Supporting Information

Phosphine-Initiated General Base Catalysis: Facile Access to Benzannulated 1,3-Diheteroatom Five-Membered Rings via Double-Michael Reactions of Allenes

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CONTENTS

General Information

All reagents, except for the tosylated pronucleophiles and allenoates/allenones, were obtained commercially and used without further purification.

TLC: Thin layer chromatography (TLC) was performed on 0.25-mm Silicycle Glass-Backed Extra-Hard-Layer, 60-Å silica gel plates (TLG-R10011B-323) and visualized under UV light or through permanganate and anisaldehyde staining.

Chromatography: Flash column chromatography was performed using Silicycle SiliaFlash® P60 (230–400 mesh, R12030B) and compressed air.

M.P.: Melting points (m.p.) were recorded using an Electrothermal capillary melting point apparatus; they are uncorrected.

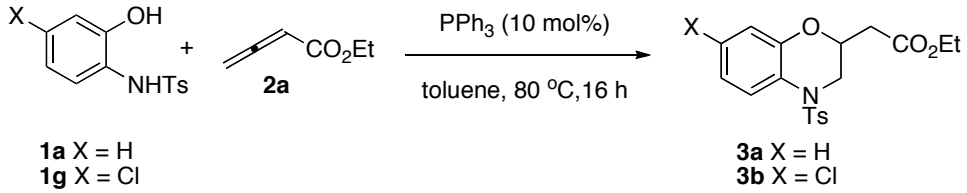
IR Spectroscopy: IR spectra were recorded using a Thermo Nicolet Avatar 370 FT-IR spectrometer.

NMR Spectroscopy: NMR spectra were recorded using Bruker ARX-400 and AV-300 instruments calibrated to $CH(D)Cl_3$ as an internal reference (7.26 and 77.00 ppm for ^{1}H and ^{13}C NMR spectra, respectively). Data for ^{1}H NMR spectra are reported as follows: chemical shift (δ, ppm), multiplicity, coupling constant (Hz), and integration. Data for ^{13}C NMR spectra are reported in terms of chemical shift (δ, ppm). The following abbreviations are used to denote the multiplicities: s = singlet; d = doublet; dd = doublet of doublets; dt = doublet of triplets; dq = doublet of quartets; dq = doublet of pentets; t = triplet; td = triplet of doublets; q = quartet; m = multiplet.

Mass Spectrometry: Mass spectra were recorded using a Waters LCT Premier XE Time-of-Flight Instrument controlled by MassLynx 4.1 software. Samples were infused using direct loop injection from a Waters Acquity UPLC into the Multi Mode Ionization source. The lock mass standard for accurate mass determination was Leucine Enkephalin (Sigma L9133).

X-ray Crystallography: X-ray crystallographic data were collected using a Bruker SMART CCD-based diffractometer equipped with a low-temperature apparatus operated at 100 K.

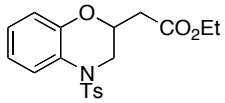
Umpolung Addition/Michael Reaction



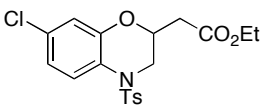
1a X = H
1g X = Cl

3a X = H
3b X = Cl

Ethyl 2,3-butadienoate (**2a**, 49.7 mg, 0.44 mmol) and PPh_3 (10.6 mg, 0.04 mmol) were added sequentially to a solution of the pronucleophile (**1a** or **1g**, 0.40 mmol) in anhydrous toluene (2 mL) under an Ar atmosphere. The mixture was stirred at 80 °C for 12 h before an additional charge of the allenoate **2a** (11.2 mg, 0.10 mmol) was added. Heating was continued for additional 4 h. After the noted disappearance (TLC) of the pronucleophile **1a** or **1g**, the solvent was evaporated under reduced pressure and the crude reaction product was purified through flash column chromatography (hexanes/EtOAc, 10:1) to afford **3a** or **3b**.



Ethyl 2-(4-Tosyl-3,4-dihydro-2*H*-benzo[*b*][1,4]oxazin-3-yl)acetate (3a). White solid (133.3 mg, 88% yield); m.p. 86–88 °C; IR (ν, cm^{-1}): 3060, 2973, 2920, 2889, 1730, 1485, 1345, 1298, 1246, 1164; ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) 7.85 (dd, *J* = 8.2, 1.3 Hz, 1H), 7.55 (d, *J* = 8.2 Hz, 2H), 7.22 (d, *J* = 8.1 Hz, 2H), 7.04 (dt, *J* = 8.1, 1.4 Hz, 1H), 6.92 (dt, *J* = 8.3, 1.4 Hz, 1H), 6.78 (dd, *J* = 8.1, 1.3 Hz, 1H), 4.44 (dd, *J* = 14.3, 2.3 Hz, 1H), 4.18 (q, *J* = 7.1 Hz, 2H), 3.85–3.77 (m, 1H), 3.17 (dd, *J* = 14.3, 9.9 Hz, 1H), 2.65 (dd, *J* = 16.2, 5.8 Hz, 1H), 2.46 (dd, *J* = 16.2, 7.4 Hz, 1H), 2.37 (s, 3H), 1.28 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ (ppm) 169.3, 146.6, 144.3, 135.5, 129.9, 127.4, 126.2, 124.3, 123.5, 121.1, 117.5, 68.2, 61.0, 48.0, 37.7, 21.6, 14.2; HRMS (ESI) calcd for $C_{19}H_{21}NO_5S$ $[M + H]^+$ 376.1213, found 376.1202.



Ethyl 2-(7-Chloro-4-tosyl-3,4-dihydro-2*H*-benzo[*b*][1,4]oxazin-3-yl)acetate (3b). White solid (135.3 mg, 82% yield); m.p. 93–95 °C; IR (ν, cm^{-1}): 2979, 2932, 2868, 1736, 1596, 1572, 1485, 1193, 1088; ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) 7.80 (d, *J* = 8.9 Hz, 1H), 7.54 (d, *J* = 8.3 Hz, 2H), 7.25 (d, *J* = 8.3 Hz, 2H), 6.90 (dd, *J* = 8.9, 2.4 Hz, 1H), 6.80 (d, *J* = 2.3 Hz, 1H), 4.44 (dd, *J*

= 14.5, 2.4 Hz, 1H), 4.18 (q, *J* = 7.1 Hz, 1H), 3.80–3.71 (m, 1H), 3.13 (dd, *J* = 14.5, 9.9 Hz, 1H), 2.63 (dd, *J* = 16.3, 5.8 Hz, 1H), 2.45 (dd, *J* = 16.3, 7.4 Hz, 1H), 2.39 (s, 3H), 1.28 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ (ppm) 169.1, 147.1, 144.6, 135.2, 131.2, 130.0, 127.4, 125.3, 122.3, 121.3, 117.6, 68.4, 61.1, 47.8, 37.5, 21.6, 14.2; HRMS (ESI) calcd for $C_{19}H_{21}ClNO_5S$ $[M + Na]^+$ 432.0643, found 432.0648.

To unequivocally establish the connectivity of the umpolung addition/Michael product, single crystals suitable for X-ray crystallography were grown as follows: **3b** (20 mg) was dissolved in MeOH (0.4 mL) in a 4-dram vial. EtOAc (3 mL) was added to this solution, followed by hexanes (1 mL), and then the resulting solution was left to undergo slow evaporation for 1 day, forming clear colorless needle-shaped free-floating crystals. The remaining mother liquor was decanted and the crystals used for the X-ray crystallographic analysis without further washing. It was critical that MeOH was used; attempts at crystallization using EtOAc and hexane resulted only in the formation of powdery solids.

Optimization of the Double-Michael Reaction

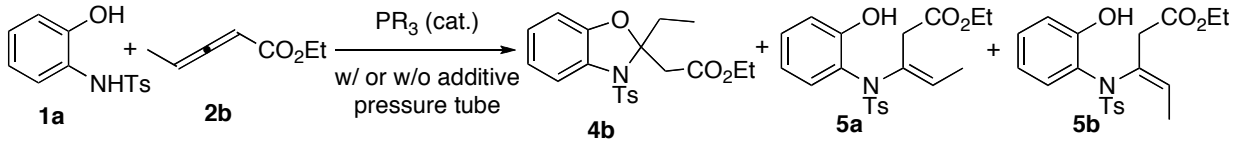
Optimization reactions were conducted for the model reaction of *N*-tosyl-2-aminophenol (**1a**)[1] and the allenoate **2b** (1.1 equiv) in a pressure tube. Typically, **2b** (0.44 mmol), the phosphine (0.04 mmol), and an additive (0.20 mmol, if required) were added sequentially to a degassed solution of **1a** (0.40 mmol) in anhydrous solvent (2 mL) under an Ar atmosphere. The tube was sealed and the mixture stirred at 90 °C for the time indicated in Table S1, at which point the solvent was evaporated under reduced pressure and the residue purified through flash column chromatography (5–10% EtOAc/hexanes) to afford the product **4b** (and **5a/b**). The reaction performed in benzene with 10 mol% PMe_3 at 90 °C afforded the benzoxazoline **4b** and a mixture of the mono-Michael adduct **5a/b** in 66% and 4% yields, respectively (Table S1, entry 1).[2] Changing to a more polar solvent, such as MeCN, increased the yield to 86% (entry 2). Additives, when applied to the reaction, did not improve the product yield (entries 3–5). No product was obtained for the reaction performed at room temperature in MeCN (entry 6). Other phosphines, PBu_3 and PPh_3, afforded a lower yield and no reaction, respectively (entries 7 and

[1] Andersen, K. K.; Gowda, G.; Jewell, L.; McGraw, P.; Phillips, B. T. *J. Org. Chem.* **1982**, *47*, 1884.

[2] To unequivocally establish the structures of the mono-Michael adducts **5a**, its 5-chlorophenyl variant **5c** was prepared and analyzed using X-ray crystallography (vide infra).

8), suggesting that PMe_3 was the best phosphine for the double-Michael reaction. Interestingly, the presence of more catalyst or more allenoate diminished the reaction efficiency (entries 9 and 10). Thus, the optimized conditions involved the reaction of the dinucleophile **1a** with 1.1 equiv of the simple allenoate **2a** in the presence of 10 mol% PMe_3 at 90 °C in a pressure tube. It was advantageous to employ additional allenoate (25 mol%) and PMe_3 (10 mol%) for the reactions involving substituted allenoates (vide infra).

