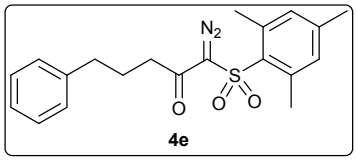
^{1}H


N2
S
O
O
O

4e

10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 ppm

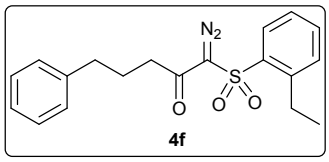
^{13}C


N2
S
O
O
O

4e

200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 ppm

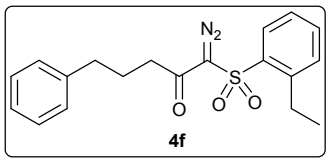
^{1}H


N2
S
O
O
O

4f

10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 ppm

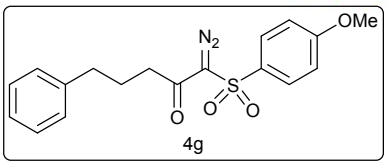
^{13}C


N2
S
O
O
O

4f

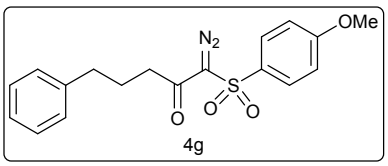
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 ppm

^{1}H


OMe
N2
S
O
O
O
4g

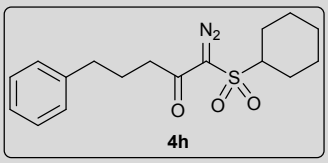
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 ppm
1.84
2.50
1.92
1.84
3.00
4.02
2.01

^{13}C


OMe
N2
S
O
O
O
4g

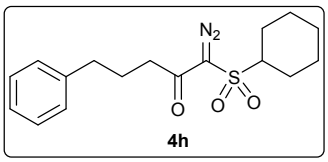
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 ppm

^{1}H


N2
S
O
O
O

4h

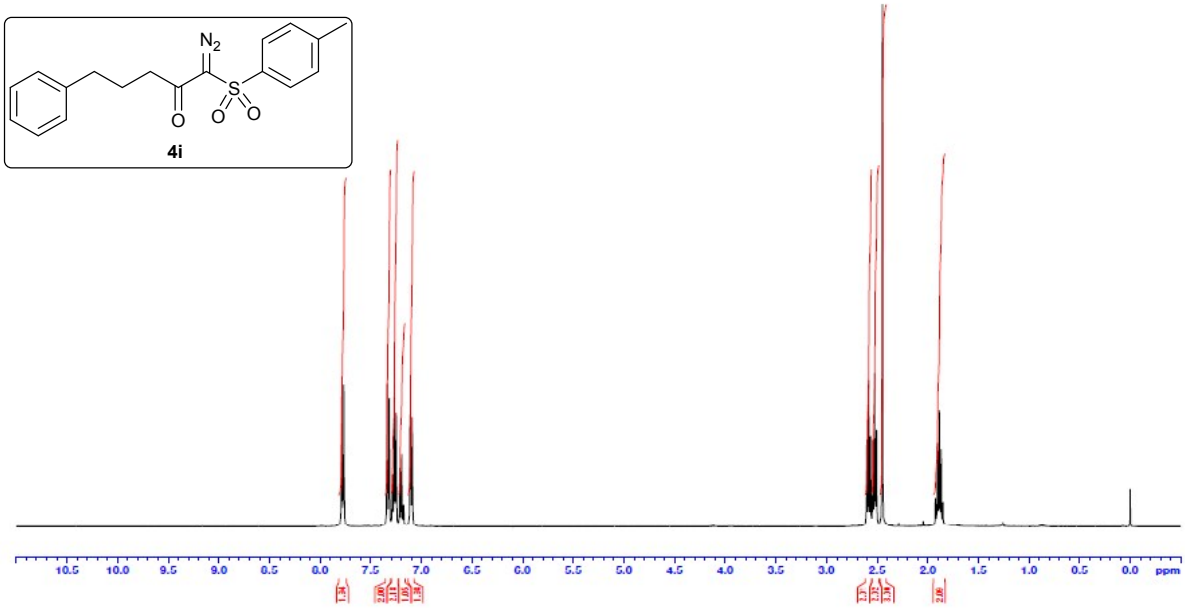
^{13}C


N2
S
O
O
O

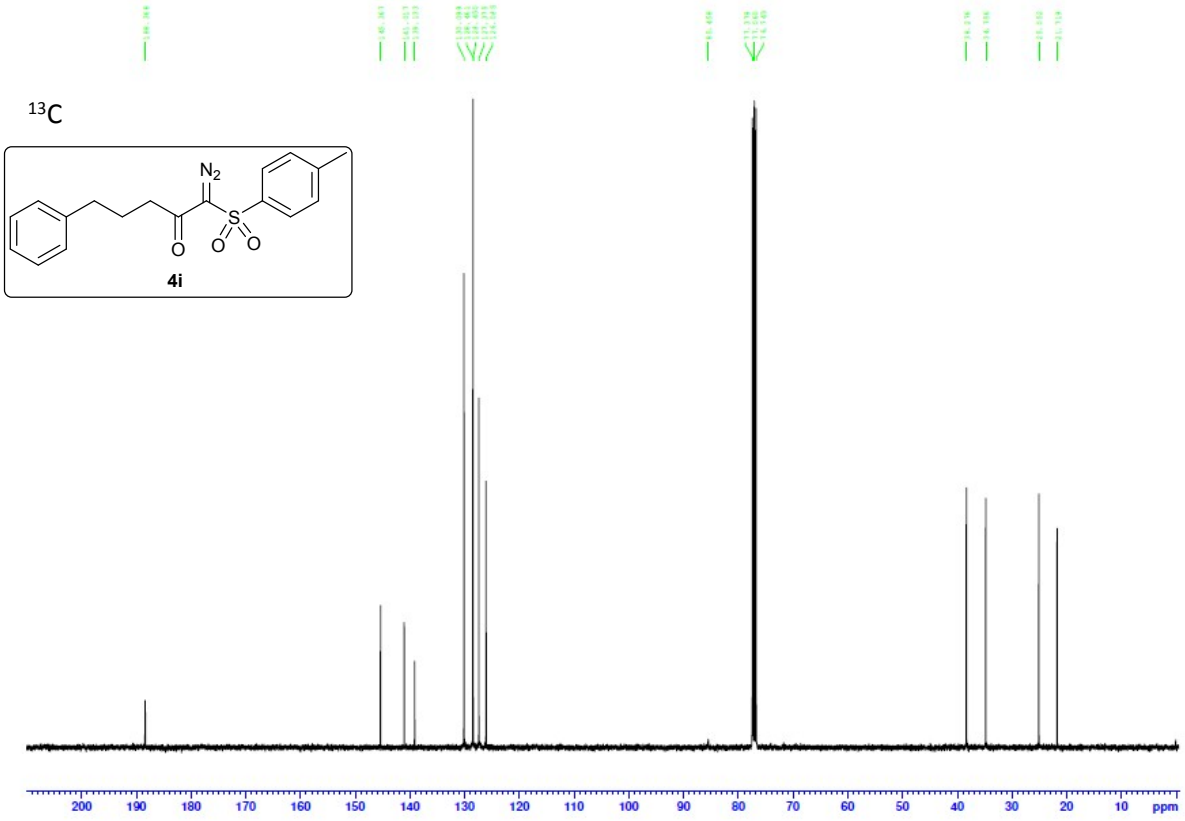
4h

200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
ppm

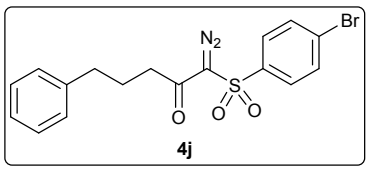
^{1}H


N2
S
O
O
O
4i
10.5 10.0 9.5 9.0 0.5 0.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 ppm