Table S1. Optimization of the Double-Michael Reaction



entry	PR_3[a]	solvent	additive[b]	temp (°C)	time (h)	yield (%)	
						4b	**5a/5b**
1	PMe_3	benzene		90	45	66	4
2	PMe_3	MeCN		90	46	86	0
3	PMe_3	MeCN	NaOAc	90	24	86	trace
4	PMe_3	MeCN	CF_3CO_2Na	90	40	73	trace
5	PMe_3	MeCN	NaOBz	90	15.5	73	trace
6	PMe_3	MeCN		rt	2 days	No reaction	No reaction
7	PBu_3	MeCN		90	42	51	4
8	PPh_3	MeCN		90	41	No reaction	No reaction
9	PMe_3[c]	MeCN		90	40	61	4
10[d]	PMe_3	MeCN		90	40	70	4

[a] 10 mol % was added unless otherwise mentioned. [b] 50 mol %. [c] 15 mol %. [d] 2.1 equiv of allenoate **2b** was used.

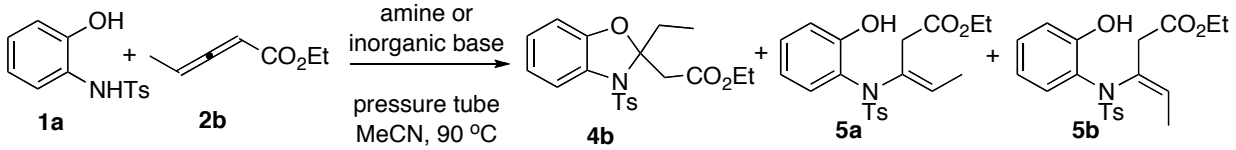
The physical and spectroscopic data for compounds **4b**, **5a**, and **5b** are provided in the following sections.

Screening of Amine and Inorganic Bases for the Double-Michael Reaction

Screening of amines and inorganic bases was conducted using a model system of *N*-tosyl-2-aminophenol (**1a**) and allenoate **2b** (1.1 equiv) in a pressure tube. Typically, **2b** (0.44 mmol) and

an amine (0.04 mmol) or inorganic base (0.44 mmol) were added sequentially to a solution of **1a** (0.40 mmol) in anhydrous MeCN (2 mL) under an Ar atmosphere. The tube was sealed and the mixture stirred at 90 °C for the time indicated in Table S2, at which point the solvent was evaporated under reduced pressure and the residue purified through flash column chromatography (5–10% EtOAc/hexanes) to afford the products **4b** and **5a/b**.

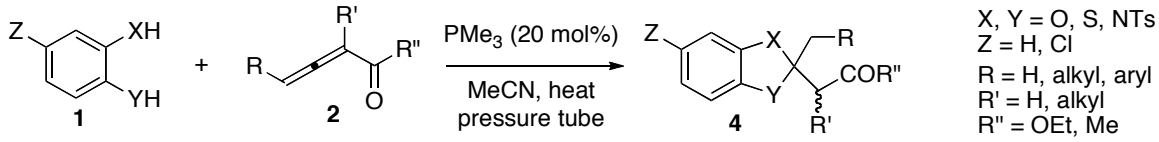
Table S2. Screening of Amine and Inorganic Bases[a]



entry	base[a]	time (h)	yield (%)[b]	
			4b	**5a/5b**
1	quinuclidine	24	26	56
2	3-hydroxyquinuclidine	24	54	30
3	DMAP	24	82	trace
4	DABCO	24	77	10
5	NaOAc[c]	24	7	57
6	NaOAc	24	53	12
7	CF_3CO_2Na	24	0	26
8	Na_2CO_3	20	35	20
9	K_2CO_3	20	49	13
10	Cs_2CO_3	20	39	18
11	$NaHCO_3$	24	16	61

[a] 10 mol % of amine bases and 1.1 eq of inorganic bases were added, unless noted otherwise. [b] Isolated yield after chromatography. [c] 10 mol %.

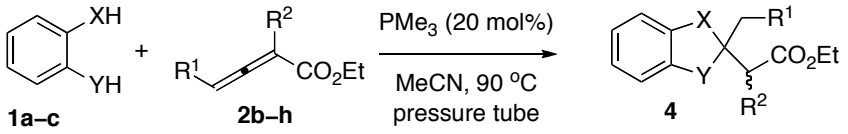
General Procedure for the Double-Michael Reaction



The allene (**2a**–**h** or **18**, 0.44 mmol) and PMe_3 (0.04 mmol)—and NaOAc (50 mol %) for **4w**–**y**—were added to a degassed solution of the pronucleophile (**1a**–**g**, 0.40 mmol) in anhydrous MeCN (2 mL) under an Ar atmosphere. The tube was sealed and the reaction mixture stirred at 90 °C [except for **4f** and **4g**, where heating at 120 °C was required with additional allenoate (0.10 mmol) and PMe_3 (0.04 mmol) for 12 h] for the time indicated in Tables 3 and S3. Additional

charges of the allenoate (0.10 mmol) and PMe_3 (0.04 mmol) were added after 12 h for the complete consumption of the pronucleophile during the reactions affording the double-Michael products **4i**–**4y**. Upon disappearance (TLC) of the nucleophiles **1a**–**g**, the solvent was evaporated under reduced pressure and the residue purified through flash column chromatography (5–10% EtOAc/hexanes) to produce the double-Michael products **4a**–**y**, and **16** (except for **4g**, which was chromatographed using 10–33% EtOAc/hexanes).

Table S3. Double-Michael Annulations of Substituted Allenoates[a]



entry	X, Y	R^1, R^2	time (h)	product	yield (%)[b]
1	O, NTs (**1a**)	Ph, H (**2c**)	48	**4i**	83
2		Bn, H (**2d**)	65	**4j**	61
3		*t*-Bu, H (**2e**)	40	**4k**	69
4	O, S (**1b**)	Me, H (**2b**)	46	**4l**	74
5		Ph, H	48	**4m**	86
6		Bn, H	65	**4n**	65
7		*t*-Bu, H	40	**4o**	58
8	O, O (**1c**)	Me, H	40	**4p**	70
9		Ph, H	48	**4q**	77
10		Bn, H	65	**4r**	89
11		*t*-Bu, H	40	**4s**	82
12		H, Me (**2f**)	35	**4t**	89
13		H, Bn (**2g**)	40	**4u**	86
14		H, CH_2CO_2Et (**2h**)	41	**4v**	80
15[c]	O, NTs	H, Me	35	**4w**	81 (1:1)[d]
16[c]		H, Bn	40	**4x**	73 (2:1)[d]
17[c]		H, CH_2CO_2Et	41	**4y**	84 (1.2:1)[d]

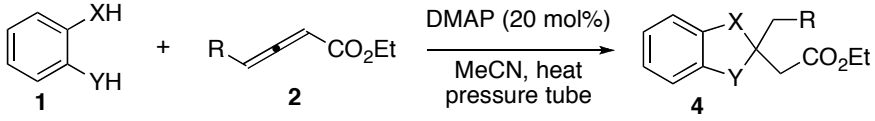
[a] All reactions were preformed using 0.4 mmol of **1** and 1.1 equiv of **2**. Additional charges of **2** (0.1 mmol) and PMe_3 (0.04 mmol) were added after 12 h. [b] Isolated yield. [c] 50 mol % of NaOAc was added. The product yields for **4w**, **4x**, and **4y** in the absence of NaOAc were 78, 53, and 70%, respectively. [d] Diastereoisomeric ratio determined using ^{1}H NMR spectroscopy.

General Procedure for the Double-Michael Reaction Using DMAP

The allene **2** (0.44 mmol) and DMAP (0.04 mmol) were added to a solution of the pronucleophile **1** (0.40 mmol) in anhydrous MeCN (2 mL) under an Ar atmosphere (Table S4). The tube was sealed and the reaction mixture stirred at 90 °C [except for entries 1 and 2, where

heating at 120 °C was required with additional allenoate (0.10 mmol) and DMAP (0.04 mmol) for 12 h] for the time indicated in Table S4. Additional charges of the allenoate (0.10 mmol) and DMAP (0.04 mmol) were added after 12 h to ensure complete consumption of the pronucleophile **1** during the reactions, affording the double-Michael products **4f–g**, **4j–l**, **4n–p**, **4r**, and **4s**. Upon disappearance (TLC) of the nucleophiles **1a–c**, **f**, and **g**, the solvent was evaporated under reduced pressure and the residue purified through flash column chromatography (5–10% EtOAc/hexanes) to produce the double-Michael products **4f**, **4j–l**, **4n–p**, **4r**, and **4s** (except for **4g**, which was chromatographed using 10–33% EtOAc/hexanes).

Table S4. Double-Michael Annulations of Substituted Allenoates

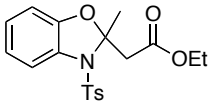


entry	X, Y	R	time (h)	product	yield (%)[b]
1	S, NTs (**1e**)	H (**2a**)	41	**4f**	53
2	NTs, NTs (**1f**)	H	41	**4g**	38
3	O, NTs (**1a**)	Bn (**2d**)	33	**4j**	77
4		*t*-Bu (**2e**)	48	**4k**	51
5	O, S (**1b**)	Me (**2b**)	13	**4l**	76
6		Bn	24	**4n**	89
7		*t*-Bu	48	**4o**	48
8	O, O (**1c**)	Me	13	**4p**	68
9		Bn	33	**4r**	74
10		*t*-Bu	48	**4s**	68

[a] All reactions were performed using 0.4 mmol of **1** and 1.1 equiv of **2**. Additional charges of **2** (0.1 mmol) and DMAP (0.04 mmol) were added after 12 h. [b] Isolated yield.

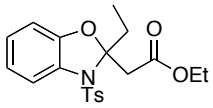
Physical and Spectroscopic Data for the Double-Michael Products

To assign the sets of peaks corresponding to each diastereoisomer for compounds **4w–y**, DEPT, HMQC, and HMBC NMR spectroscopy experiments were used. Copies of the spectra are provided.

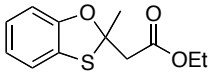


Ethyl 2-(2-Methyl-3-tosyl-2,3-dihydrobenzo[*d*]oxazol-2-yl)acetate (4a). White solid (130.9 mg, 92% yield); m.p. 76–78 °C; IR (ν, cm^{-1}): 3066, 2984, 2932, 2897, 1736, 1596, 1479, 1363,

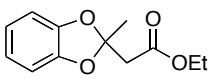
1252, 1158; ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) 7.79 (d, *J* = 8.4 Hz, 2H), 7.39 (dd, *J* = 7.2, 1.2 Hz, 1H), 7.27 (d, *J* = 8.1 Hz, 2H), 6.95–6.84 (m, 2H), 6.74 (dd, *J* = 7.2, 1.5 Hz, 1H), 4.04 (q, *J* = 6.9 Hz, 2H), 3.23 (d, *J* = 15.0 Hz, 1H), 3.13 (d, *J* = 15.0 Hz, 1H), 2.39 (s, 3H), 1.92 (s, 3H), 1.13 (t, *J* = 7.2 Hz, 3H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ (ppm) 168.1, 148.6, 144.4, 137.8, 129.9, 129.7, 126.9, 123.9, 121.5, 113.1, 109.4, 102.5, 60.8, 45.4, 24.9, 21.6, 13.9; HRMS (ESI) calcd for $C_{19}H_{21}NO_5S$ $[M + H]^+$ 376.1213, found 376.1202.



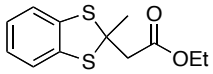
Ethyl 2-(2-Ethyl-3-tosyl-2,3-dihydrobenzo[*d*]oxazol-2-yl)acetate (4b). White solid (127.3 mg, 86% yield); m.p. 86–88 °C; IR (ν, cm^{-1}): 3060, 2979, 2932, 2880, 1736, 1596, 1474, 1363, 1164; ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) 7.86 (d, *J* = 8.4 Hz, 2H), 7.34–7.31 (m, 1H), 7. 28 (d, *J* = 8.4 Hz, 2H), 6.90–6.80 (m, 2H), 6.73–6.70 (m, 1H), 3.95–3.80 (m, 2H), 3.33 (d, *J* = 15.6 Hz, 1H), 3.10 (d, *J* = 15.6 Hz, 1H), 2.40 (s, 3H), 2.30 (dq, *J* = 15.0, 7.2 Hz, 1H), 2.25 (dq, *J* = 15.0, 7.2 Hz), 0.98 (t, *J* = 7.2 Hz, 3H), 0.84 (t, *J* = 7.2 Hz, 3H); ^{13}C NMR (100.6 MHz, $CDCl_3$) δ (ppm) 168.1, 149.4, 144.3, 137.6, 130.6, 129.8, 127.0, 123.4, 121.1, 111.9, 108.5, 105.1, 60.7, 43.5, 32.6, 29.7, 21.5, 13.7, 7.0; HRMS (ESI) calcd for $C_{20}H_{23}NO_5S$ $[M + H]^+$ 390.1370, found 390.1369.



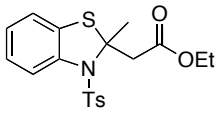
Ethyl 2-(2-Methylbenzo[*d*][1,3]oxathiol-2-yl)acetate (4c). Colorless oil (88.1 mg, 93% yield); IR (ν, cm^{-1}): 3056, 2979, 1736, 1461, 1374, 1339, 1234, 1176; ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) 7.10 (d, *J* = 7.5, 1.3 Hz, 1H), 6.99 (dt, *J* = 7.7, 1.4 Hz, 1H), 6.87 (dt, *J* = 7.5, 1.2 Hz, 1H), 6.79 (dd, *J* = 8.0, 1.0 Hz, 1H), 4.17 (q, *J* = 7.1 Hz, 2H), 3.16 (d, *J* = 15.7 Hz, 1H), 3.07 (d, *J* = 15.6 Hz, 1H), 1.97 (s, 3H), 1.26 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (100.6 MHz, $CDCl_3$) δ (ppm) 169.1, 154.4, 126.2, 125.8, 122.3, 122.0, 110.7, 96.5, 60.9, 47.3, 28.5, 14.1; HRMS (ESI) calcd for $C_{12}H_{14}O_3S$ $[M + Na]^+$ 261.0556, found 261.0549.



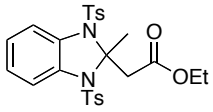
Ethyl 2-(2-Methylbenzo[*d*][1,3]dioxol-2-yl)acetate (4d). Colorless oil (72.8 mg, 80% yield); IR (ν, cm^{-1}): 3060, 2979, 2932, 2903, 1736, 1485, 1374, 1223; ^1H NMR (300 MHz, $CDCl_3$) δ (ppm) 6.82–6.75 (m, 4H), 4.14 (q, *J* = 7.1 Hz, 2H), 2.95 (s, 2H), 1.82 (s, 3H), 1.19 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (100.6 MHz, $CDCl_3$) δ (ppm) 168.2, 146.9, 121.4, 115.6, 108.7, 60.9, 44.0, 24.6, 14.0; HRMS (ESI) calcd for $C_{12}H_{14}O_4$ $[M + Na]^+$ 245.0784, found 245.0783.



Ethyl 2-(2-Methylbenzo[*d*][1,3]dithiol-2-yl)acetate (4e). Colorless oil (73.2 mg, 74% yield); IR (ν, cm^{-1}): 3049, 2979, 2915, 2845, 1724, 1444, 1363, 1334, 1188; ^1H NMR (300 MHz, $CDCl_3$) δ (ppm) 7.19–7.15 (m, 2H), 7.05–6.99 (m, 2H), 4.17 (q, *J* = 7.1 Hz, 2H), 3.16 (s, 2H), 2.02 (s, 3H), 1.27 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ (ppm) 169.4, 137.7, 125.6, 122.6, 64.5, 60.9, 47.5, 28.6, 14.2; HRMS (ESI) calcd for $C_{12}H_{14}O_2S_2$ $[M + Na]^+$ 277.0327, found 277.0327.

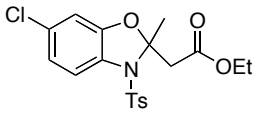


Ethyl 2-(2-Methyl-3-tosyl-2,3-dihydrobenzo[*d*]thiazol-2-yl)acetate (4f). Yellow oil (106.4 mg, 68% yield); IR (ν, cm^{-1}): 3060, 2979, 2926, 2862, 1730, 1596, 1672, 1461, 1362; ^1H NMR (300 MHz, $CDCl_3$) δ (ppm) 7.66–7.63 (m, 1H), 7.57 (d, *J* = 8.4 Hz, 2H), 7.21 (d, *J* = 8.3 Hz, 2H), 7.10–7.00 (m, 3H), 4.20–4.09 (m, 2H), 3.35 (d, *J* = 15.3 Hz, 1H), 3.13 (d, *J* = 15.3 Hz, 1H), 2.38 (s, 3H), 2.18 (s, 3H), 1.25 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ (ppm) 169.1, 144.1, 138.8, 138.1, 129.8, 129.6, 126.8, 125.5, 125.4, 122.4, 119.1, 78.2, 60.9, 47.9, 26.0, 21.6, 14.1; HRMS (ESI) calcd for $C_{12}H_{14}O_2S_2$ $[M + Na]^+$ 277.0327, found 277.0321.

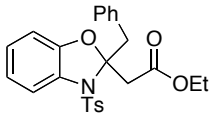


Ethyl 2-(2-Methyl-1,3-ditosyl-2,3-dihydro-1*H*-benzo[*d*]imidazol-2-yl)acetate (4g). White solid (169.1 mg, 79% yield); m.p. 194–196 °C; IR (ν, cm^{-1}): 3060, 2973, 2921, 2891, 1730, 1590, 1479, 1369, 1257; ^1H NMR (300 MHz, $CDCl_3$) δ (ppm) 7.67 (d, *J* = 8.3 Hz, 4H), 7.52–7.46 (m, 2H), 7.18 (d, *J* = 8.4 Hz, 4H), 6.98–6.92 (m, 2H), 3.80 (q, *J* = 7.1 Hz, 2H), 3.49 (s, 2H),

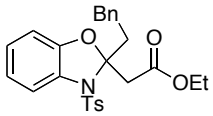
2.37 (s, 6H), 2.14 (s, 3H), 0.96 (t, J = 7.1 Hz, 3H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ (ppm) 168.1, 144.2, 137.9, 131.9, 129.7, 126.9, 123.7, 113.6, 88.8, 60.7, 45.6, 25.4, 21.6, 13.6; HRMS (ESI) calcd for $C_{26}H_{28}N_2O_6S_2$ $[M + H]^+$ 529.1462, found 529.1442.



Ethyl 2-(6-Chloro-2-methyl-3-tosyl-2,3-dihydrobenzo[*d*]oxazol-2-yl)acetate (4h). White solid (139.5 mg, 84% yield); m.p. 70–72 °C; IR (ν, cm^{-1}): 3054, 2985, 2926, 2856, 1736, 1590, 1474, 1363, 1246; ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) 7.76 (d, J = 8.3 Hz, 2H), 7.30 (d, J = 8.3 Hz, 2H), 7.27 (d, J = 8.5 Hz, 1H), 6.85 (dd, J = 8.4, 2.0 Hz, 1H), 6.72 (d, J = 2.0 Hz, 1H), 4.04 (q, J = 7.14 Hz, 2H), 3.23 (d, J = 15.3 Hz, 1H), 3.09 (d, J = 15.3 Hz, 1H), 2.40 (s, 3H), 1.89 (s, 3H), 1.14 (t, J = 7.14 Hz, 3H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ (ppm) 167.9, 149.4, 144.7, 129.9, 128.9, 128.8, 126.9, 121.3, 113.4, 110.2, 103.5, 60.9, 45.2, 25.0, 21.6, 13.9; HRMS (ESI) calcd for $C_{19}H_{21}ClNO_5S$ $[M + H]^+$ 410.0823, found 410.0824.

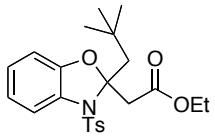


Ethyl 2-(2-Benzyl-3-tosyl-2,3-dihydrobenzo[*d*]oxazol-2-yl)acetate (4i). Colorless oil (141.9 mg, 83% yield); IR (ν, cm^{-1}): 3062, 3025, 2979, 2923, 2868, 1740, 1594, 1481, 1363; ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) 7.81 (d, J = 8.4 Hz, 2H), 7.42–7.17 (m, 8H), 6.86–6.68 (m, 3H), 3.88–3.71 (m, 2H), 3.60 (d, J = 14.0 Hz, 1H), 3.43 (d, J = 13.9 Hz, 1H), 3.40 (d, J = 16.2, 1H), 3.06 (d, J = 16.3 Hz, 1H), 2.38 (s, 3H), 0.94 (t, J = 7.1 Hz, 3H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ (ppm) 167.8, 149.0, 144.4, 137.7, 133.9, 131.2, 130.3, 129.8, 128.1, 127.2, 127.0, 123.5, 121.2, 112.2, 108.8, 103.8, 60.6, 45.7, 41.6, 21.6, 13.7; HRMS (ESI) for $C_{25}H_{25}NO_5S$ $[M + H]^+$ 452.1526, found 452.1513.