^{13}C


N2
S
O
O
O
4i
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 ppm

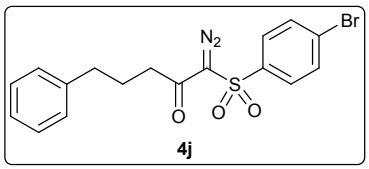
^{1}H


Br
N2
S
O
O
O

4j

10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 ppm

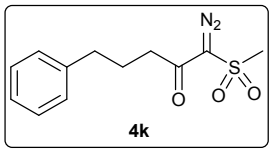
^{13}C


Br
N2
S
O
O
O

4j

200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 ppm

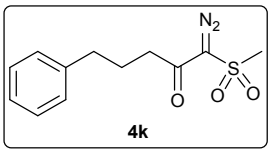
^{1}H


N2
S
O
O
O

4k

10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 ppm

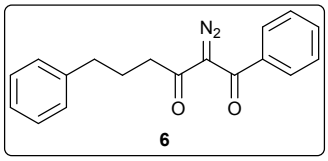
^{13}C


N2
S
O
O
O

4k

200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 ppm

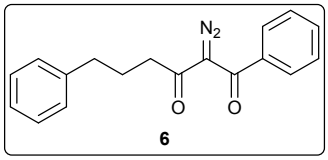
^{1}H


N2
O
O

6

10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 ppm

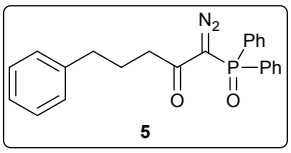
^{13}C


N2
O
O

6

200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 ppm

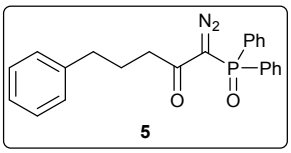
^{1}H


N2
Ph
P
Ph
O
O

5

10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 ppm
3.96
6.00
3.54
1.94
3.07
2.00

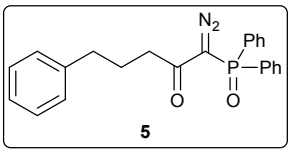
^{13}C


N2
Ph
P
Ph
O
O

5

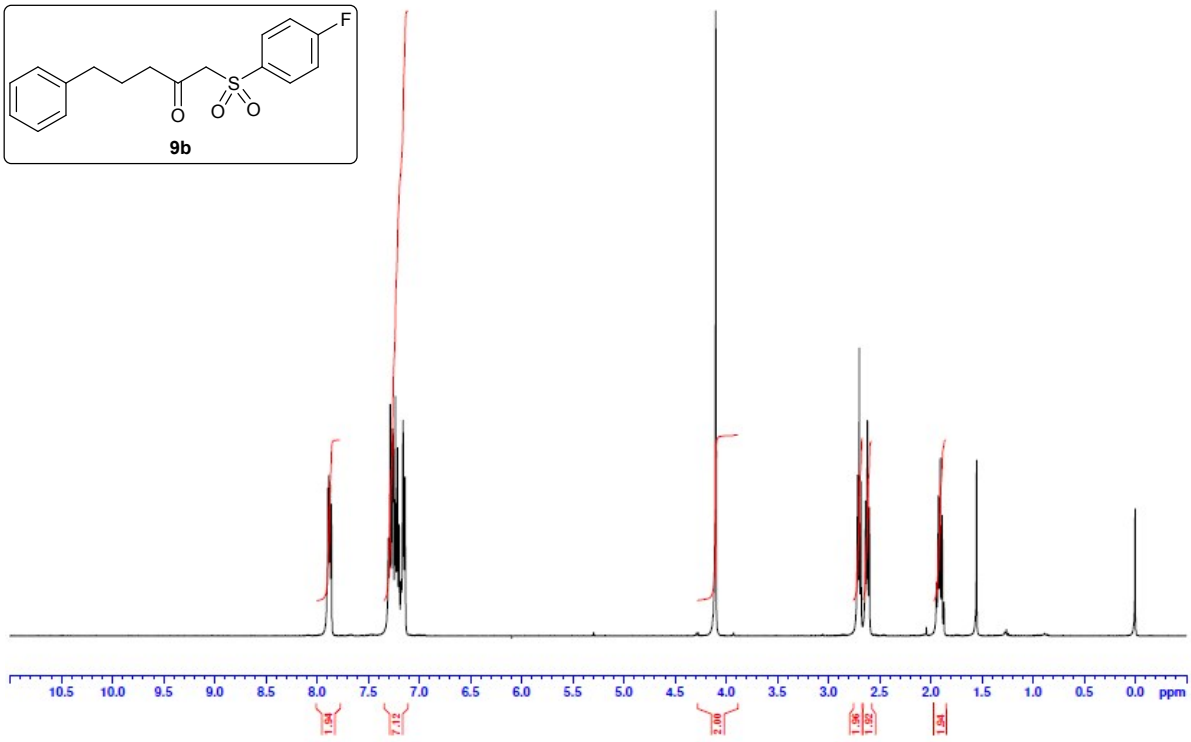
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 ppm

^{31}P

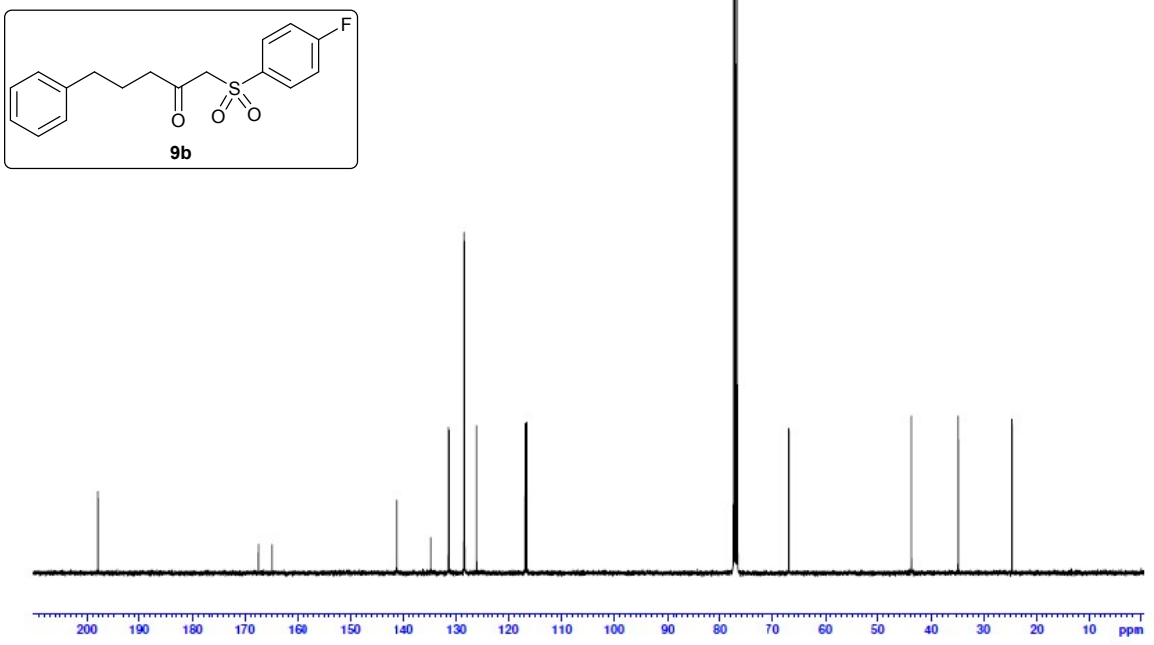


5

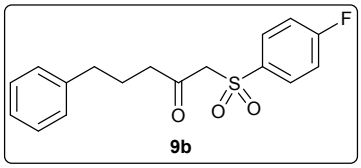
^{1}H


F
S
O
O
O
9b
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 ppm
1.94
7.12
2.00
1.96
1.92
1.94

^{13}C


F
S
O
O
O
9b
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 ppm

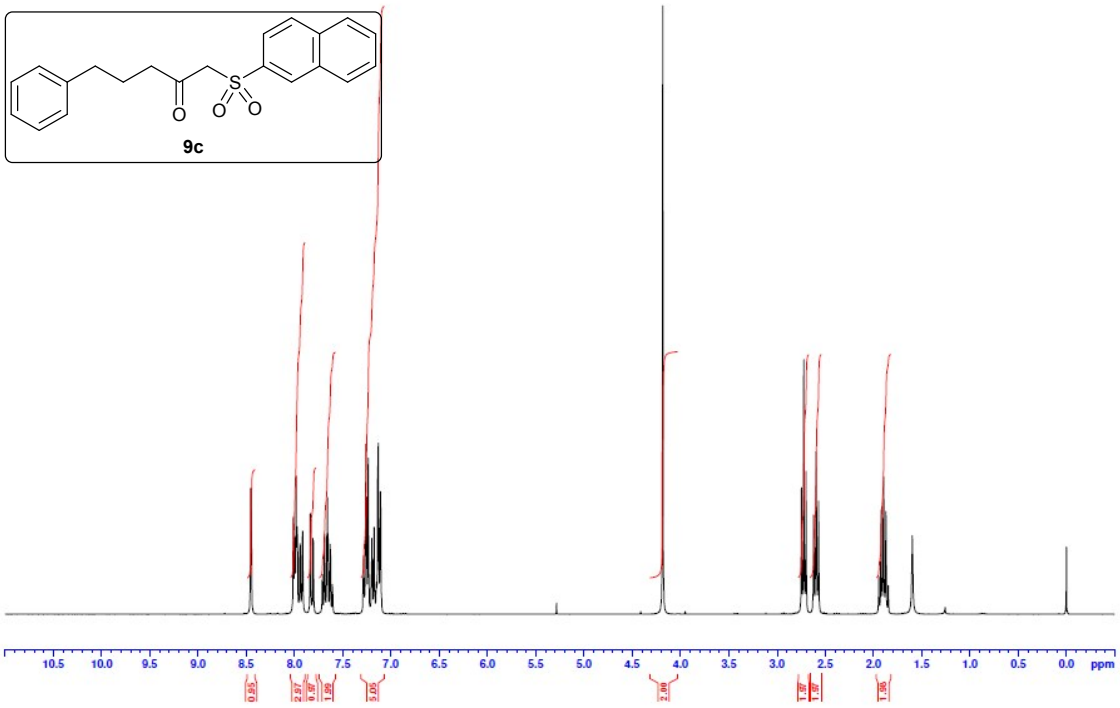
^{19}F


F
S
O
O
O

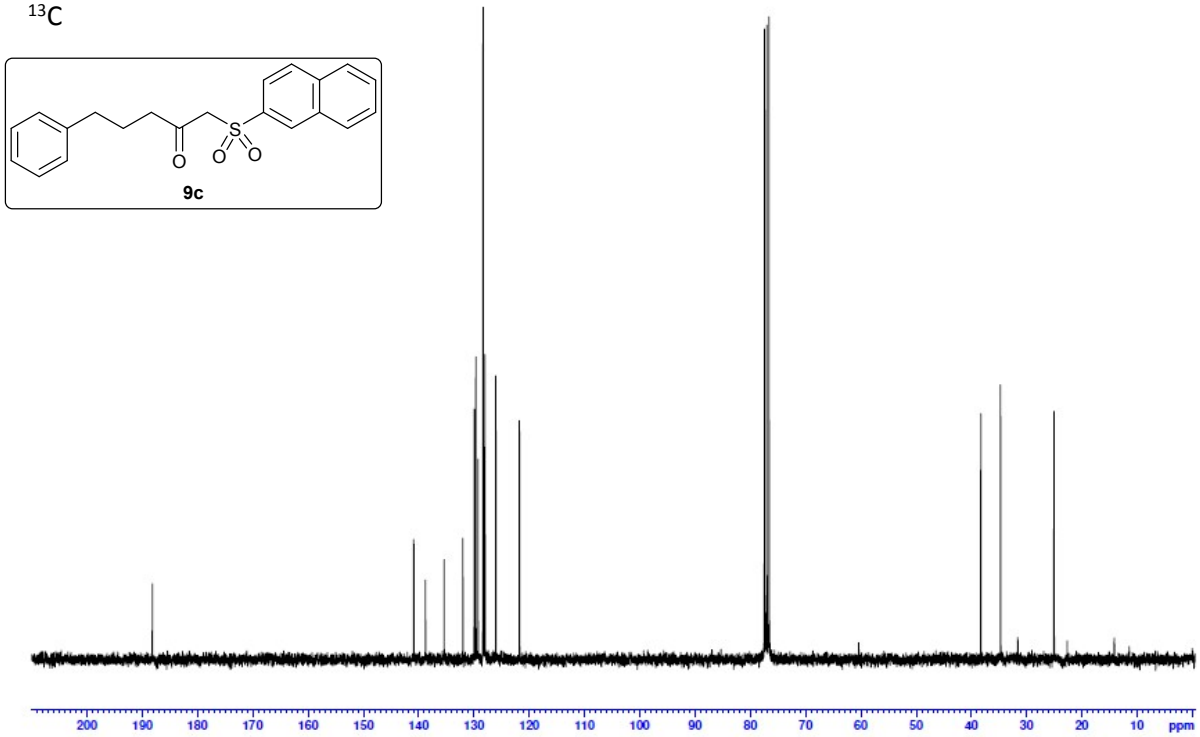
9b

-15
-20
-25
-30
-35
-40
-45
-50
-55
-60
-65
-70
-75
-80
-85
-90
-95
-100
-105
-110
-115
-120
-125
ppm