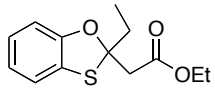


Ethyl 2-(2-Phenethyl-3-tosyl-2,3-dihydrobenzo[*d*]oxazol-2-yl)acetate (4j). White solid (114.2 mg, 61% yield); m.p. 79–81 °C; IR (ν, cm^{-1}): 3061, 3026, 2979, 2932, 2868, 1736, 1596, 1479,

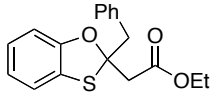
1369, 1252, 1164, 1106; ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) 7.88 (d, *J* = 8.3 Hz, 2H), 7.39–7.14 (m, 6H), 7.07 (d, *J* = 8.0 Hz, 2H), 6.9 (dq, *J* = 7.7, 1.6 Hz, 2H), 6.76 (dd, *J* = 6.9, 1.9 Hz, 1H), 3.82–3.99 (m, 2H), 3.37 (d, *J* = 15.9 Hz, 1H), 3.14 (d, *J* = 15.6 Hz, 1H), 2.62 (m, 4H), 2.40 (s, 3H), 0.99 (t, *J* = 7.2 Hz, 3H); ^{13}C NMR (100.6 MHz, $CDCl_3$) δ (ppm) 167.9, 149.2, 144.5, 140.6, 137.6, 130.5, 130.0, 128.4, 127.1, 126.0, 123.5, 121.3, 112.0, 108.7, 104.2, 60.7, 43.6, 41.3, 28.7, 21.6, 13.7; HRMS (ESI) calcd for $C_{26}H_{27}NO_5S$ $[M + H]^+$ 466.1683, found 466.1672.



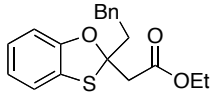
Ethyl 2-(2-Neopentyl-3-tosyl-2,3-dihydrobenzo[*d*]oxazol-2-yl)acetate (4k). White solid (120.1 mg, 69% yield); m.p. 82–84 °C; IR (ν, cm^{-1}): 2950, 2897, 2862, 1713, 1631, 1503, 1491, 1368, 1339; ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm); 7.84 (d, *J* = 8.4 Hz, 2H), 7.41–7.38 (m, 1H), 7.27 (d, *J* = 8.4 Hz, 2H), 6.92–6.84 (m, 2H), 6.71–6.68 (m, 1H), 3.87–3.68 (m, 2H), 3.29 (d, *J* = 16.0 Hz, 1H), 3.13 (d, *J* = 16.0 Hz, 1H), 2.39 (s, 3H), 2.36 (d, *J* = 15.2 Hz, 1H), 2.22 (d, *J* =15.2 Hz, 1H), 0.99 (s, 9H), 0.93 (t, *J* = 7.1 Hz, 1H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ (ppm) 167.9, 149.2, 144.3, 137.8, 130.0, 129.7, 127.2, 123.5, 121.1, 112.3, 108.8, 105.1, 60.5, 51.3, 44.4, 31.0, 21.5, 13.6; HRMS (ESI) calcd for $C_{23}H_{29}NO_5S$ $[M + Na]^+$ 454.1659, found 454.1658.



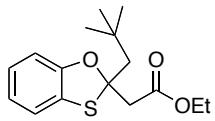
Ethyl 2-(2-Ethylbenzo[*d*][1,3]oxathiol-2-yl)acetate (4l). Colorless oil (80.7 mg, 74% yield); IR (ν, cm^{-1}): 3066, 2967, 2926, 2874, 1730, 1573, 1462, 1369, 1234, 1182; ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) 7.09 (dd, *J* = 7.5, 0.9 Hz, 1H), 6.98 (td, *J* = 7.8, 1.2 Hz, 1H), 6.85 (td, *J* = 7.5, 1.2 Hz, 1H), 6.78 (dd, *J* = 7.8, 0.9 Hz, 1H), 4.14 (q, *J* = 6.9 Hz, 2H), 3.14 (d, *J* = 15.6 Hz, 1H), 3.08 (d, *J* = 15.6 Hz, 1H), 2.27 (dq, *J* = 14.4, 7.2 Hz, 1H), 2.23 (dq, J = 14.4, 7.2 Hz, 1H), 1.23 (t, *J* = 7.2 Hz, 3H), 1.09 (t, *J* = 7.2 Hz, 3H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ (ppm) 169.1, 155.1, 126.0, 125.6, 122.1, 121.8, 110.3, 100.3, 60.9, 45.6, 33.6, 14.1, 8.9; HRMS (ESI) calcd for $C_{13}H_{16}O_3S$ $[M + Na]^+$ 275.0712, found 275.0709.



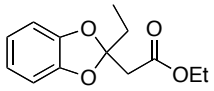
Ethyl 2-(2-Benzylbenzo[*d*][1,3]oxathiol-2-yl)acetate (4m). Yellow oil (106.9 mg, 86% yield); IR (ν, cm^{-1}): 3062, 3030, 2978, 2933, 1730, 1572, 1455, 1373, 1233; ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) 7.32–7.27 (m, 5H), 7.11 (dd, *J* = 7.5, 1.4 Hz, 1H), 7.00 (td, *J* = 7.7, 1.4 Hz, 1H), 6.88 (td, *J* = 7.5, 1.2 Hz, 1H), 6.84 (dd, *J* = 7.5, 1.1 Hz, 1H), 4.25–4.15 (m, 2H), 3.64 (d, *J* = 14.0 Hz, 1H), 3.46 (d, *J* = 14.0 Hz, 1H), 3.10 (d, *J* = 16.3 Hz, 1H), 2.98 (d, *J* = 16.3 Hz, 1H), 1.28 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (100.6 MHz, $CDCl_3$) δ (ppm) 169.4, 154.4, 135.5, 130.7, 128.3, 127.2, 126.2, 125.8, 122.3, 122.0, 110.7, 99.1, 61.0, 46.3, 43.8, 14.2; HRMS (ESI) calcd for $C_{18}H_{18}O_3S$ $[M + H]^+$ 315.1049, found 315.1038.



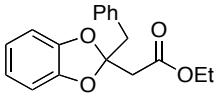
Ethyl 2-(2-Phenethylbenzo[*d*][1,3]oxathiol-2-yl)acetate (4n). Colorless oil (85.0 mg, 65% yield); IR (ν, cm^{-1}): 3072, 3026, 2973, 2926, 2851, 1730, 1602, 1573, 1462, 1369; ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 7.31–7.27 (m, 2H), 7.22–7.17 (m, 3H), 7.13 (dd, *J* = 7.6, 1.3 Hz, 1H), 7.01 (td, *J* = 7.6, 1.4 Hz, 1H), 6.89 (td, *J* = 7.5, 1.2 Hz, 1H), 6.82 (dd, *J* = 7.9, 0.9 Hz, 1H), 4.16 (q, *J* = 7.2 Hz, 2H), 3.20 (d, *J* = 15.7 Hz, 1H), 3.14 (d, *J* = 15.7 Hz, 1H), 3.01–2.93 (m, 1H), 2.86–2.79 (m, 1H), 2.60–2.45 (m, 2H), 1.25 (t, *J* = 7.2 Hz, 3H); ^{13}C NMR (100.6 MHz, $CDCl_3$) δ (ppm) 169.0, 154.9, 141.1, 128.5, 126.0, 125.9, 125.8, 125.8, 122.2, 121.9, 110.4, 99.2, 60.9, 46.1, 42.3, 30.9, 14.1; HRMS (ESI) calcd for $C_{19}H_{20}O_3S$ $[M + Na]^+$ 351.1025, found 351.1020.



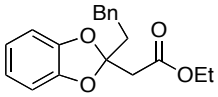
Ethyl 2-(2-Neopentylbenzo[*d*][1,3]oxathiol-2-yl)acetate (4o). Colorless oil (67.5 mg, 58% yield); IR (ν, cm^{-1}): 3067, 2951, 2904, 2865, 1733, 1574, 1465, 1368, 1236; ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) 7.10 (dd, *J* = 7.5, 1.3 Hz, 1H), 6.98 (td, *J* = 7.7, 1.4 Hz, 1H), 6.86 (td, *J* = 7.5, 1.2 Hz, 1H), 6.78 (dd, *J* = 7.9, 0.9 Hz, 1H), 4.21–4.10 (m, 2H), 3.22 (s, 2H), 2.33 (d, *J* = 15.3 Hz, 1H), 2.22 (d, *J* = 15.3 Hz, 1H), 1.24 (t, *J* = 7.1 Hz, 3H), 1.1 (s, 9H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ (ppm) 169.4, 154.3, 126.5, 125.6, 122.1, 121.7, 110.7, 99.7, 60.8, 51.4, 47.0, 31.8, 31.0, 14.1; HRMS (ESI) calcd for $C_{16}H_{22}O_3S$ [M + H] 295.1362, found 295.1354.



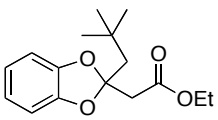
Ethyl 2-(2-Ethylbenzo[*d*][1,3]dioxol-2-yl)acetate (4p). Colorless oil (97.5 mg, 70% yield); IR (ν, cm^{-1}): 3066, 2979, 2932, 1742, 1596, 1479, 1369; ^1H NMR (300 MHz, $CDCl_3$) δ (ppm) 6.78 (s, 4H), 4.10 (q, *J* = 7.1 Hz, 2H), 2.93 (s, 2H), 2.13 (q, *J* = 7.4, 2H), 1.16 (t, *J* = 7.1 Hz, 3H), 1.03 (t, *J* = 7.4 Hz, 3H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ (ppm) 168.2, 147.5, 121.3, 117.4, 108.4, 60.8, 42.5, 30.9, 13.9, 6.9; MS (EI) calcd for $C_{13}H_{16}O_4$ $[M + Na]^+$ 259.0941, found 259.0937.



Ethyl 2-(2-Benzylbenzo[*d*][1,3]dioxol-2-yl)acetate (4q). Colorless oil (94.8 mg, 77% yield); IR (ν, cm^{-1}): 3062, 3030, 2981, 2925, 1736, 1485, 1333, 1234, 1088; ^1H NMR (300 MHz, $CDCl_3$) δ (ppm) 7.36–7.23 (m, 5H), 6.77 (s, 4H), 4.28 (q, *J* = 7.2 Hz, 2H), 3.41 (s, 2H), 2.88 (s, 2H), 1.17 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ (ppm) 168.3, 147.1, 134.2, 130.7, 128.3, 127.2, 121.4, 116.5, 108.6, 60.9, 43.5, 41.6, 14.0; HRMS (ESI) calcd for $C_{18}H_{18}O_4$ $[M + Na]^+$ 321.1097, found 321.1098.

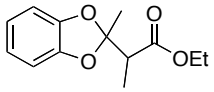


Ethyl 2-(2-Phenethylbenzo[*d*][1,3]dioxol-2-yl)acetate (4r). Colorless oil (111.9 mg, 89% yield); IR (ν, cm^{-1}): 3060, 3019, 2976, 2932, 2862, 1736, 1479, 1234, 1099; ^1H NMR (300 MHz, $CDCl_3$) δ (ppm) 7.32–7.27 (m, 2H), 7.23–7.17 (m, 2H), 6.84 (s, 4H), 4.14 (q, *J* = 7.1 Hz, 2H), 2.99 (s, 2H), 2.87–2.82 (m, 2H), 2.50–2.44 (m, 2H), 1.19 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ (ppm) 168.1, 147.4, 141.0, 128.5, 128.4, 126.1, 121.5, 116.6, 108.6, 61.0, 43.0, 39.6, 28.9, 14.0; HRMS (ESI) calcd for $C_{19}H_{20}O_4$ $[M + Na]^+$ 335.1254, found 335.1243.