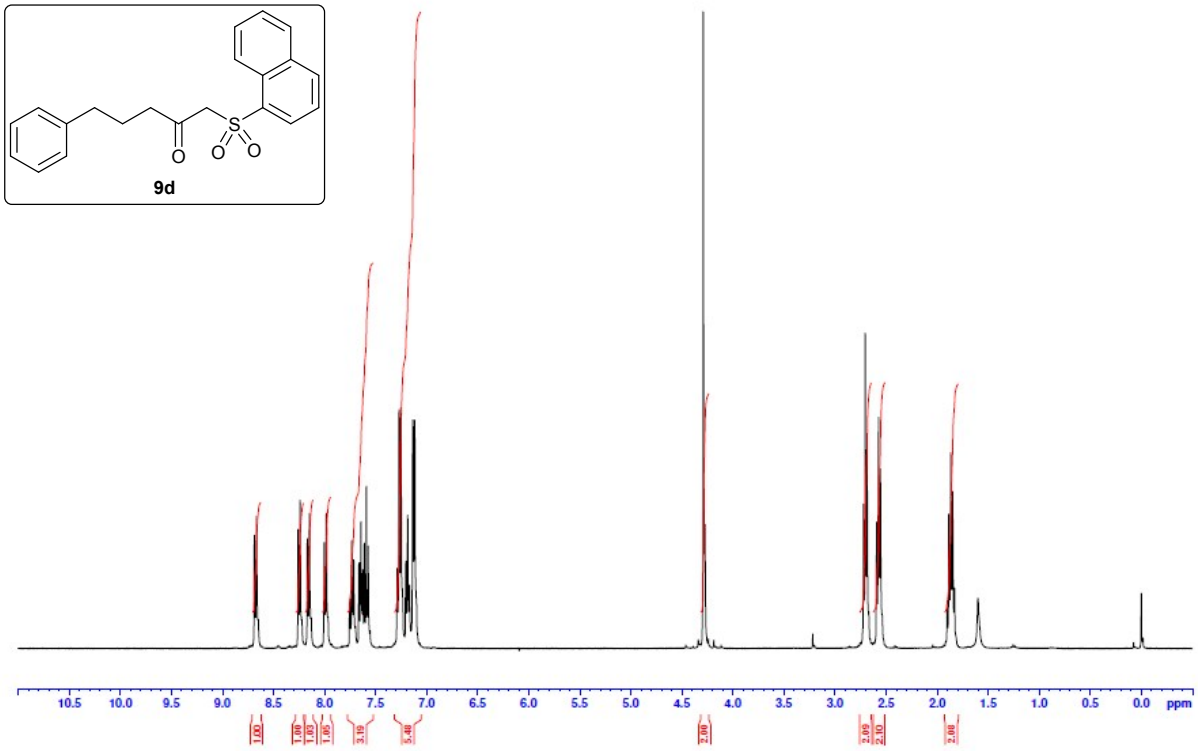
^{1}H


9c
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 ppm

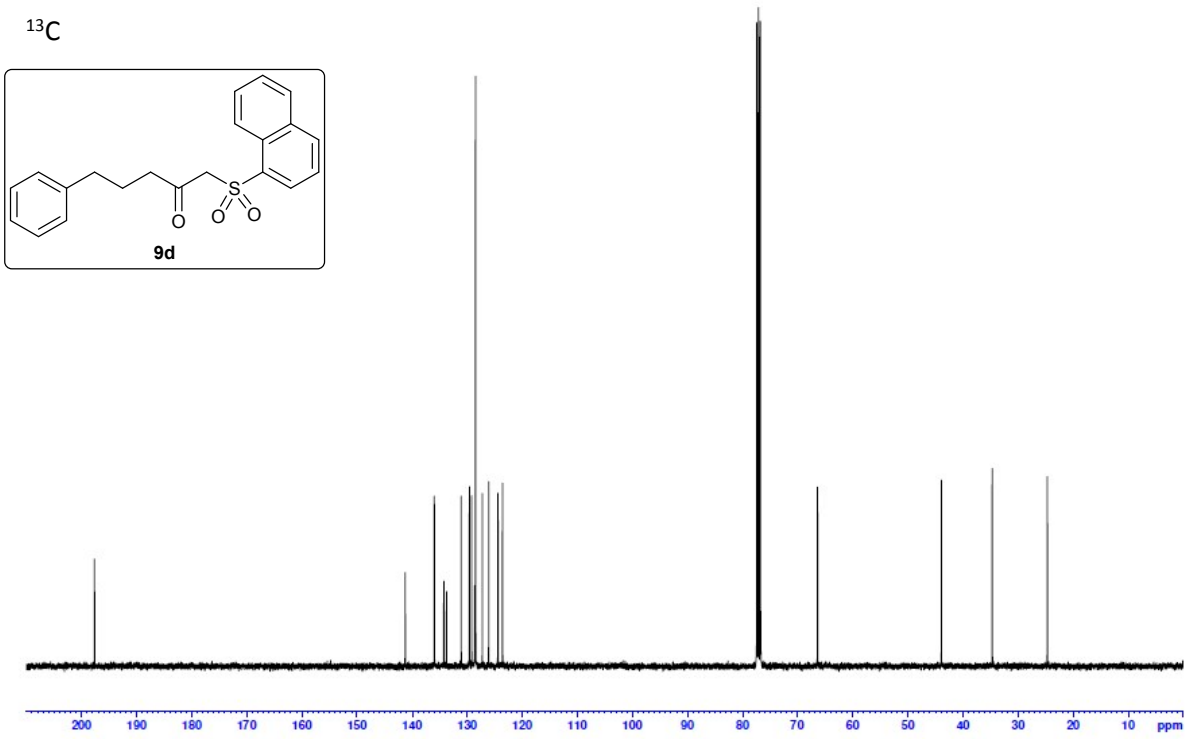
^{13}C


9c
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 ppm

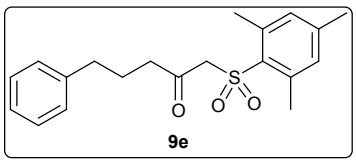
^{1}H


9d
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 ppm

^{13}C


9d
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 ppm

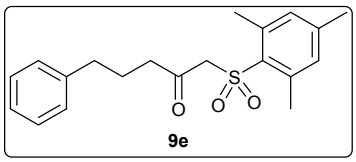
^{1}H


O
S
O
O

9e

10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 ppm

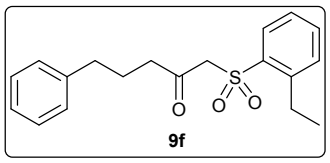
^{13}C


O
S
O
O

9e

200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 ppm

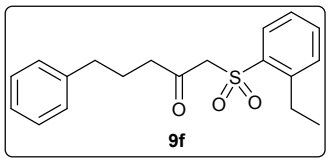
^{1}H


S
O
O
O

9f

10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 ppm

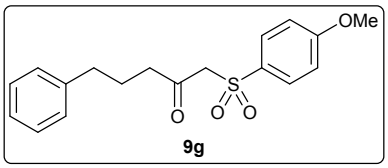
^{13}C


S
O
O
O

9f

200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 ppm

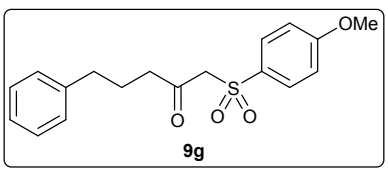
^{1}H


OMe
S
O
O
O

9g

10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 ppm
2.00
5.79
2.05
2.00
3.10
2.07
2.14
2.11

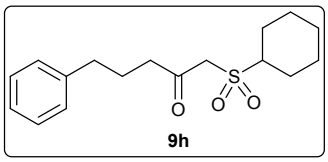
^{13}C


OMe
S
O
O
O

9g

200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 ppm

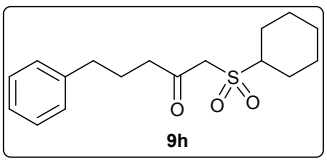
^{1}H


O
S
O
O

9h

10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
ppm

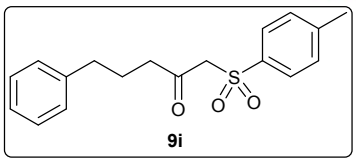
^{13}C


O
S
O
O

9h

200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
ppm

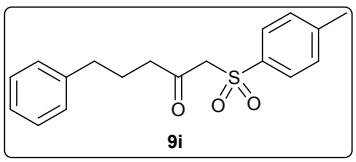
^{1}H


O
S
O
O

9i

10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 ppm
1.92
2.16
2.06
2.00
1.99
3.07
2.01

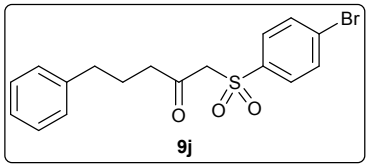
^{13}C


O
S
O
O

9i

200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 ppm

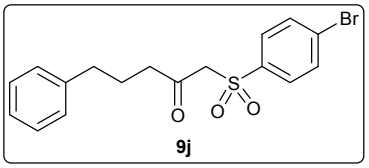
^{1}H


Br
S
O
O
O

9j

10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 ppm
3.80
8.10
2.00
1.98
2.00
2.00

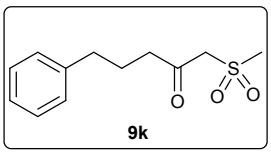
^{13}C


Br
S
O
O
O

9j

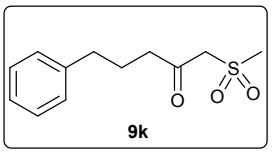
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 ppm

^{1}H


9k

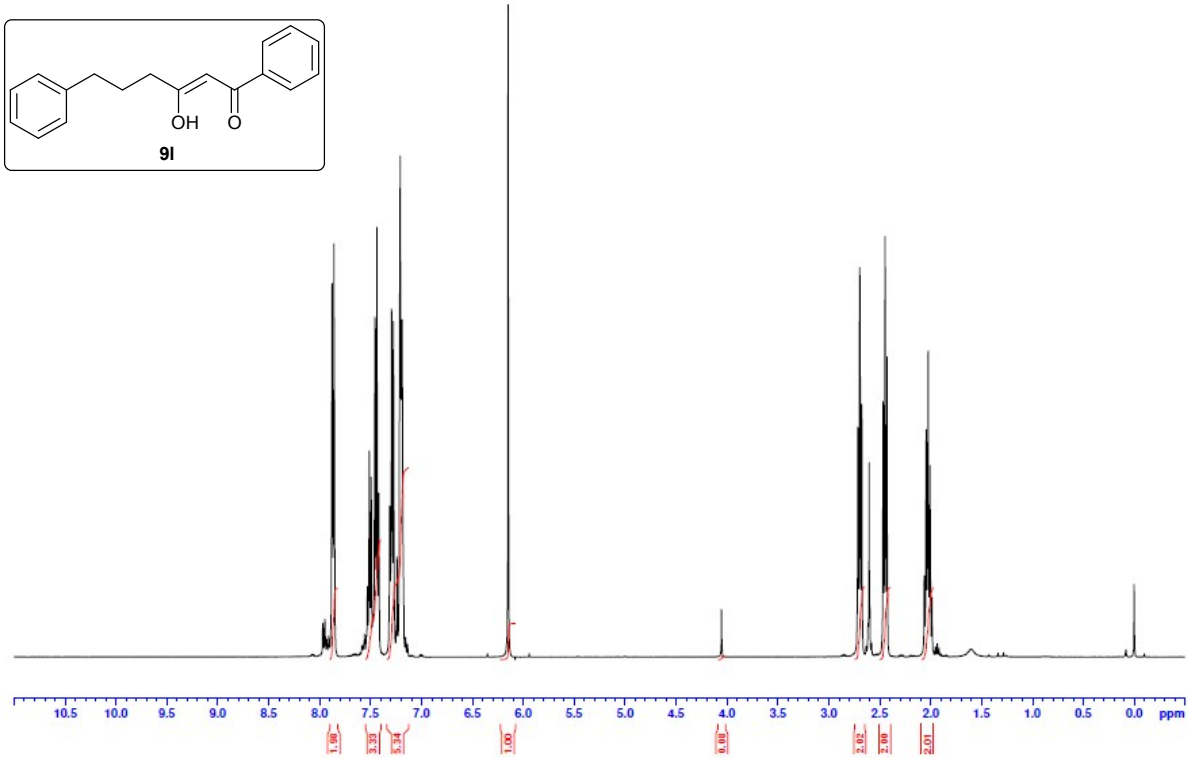
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 ppm