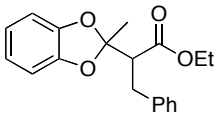


Ethyl 2-(2-Neopentylbenzo[*d*][1,3]dioxol-2-yl)acetate (4s). Colorless oil (92.6 mg, 82% yield); IR (ν, cm^{-1}): 3066, 2953, 2906, 2867, 1735, 1495, 1365, 1234, 1087; ^1H NMR (300 MHz, $CDCl_3$) δ (ppm) 6.82–6.75 (m, 4H), 4.09 (q, *J* = 7.1 Hz, 2H), 2.88 (s, 2H), 2.14 (s, 2H), 1.16 (t, *J*

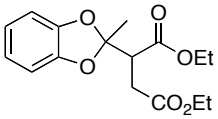
= 7.1 Hz, 3H), 1.00 (s, 9H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ (ppm) 168.4, 147.0, 121.4, 117.7, 108.7, 60.8, 48.5, 45.0, 30.8, 30.7, 14.0; HRMS (ESI) calcd for $C_{16}H_{22}O_4$ $[M + Na]^+$ 301.1410, found 301.1404.



Ethyl 2-(2-Methylbenzo[*d*][1,3]dioxol-2-yl)propanoate (4t). Colorless oil (85.4 mg, 89% yield); IR (ν, cm^{-1}): 3066, 2984, 2938, 2903, 1736, 1485, 1374, 1339, 1234, 1199; ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) 6.81–6.74 (m, 4H), 4.20–4.10 (m, 2H), 3.06 (q, *J* = 7.2 Hz, 1H), 1.73 (s, 3H), 1.32 (d, *J* = 7.1 Hz, 3H), 1.22 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ (ppm) 172.0, 147.2, 121.3, 117.8, 108.5, 60.8, 48.1, 21.9, 14.1, 12.3; HRMS (ESI) calcd for $C_{13}H_{16}O_4$ $[M + Na]^+$ 259.0941, found 259.0937.

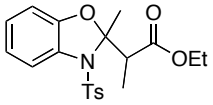


Ethyl 2-(2-Methylbenzo[*d*][1,3]dioxol-2-yl)-3-phenylpropanoate (4u). Colorless oil (108.2 mg, 86% yield); IR (ν, cm^{-1}): 3061, 3029, 2978, 2937, 1736, 1484, 1375, 1240; ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) 7.27–7.15 (m, 5H), 6.83–6.79 (m, 4H), 4.02 (q, *J* = 7.1 Hz, 2H), 3.28 (t, *J* = 6.9 Hz, 1H), 3.08 (d, *J* = 6.7 Hz, 2H), 1.80 (s, 3H), 1.04 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (100.6 MHz, $CDCl_3$) δ (ppm) 170.8, 147.1, 147.0, 138.3, 128.8, 128.5, 126.5, 121.5, 121.4, 117.3, 108.8, 108.7, 60.8, 56.4, 33.4, 22.2, 14.0; HRMS (ESI) calcd for $C_{19}H_{20}O_4$ $[M + Na]^+$ 335.1254, found 335.1241.

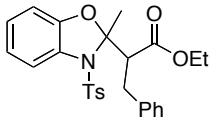


Diethyl 2-(2-Methylbenzo[*d*][1,3]dioxol-2-yl)succinate (4v). Colorless oil (99.1 mg, 80% yield); IR (ν, cm^{-1}): 3072, 2984, 2932, 2903, 1736, 1485, 1368, 1245, 1158, 1029; ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) 6.82–6.75 (m, 4H), 4.28–4.19 (m, 2H), 4.17–4.08 (m, 2H), 3.45 (dd, *J* = 10.9, 3.9 Hz, 1H), 2.93 (dd, *J* = 16.9, 10.9 Hz, 1H), 2.70 (dd, *J* = 16.9, 3.9 Hz, 1H), 1.71 (s, 3H), 1.29 (t, *J* = 7.1 Hz, 3H), 1.22 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ (ppm) 171.5,

170.3, 146.9, 146.8, 121.6, 121.6, 116.6, 108.8, 108.7, 61.3, 60.9, 50.2, 31.7, 22.9, 14.1, 14.0; HRMS (ESI) calcd for $C_{16}H_{20}O_6$ $[M + Na]^+$ 331.1152, found 331.1136.

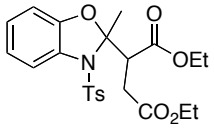


Ethyl 2-(2-Methyl-3-tosyl-2,3-dihydrobenzo[*d*]oxazol-2-yl)propanoate (4w). Yellow solid (126.9 mg; d.r. = 1:1; 81% yield); m.p. 72–74 °C; IR (ν, cm^{-1}): 3060, 2978, 2944, 2886, 1736, 1479, 1363, 1251, 1164. Diastereoisomer 1: ^1H NMR (300 MHz, $CDCl_3$) δ (ppm) 7.75 (d, *J* = 8.4 Hz, 2H), 7.48–7.47 (m, 1H), 7.26–7.20 (m, 2H), 6.99–6.89 (m, 2H), 6.76 (dd, *J* = 7.7, 1.7 Hz, 1H), 4.11–3.90 (m, 2H), 3.26 (q, *J* = 7.2 Hz, 1H), 2.37 (s, 3H), 1.83 (s, 3H), 1.37 (d, *J* = 7.2 Hz, 3H), 1.10 (t, *J* = 7.2 Hz, 3H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ (ppm) 171.9, 149.4, 144.4, 137.7, 130.0, 129.7, 127.0, 124.3, 121.4, 113.6, 109.4, 104.9, 60.7, 48.8, 22.3, 21.5, 13.9, 12.3. Diastereoisomer 2: ^1H NMR (300 MHz, $CDCl_3$) δ (ppm) 7.67 (d, *J* = 8.4 Hz, 2H), 7.51–7.50 (m, 1H), 7.26–7.20 (m, 2H), 6.87–6.70 (m, 2H), 6.72 (dd, *J* = 7.7, 1.3 Hz, 1H), 4.25–4.13 (m, 2H), 3.41 (q, *J* = 6.9 Hz, 1H), 2.38 (s, 3H), 1.86 (s, 3H), 1.26 (t, *J* = 7.2 Hz, 3H), 1.23 (d, *J* = 7.0 Hz, 3H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ (ppm) 171.8, 149.5, 144.3, 137.7, 130.0, 129.7, 127.0, 124.9, 121.5, 114.8, 109.2, 104.7, 60.9, 49.9, 21.5, 20.4, 14.1, 11.6. HRMS (ESI) calcd for $C_{20}H_{23}NO_5S$ $[M + H]^+$ 390.1370, found 390.1371.

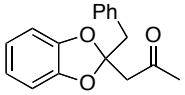


Ethyl 2-(2-Methyl-3-tosyl-2,3-dihydrobenzo[*d*]oxazol-2-yl)-3-phenylpropanoate (4x). Yellow solid (129.1 mg; d.r. = 2:1; 73% yield); m.p. 92–97 °C; IR (ν, cm^{-1}): 3066, 3026, 2973, 2926, 2856, 1736, 1596, 1479, 1363, 1252, 1164. Major diastereoisomer: ^1H NMR (300 MHz, $CDCl_3$) δ (ppm) 7.79 (d, *J* = 8.4 Hz, 2H), 7.64 (d, *J* = 8.4 Hz, 2H), 7.60–7.53 (m, 2H), 7.39–7.15 (m, 5H), 7.05–6.92 (m, 2H), 3.98–3.79 (m, 2H), 3.37 (dd, *J* = 12.0, 3.3 Hz, 1H), 3.29 (dd, *J* = 13.5, 3.0 Hz, 1H), 3.13–3.01 (m, 1H), 2.37 (s, 3H), 1.99 (s, 3H), 0.99 (t, *J* = 7.2 Hz, 3H); ^{13}C NMR (100.6 MHz, $CDCl_3$) δ (ppm) 170.8, 149.8, 144.4, 138.5, 137.6, 130.0, 129.8, 128.9, 128.4, 127.1, 126.5, 125.6, 116.2, 109.7, 104.4, 60.7, 57.1, 33.2, 21.5, 19.6, 13.9. Minor diastereoisomer: ^1H NMR (300 MHz, $CDCl_3$) δ (ppm) 7.79 (d, *J* = 8.4 Hz, 2H), 7.64 (d, *J* = 8.4

Hz, 2H), 7.39–7.15 (m, 5H), 7.05–6.92 (m, 2H), 6.91–6.74 (m, 2H), 4.12–4.00 (m, 2H), 3.64 (dd, J = 10.2, 4.8 Hz, 1H), 3.13–3.01 (m, 2H), 2.36 (s, 3H), 1.84 (s, 3H), 1.12 (t, J = 7.2 Hz, 3H); ^{13}C NMR (100.6 MHz, $CDCl_3$) δ (ppm); 170.6, 149.2, 144.5, 138.5, 137.8, 130.0, 129.9, 129.0, 128.3, 127.0, 126.4, 124.5, 114.0, 109.5, 104.2, 60.9, 58.2, 32.5, 22.3, 19.6, 14.0. HRMS (ESI) calcd for $C_{26}H_{27}NO_5S$ $[M + Na]^+$ 466.1683, found 466.1671.