^{13}C

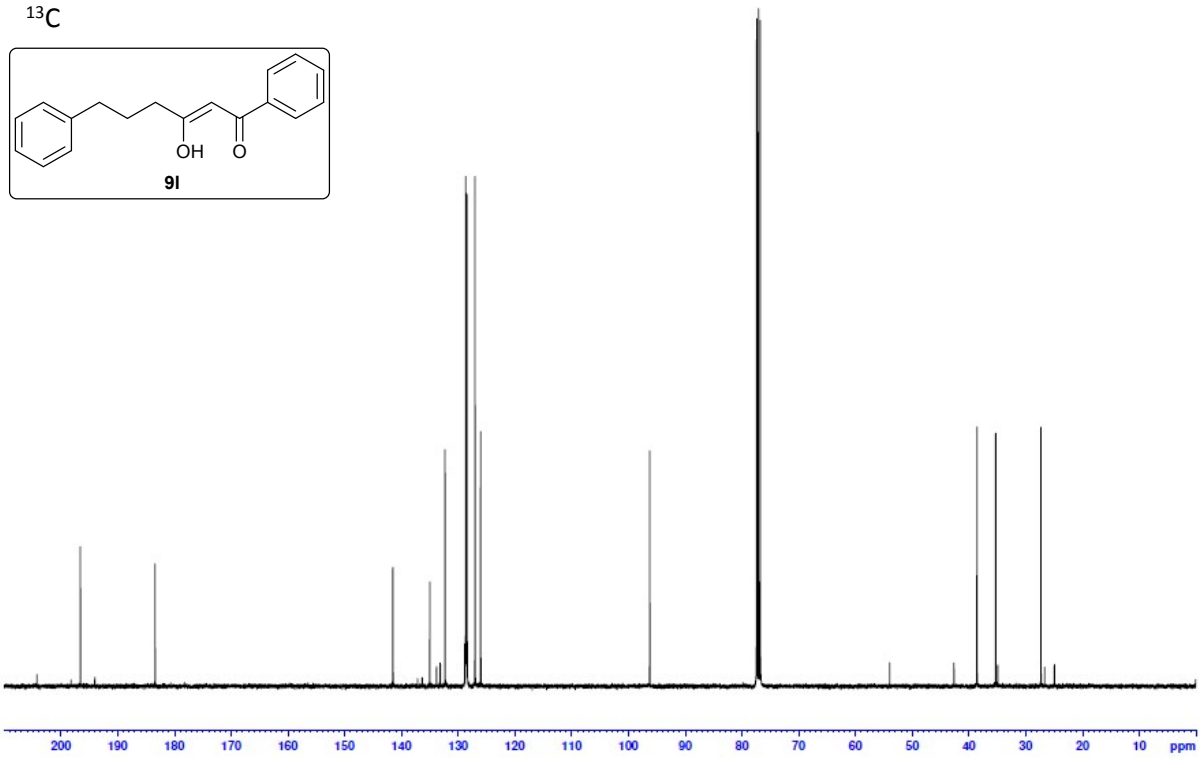

9k

200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 ppm

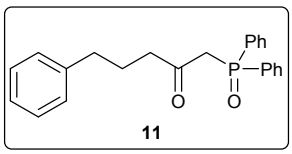
^{1}H


OH
O
9l
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 ppm
1.98
3.33
5.34
1.00
0.88
2.02
2.00
2.01

^{13}C


OH
O
9l
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 ppm

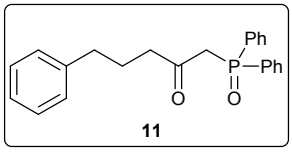
^{1}H


Ph
P
Ph
O
O

11

10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 ppm

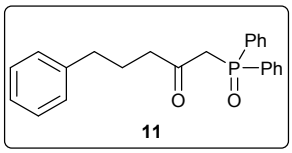
^{13}C


Ph
P
Ph
O
O

11

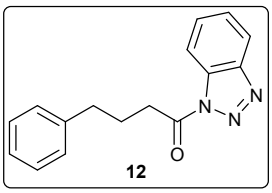
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 ppm

^{31}P



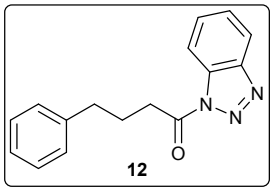
11

^{1}H


12

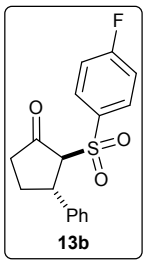
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 ppm

^{13}C


12

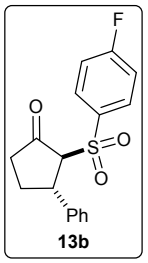
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 ppm

^{1}H



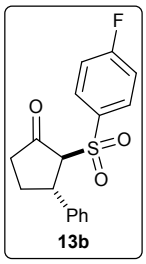
13b

^{13}C



13b

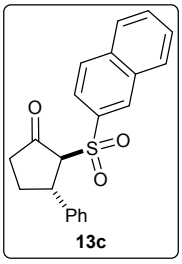
^{19}F


F
O
S
O
O
Ph

13b

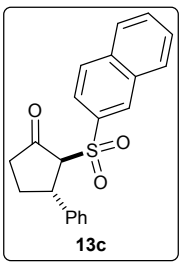
-15
-20
-25
-30
-35
-40
-45
-50
-55
-60
-65
-70
-75
-80
-85
-90
-95
-100
-105
-110
-115
-120
-125
ppm

^{1}H



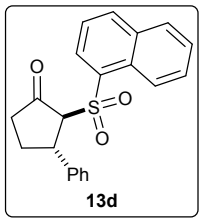
13c

^{13}C



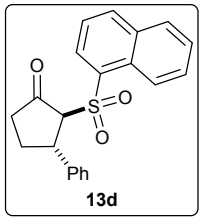
13c

^{1}H



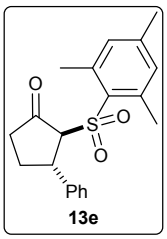
13d

^{13}C



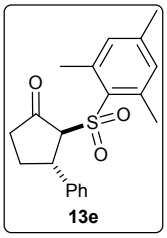
13d

^{1}H



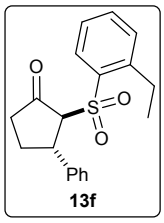
13e

^{13}C



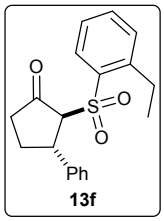
13e

^{1}H



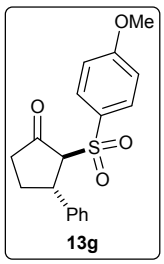
13f

^{13}C



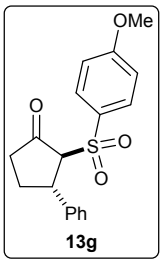
13f

^{1}H



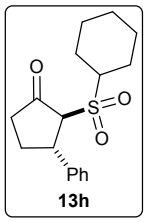
13g

^{13}C



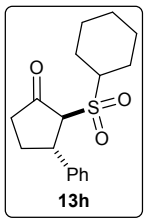
13g

^{1}H



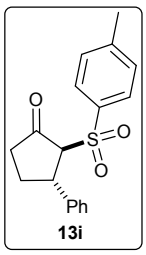
13h

^{13}C



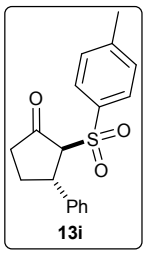
13h

^{1}H



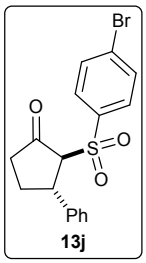
13i

^{13}C



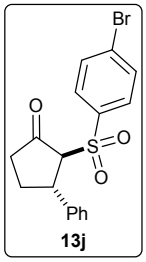
13i

^{1}H



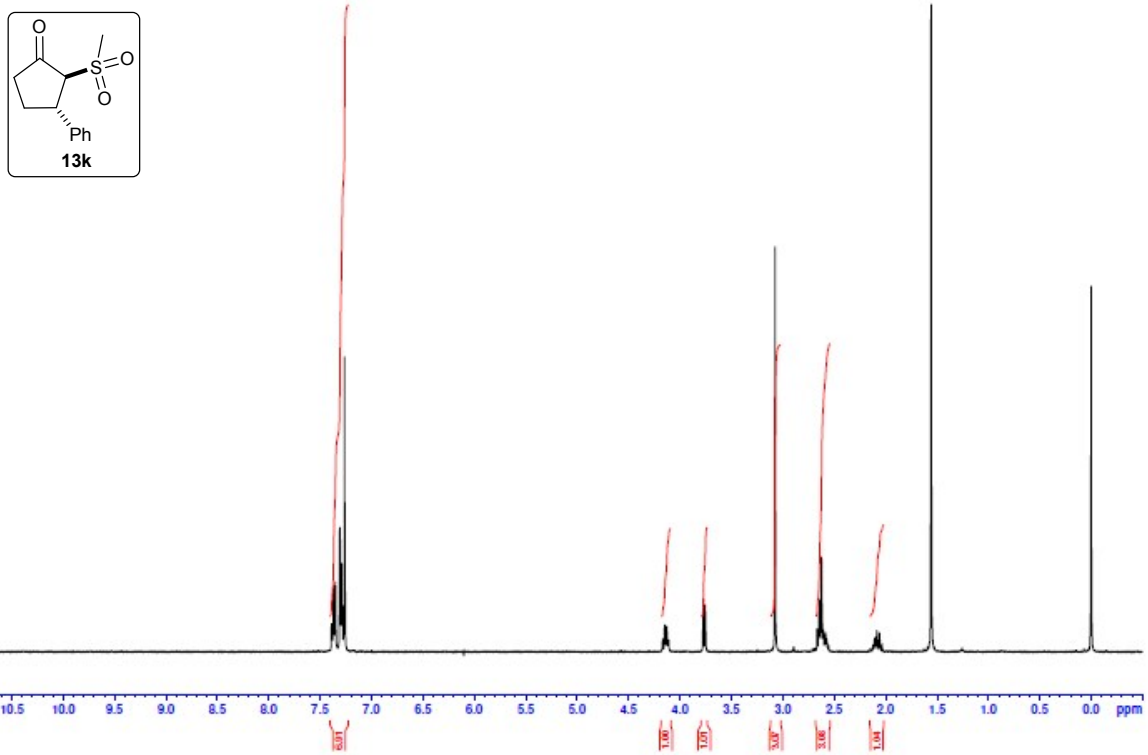
13j

^{13}C

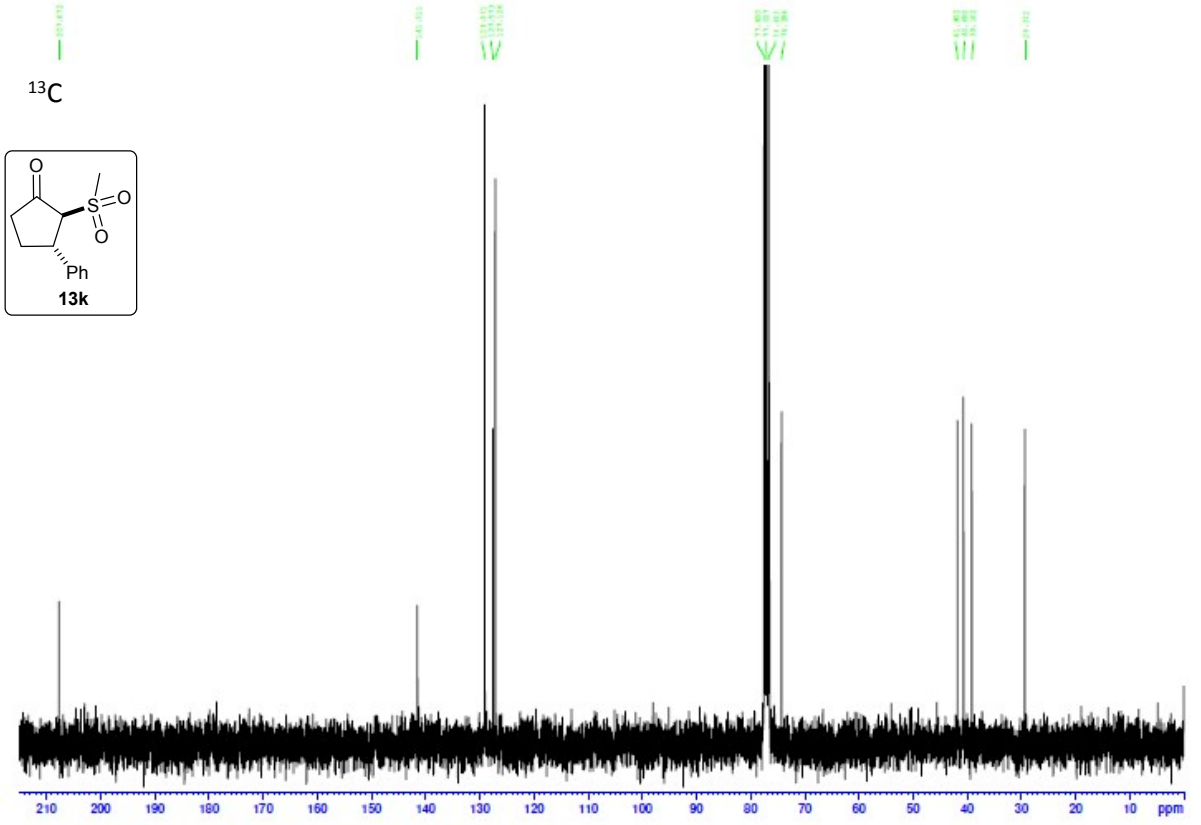


13j

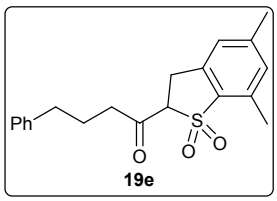
^{1}H


O
S
O
O
Ph
13k
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 ppm

^{13}C

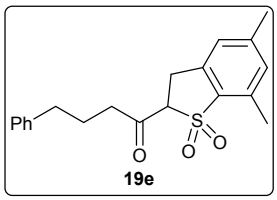

O
S
O
O
Ph
13k
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 ppm

^{1}H


Ph
S
O
O
O
19e

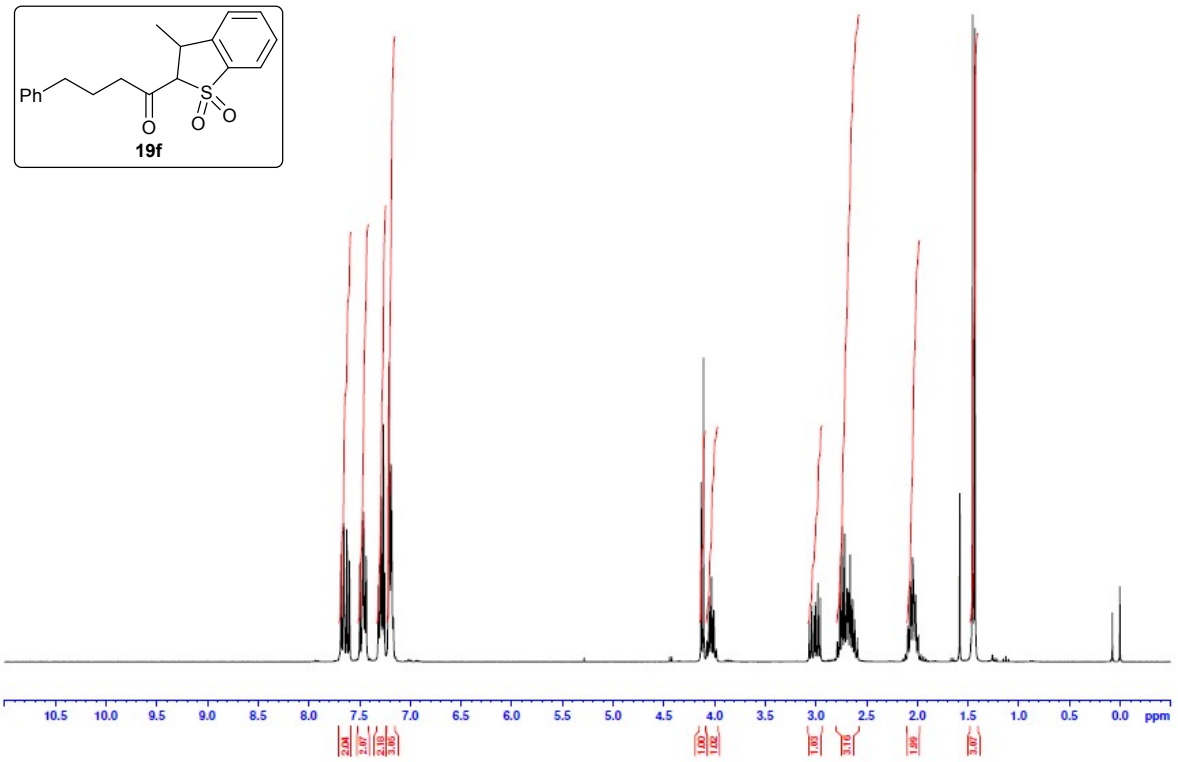
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 ppm
2.17
2.94
2.05
1.00
1.01
1.03