Diethyl 2-(2-Methyl-3-tosyl-2,3-dihydrobenzo[*d*]oxazol-2-yl)succinate (4y). Yellow solid (147.4 mg; d.r. = 1.2:1; 84% yield); m.p. 127–130 °C; IR (ν, cm^{-1}): 3066, 2979, 2903, 2868, 1742, 1590, 1468, 1363, 1246, 1164. Major diastereoisomer: ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) 7.75 (d, J = 8.4 Hz, 2H), 7.60 (d, J = 8.4 Hz, 2H), 7.56–7.51 (m, 1H), 7.27–7.12 (m, 2H), 6.76–6.74 (m, 1H), 4.28–4.20 (m, 2H), 3.50 (dd, J = 11.1, 3.9 Hz, 1H), 3.04–2.85 (m, 2H), 2.35 (s, 3H), 1.86 (s, 3H), 1.26–1.16 (m, 6H); ^{13}C NMR (100.6 MHz, $CDCl_3$) δ (ppm) 171.4, 170.5, 149.5, 144.4, 137.4, 129.9, 129.8, 127.0, 125.6, 121.9, 116.2, 109.8, 103.5, 61.2, 60.9, 50.7, 32.1, 21.5, 19.7, 14.1, 13.9. Minor diastereoisomer: ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) 7.75 (d, J = 8.4 Hz, 2H), 7.60 (d, J = 8.4 Hz, 2H), 7.25–7.04 (m, 2H), 7.04–6.88 (m, 2H), 4.16–4.01 (m, 2H), 3.75 (dd, J = 11.1, 3.9 Hz, 1H), 3.04–2.85 (m, 1H), 2.61 (dd, J = 17.1, 3.3 Hz, 1H), 2.37 (s, 3H), 1.83 (s, 3H), 1.32 (t, J = 8.1 Hz, 3H), 1.26–1.16 (m, 3H); ^{13}C NMR (100.6 MHz, $CDCl_3$) δ (ppm) 171.4, 170.3, 148.7, 144.5, 137.5, 129.9, 129.6, 127.0, 124.5, 121.8, 113.9, 109.5, 103.7, 61.4, 60.8, 51.7, 31.6, 22.8, 19.7, 14.1, 14.0. HRMS (ESI) calcd for $C_{23}H_{27}NO_7S$ $[M + H]^+$ 462.1581, found 462.1594.

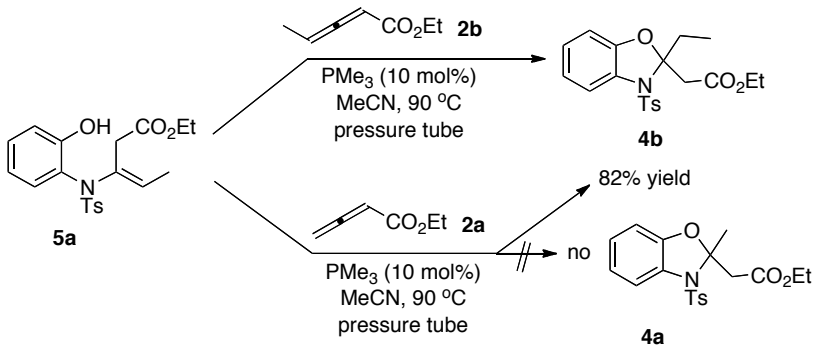


1-(2-Benzylbenzo[d][1,3]dioxol-2-yl)propan-2-one (16). White solid (53.0 mg, 90% yield); m.p. = 76–78 °C; IR (ν, cm^{-1}): 3061, 3019, 2909, 2844, 1718, 1479, 1357, 1229; ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) 7.34–7.24 (m, 5H), 6.80 (s, 4H), 3.37 (s, 2H), 2.98 (s, 2H), 2.17 (s, 2H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ (ppm) 204.1, 146.9, 134.3, 130.7, 128.3, 127.2, 121.6, 116.8, 108.8, 49.2, 43.3, 31.7; MS (ESI) calcd for $C_{17}H_{16}O_3$ $[M + Na]^+$ 291.0092, found 291.1000.

Mechanistic Study

Treatment of the mono-Michael adduct **5a** in MeCN with 10 mol% PMe_3 at 90 °C in a pressure tube for 24 h did not facilitate the formation of the double-Michael product **4b** (Scheme S1). TLC analysis revealed a very small spot corresponding to the cyclized product **4b**, with the majority of the compound **5a** remaining unreacted. Treatment of **5a** in MeCN with 1.1 equiv of the allenoate **2b** also did not lead to facile conversion to **4b**. On the other hand, treatment of **5a** in MeCN with 10 mol% PMe_3 and 0.1 equiv of the allenoate **2b** at 90 °C in a pressure tube for 12 h provided the cyclized product **4b** in 80% isolated yield. Interestingly, when the mono-Michael adduct **5a** in MeCN was treated with 10 mol% PMe_3 and 1.1 equiv of allenoate **2a** at 90 °C in a pressure tube for 8 h, the cyclized product **4b** was obtained in 82% yield without a trace of the 1,3-benzoxazoline **4a**, which would have arisen from the allenoate **2a**.[3]

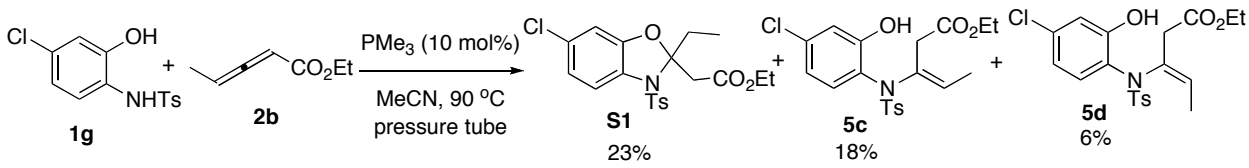
Scheme S1. Conversion of the Mono-Michael Adduct **5a** to **4b**

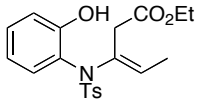


The reaction of *N*-tosyl-2-amino-5-chlorophenol (**1g**) with ethyl 2,3-pentadienoate (**2b**) was stopped prematurely to provide the mono-Michael adducts (Scheme S2). The mono-Michael adduct **5c** provided single crystals amenable to X-ray crystallographic analysis, which unequivocally proved its structure. The minor mono-Michael adduct **5d** did not provide crystals; its structure was assigned as shown based on its ^1H and ^{13}C NMR data and the fact that both **5c** and **5d** exhibit a sharp singlet as the signal for the phenolic OH unit in their ^1H NMR spectra; the signal for the aniline proton appears as a broad singlet.

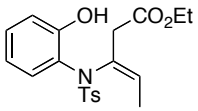
[3] See the main text of the paper for further discussions.

Scheme S2. Formation and Isolation of Mono-Michael Adducts **5c/d**

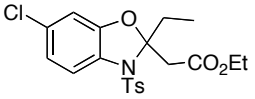




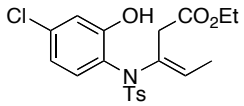
(*E*)-Ethyl 3-(*N*-(2-Hydroxyphenyl)-4-methylphenylsulfonamido)pent-3-enoate (5a). Colorless oil (4.4 mg, 3% yield; Table S1, entry 1); IR (ν, cm^{-1}): 2979, 2921, 2862, 1730, 1684, 1602, 1497, 1170; ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) 8.30 (s, 1H), 7.75 (dd, *J* = 8.1, 1.5 Hz, 1H), 7.68 (d, *J* = 8.3, 2H), 7.16 (d, *J* = 8.1, 2H), 7.10 (dt, *J* = 7.6, 1.5 Hz, 1H), 6.98 (dt, *J* = 8.0, 1.6 Hz, 1H), 6.87 (dd, *J* = 8.0, 1.6 Hz, 1H), 4.33 (q, *J* = 7.1 Hz, 2H), 4.17 (q, *J* = 7.0 Hz, 1H), 3.30 (s, 2H), 2.34 (s, 3H), 1.39 (d, *J* = 7.0 Hz, 3H), 1.34 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ (ppm) 171.1, 148.5, 143.4, 143.0, 136.8, 130.6, 129.3, 127.3, 125.6, 124.3, 122.3, 120.4, 100.9, 61.8, 34.8, 21.5, 14.3, 11.5; HRMS (ESI) calcd for $C_{20}H_{23}NO_5S$ $[M + Na]^+$ 412.1189, found 412.1200.



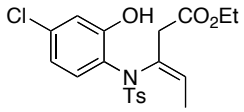
(*Z*)-Ethyl 3-(*N*-(2-Hydroxyphenyl)-4-methylphenylsulfonamido)pent-3-enoate (5b). Colorless oil (1.5 mg, 1% yield; Table S1, entry 1); IR (ν, cm^{-1}): 3056, 2979, 2873, 1736, 1630, 1461, 1450, 1176; ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) 8.38 (s, 1H), 7.58 (d, *J* = 8.3 Hz, 2H), 7.25–7.18 (m, 3H), 6.95 (d, *J* = 8.0, 1.1 Hz, 2H), 6.76 (dt, *J* = 7.4, 1.5 Hz, 1H), 5.69 (q, *J* = 7.0 Hz, 1H), 4.22 (q, *J* = 7.1 Hz, 2H), 3.34 (s, 2H), 2.41 (s, 3H), 1.69 (d, *J* = 7.0 Hz, 3H), 1.31 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ (ppm) 170.4, 147.6, 144.9, 143.5, 135.8, 129.5, 128.3, 127.9, 125.8, 123.7, 122.1, 116.9, 114.6, 62.8, 39.0, 20.5, 14.1, 10.6; HRMS (ESI) calcd for $C_{20}H_{23}NO_5S$ $[M + Na]^+$ 412.1189, found 412.1194.



Ethyl 2-(6-Chloro-2-ethyl-3-tosyl-2,3-dihydrobenzo[*d*]oxazol-2-yl)acetate (S1). White solid (39.9 mg, 23% yield); m.p. 106–108 °C; IR (ν, cm^{-1}): 3072, 2979, 2938, 2886, 1736, 1590, 1485, 1363, 1246, 1156; ^{1}H NMR (300 MHz, $CDCl_3$) δ (ppm) 7.82 (d, *J* = 8.4 Hz, 2H), 7.29 (d, *J* = 8.4 Hz, 2H), 7.23 (d, *J* = 8.4 Hz, 1H), 6.80 (dd, *J* = 8.4, 2.0 Hz, 1H), 6.70 (d, *J* = 2.0 Hz, 1H), 3.94–3.83 (m, 2H), 3.32 (d, *J* = 16.0, 1H), 3.07 (d, *J* = 16.0, 1H), 2.40 (s, 3H), 2.35–2.14 (m, 2H), 1.01 (t, *J* = 7.1 Hz, 3H), 0.82 (t, *J* = 7.3 Hz, 3H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ (ppm) 167.8, 150.2, 144.6, 137.3, 129.9, 129.8, 128.2, 127.0, 120.8, 112.0, 109.3, 106.1, 60.8, 43.2, 32.8, 21.6, 13.7, 6.9; HRMS (ESI) calcd for $C_{20}H_{22}ClNO_5S$ $[M + H]^+$ 424.0985, found 424.0979.