1.03
3.11
2.86
3.05
2.05

^{13}C

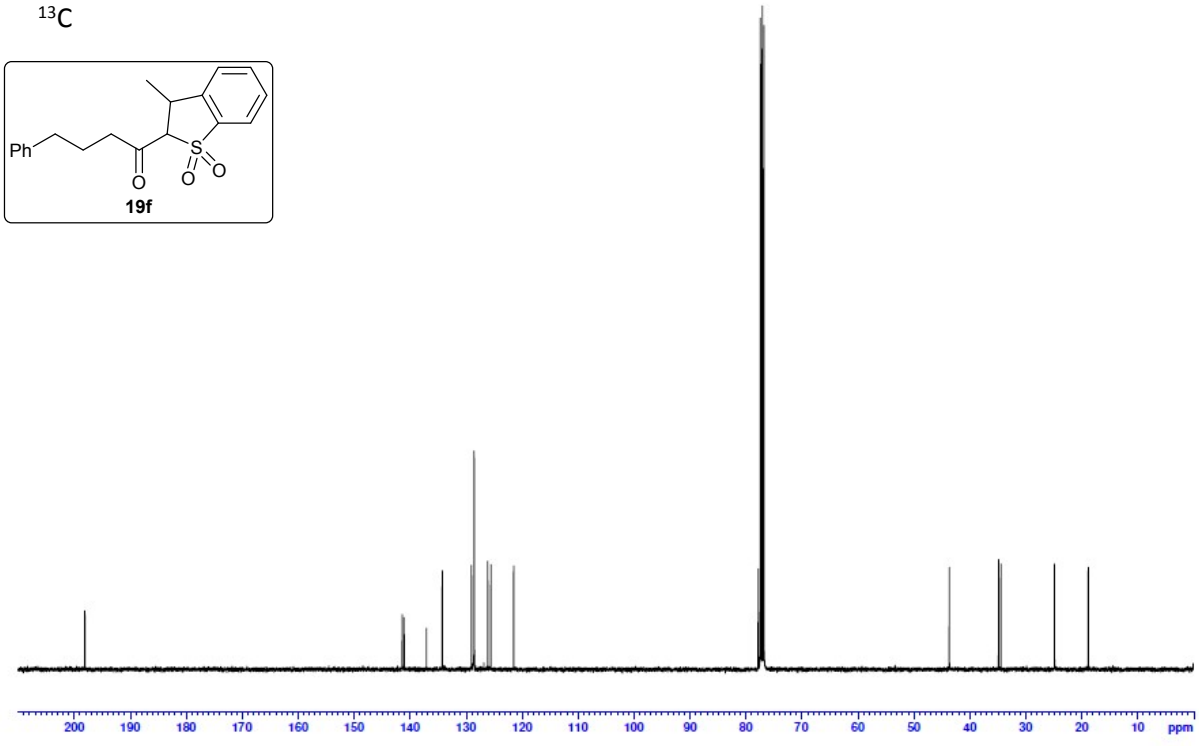

Ph
S
O
O
O
19e

200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 ppm

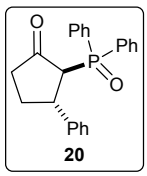
^{1}H


Ph
O
S
O
O
19f
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 ppm
2.04
2.07
2.18
3.85
1.00
1.02
1.03
3.16
1.99
3.87

^{13}C


Ph
O
S
O
O
19f
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 ppm

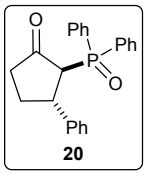
^{1}H


O
Ph
Ph
P
O
Ph

20

10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 ppm
10.56
1.01
1.00
3.25
1.35

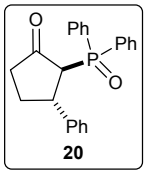
^{13}C


O
Ph
Ph
P
O
Ph

20

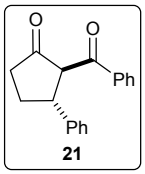
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 ppm

^{31}P



20

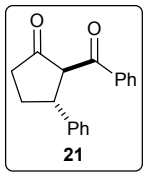
^{1}H


O
O
Ph
Ph

21

10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 ppm
2.36
1.62
2.01
11.12
1.00
1.04
3.66
1.32

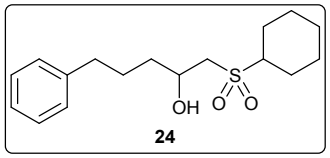
^{13}C


O
O
Ph
Ph

21

210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 ppm

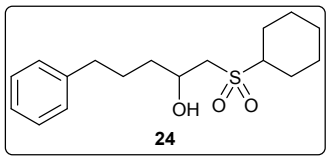
^{1}H


OH
O
O
S

24

10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 ppm
3.15
3.00
1.00
1.00
1.03
2.00
2.07
15.21

^{13}C


OH
O
O
S

24

200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 ppm