(*E*)-Ethyl 3-(*N*-(4-Chloro-2-hydroxyphenyl)-4-methylphenylsulfonamido)pent-3-enoate (5c). White solid (30.1 mg, 18% yield); m.p. 118–121 °C; IR (ν, cm^{-1}): 2984, 2926, 2856, 1718, 1584, 1479, 1350, 1158; ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 8.30 (s, 1H), 7.70 (d, *J* = 8.8 Hz, 2H), 7.66 (d, *J* = 8.3 Hz, 2H), 7.17 (d, *J* = 8.1 Hz, 2H), 7.06 (dd, *J* = 8.8, 2.4 Hz, 1H), 6.88 (d, *J* = 2.4 Hz, 1H), 4.31 (q, *J* = 7.2 Hz, 2H), 4.23 (q, *J* = 7.0 Hz, 1H), 3.28 (s, 2H), 2.35 (s, 3H), 1.41 (d, *J* = 7.0 Hz, 3H), 1.33 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (100.6 MHz, $CDCl_3$) δ (ppm) 171.0, 148.2, 143.7, 143.6, 136.5, 129.5, 129.3, 129.0, 127.3, 125.5, 122.4, 121.3, 102.1, 61.8, 34.6, 21.5, 14.2, 11.5; HRMS (ESI) calcd for $C_{20}H_{22}ClNO_5S$ $[M + Na]^+$ 466.0799, found 446.0812.

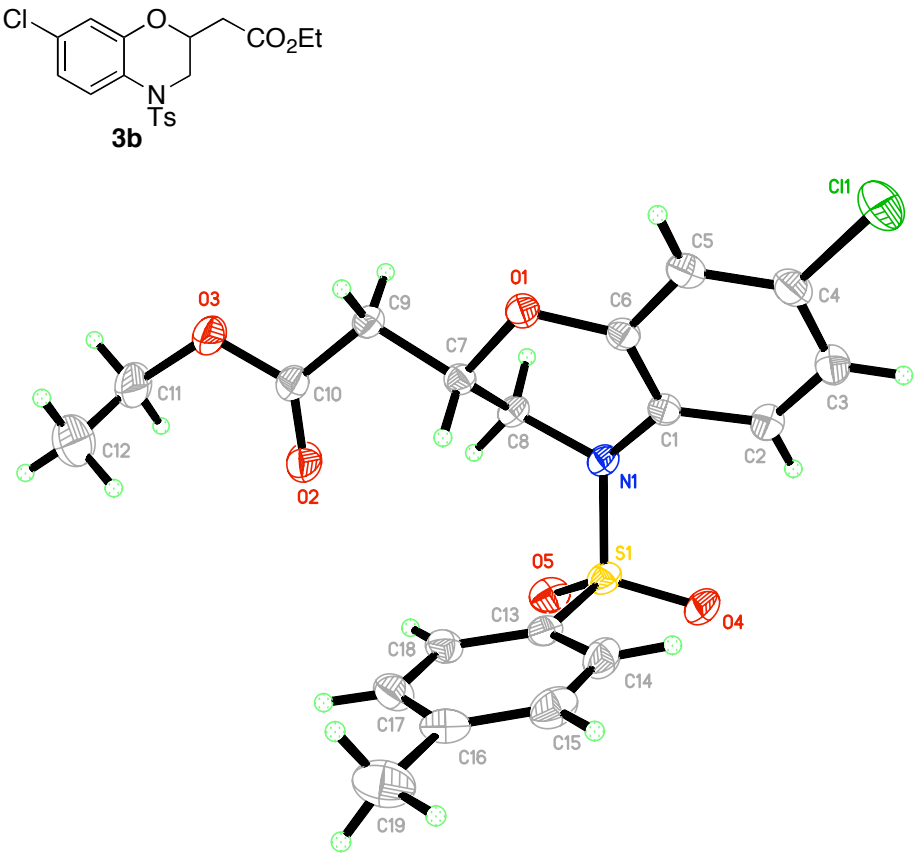


(*Z*)-Ethyl 3-(*N*-(4-Chloro-2-hydroxyphenyl)-4-methylphenylsulfonamido)pent-3-enoate (5d). Colorless oil (10.4 mg, 6% yield); IR (ν, cm^{-1}): 2956, 2902, 2869, 1715, 1568, 1480, 1397, 1160; ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) 7.65 (d, *J* = 8.0 Hz, 2H), 7.54 (d, *J* = 8.6 Hz, 1H), 7.20 (d, *J* = 8.0 Hz, 2H), 6.95 (dd, *J* = 8.6, 2.3 Hz, 1H), 6.70 (d, *J* = 2.3 Hz, 1H), 5.26 (q, *J* = 6.9 Hz, 1H), 4.13 (q, *J* = 7.2 Hz, 2H), 2.93 (s, 2H), 2.36 (s, 3H), 1.31 (dt, *J* = 6.9, 1.0 Hz, 3H), 1.24 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (100.6 MHz, $CDCl_3$) δ (ppm) 169.4, 146.6, 143.9, 143.5, 136.3, 130.5, 129.6, 127.3, 125.7, 123.3, 122.9, 116.0, 114.9, 61.4, 38.0, 21.5, 14.1, 10.6; HRMS (ESI) calcd for $C_{20}H_{22}ClNO_5S$ $[M + Na]^+$ 466.0799, found 446.0806.

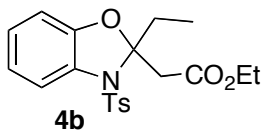
X-ray Crystallography

X-ray crystallography of the compounds **3b** and **4b** provided unambiguous structural confirmation for the umpolung addition/Michael and double-Michael reaction modalities, respectively. Crystallographic data for **3b**, **4b**, and **5c** have been deposited with the Cambridge Crystallographic Data Centre as supplementary numbers CCDC 779839, 779840, and 779841, respectively. These data can be obtained online free of charge [or from the Cambridge Crystallographic Data Center, 12, Union Road, Cambridge CB2 1EZ, UK; fax: (+44) 1223-336-033; or deposit@ccdc.cam.ac.uk].

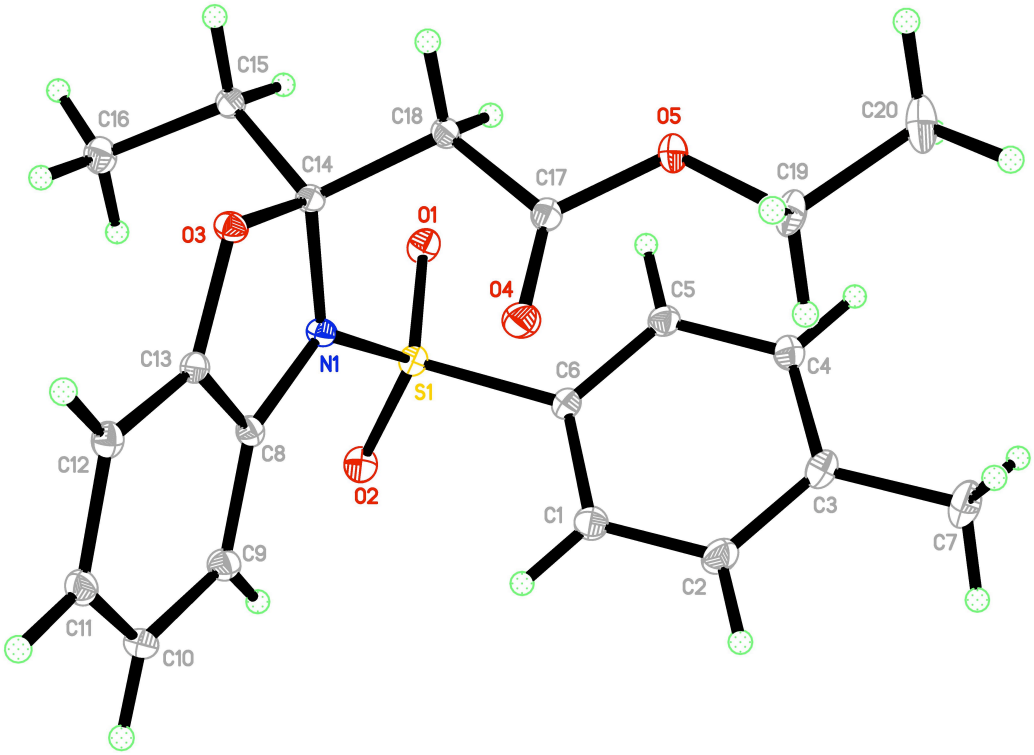
ORTEP Representation of the Solid State Structure of Compound 3b



ORTEP Representation of the Solid State Structure of Compound 4b

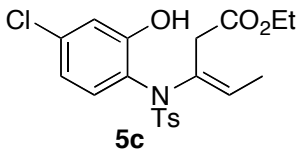


4b

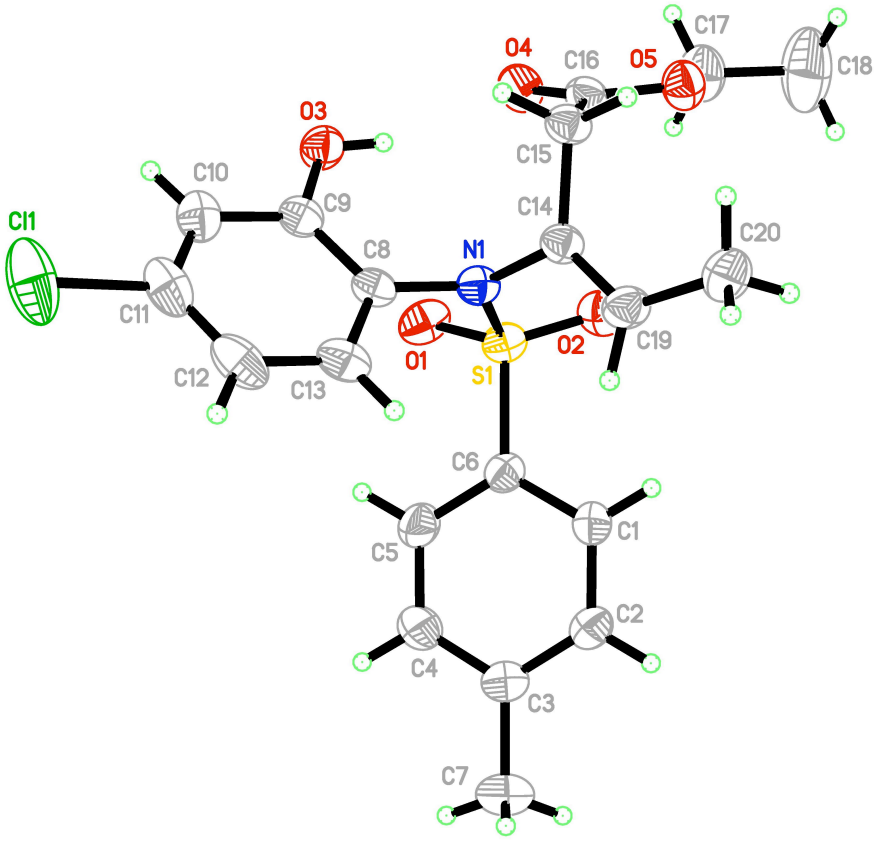


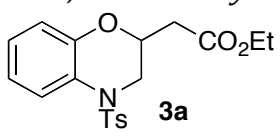
ORTEP Representation of the Solid State Structure of Compound 5c

Structural confirmation of the mono-Michael adduct **5c** was provided unambiguously through X-ray crystallographic analysis.

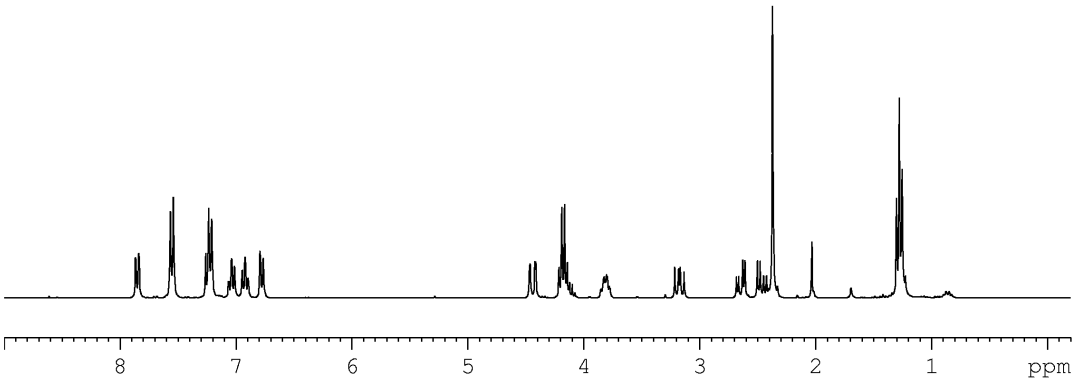


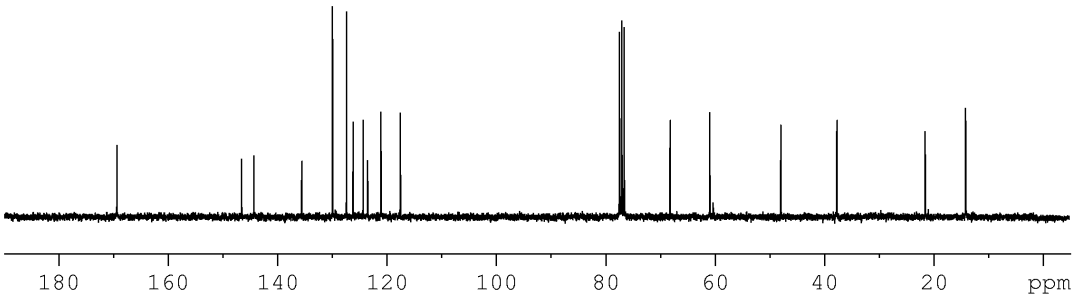
5c

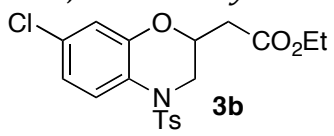




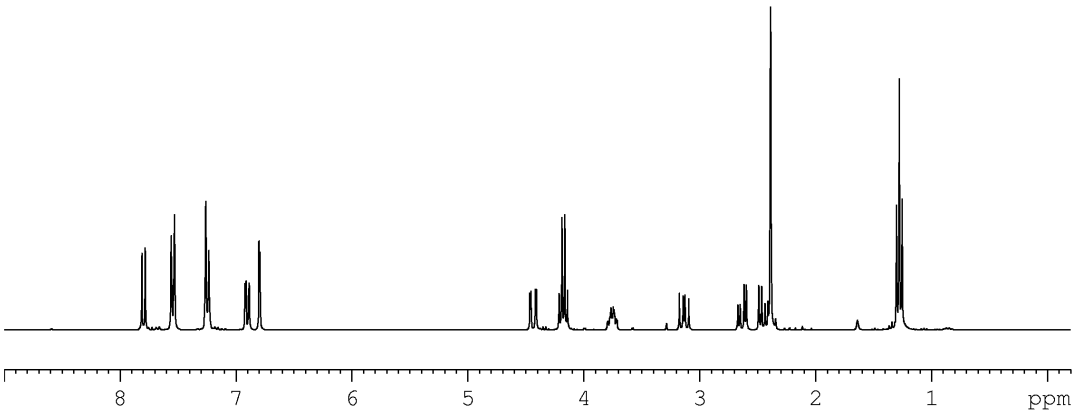
3a

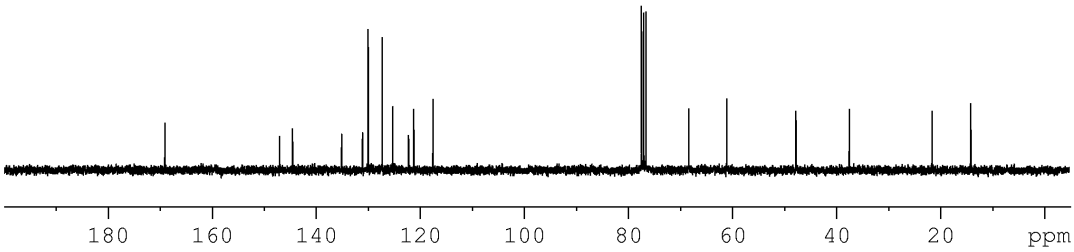


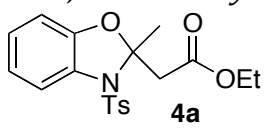




3b







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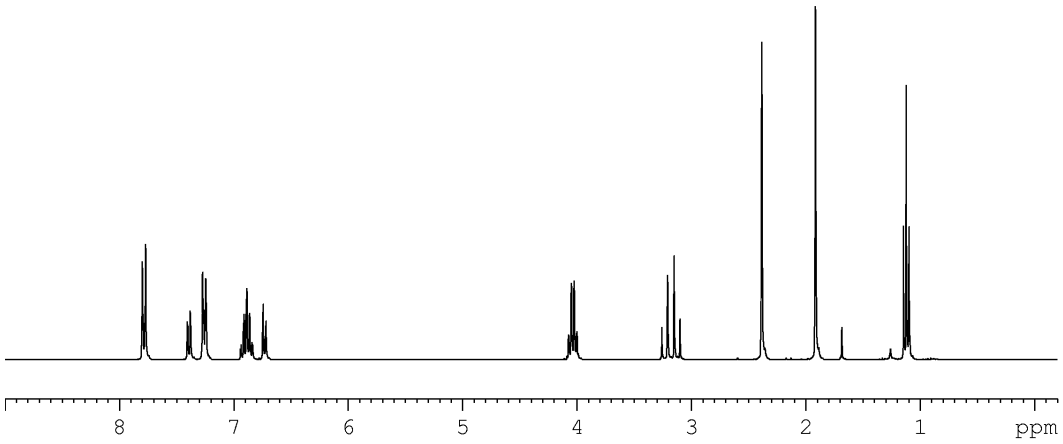

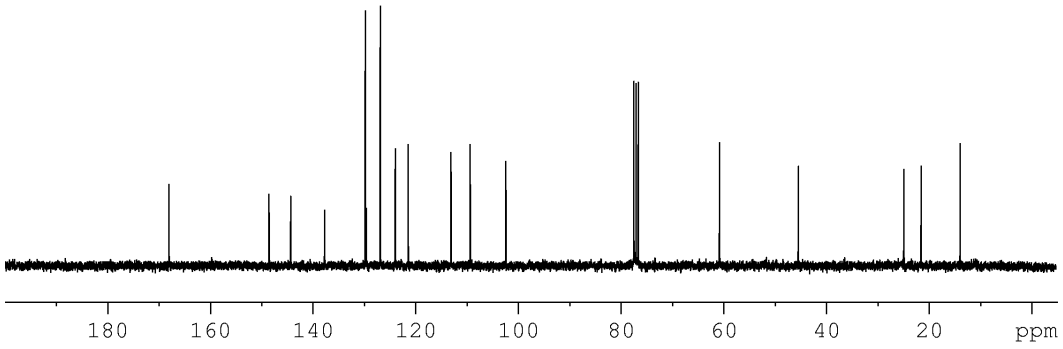

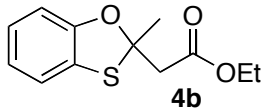

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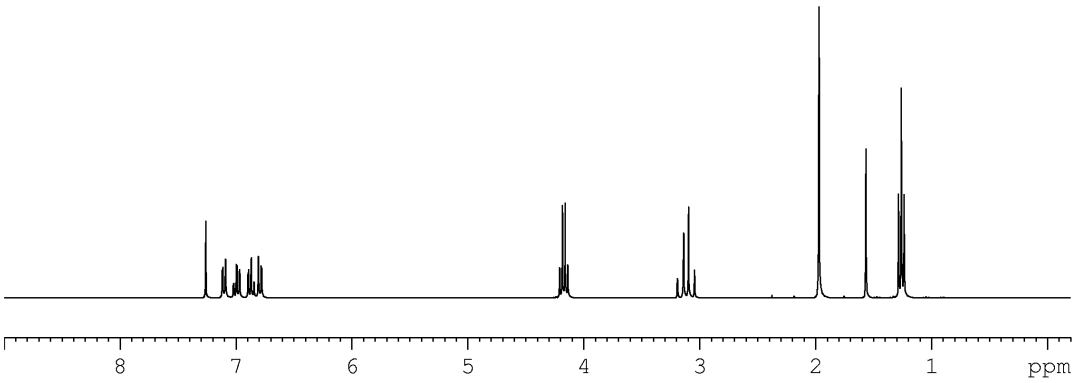

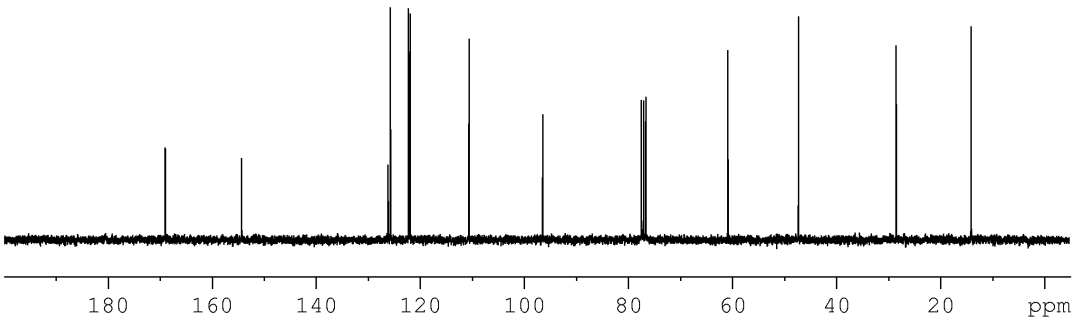

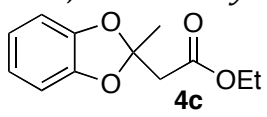

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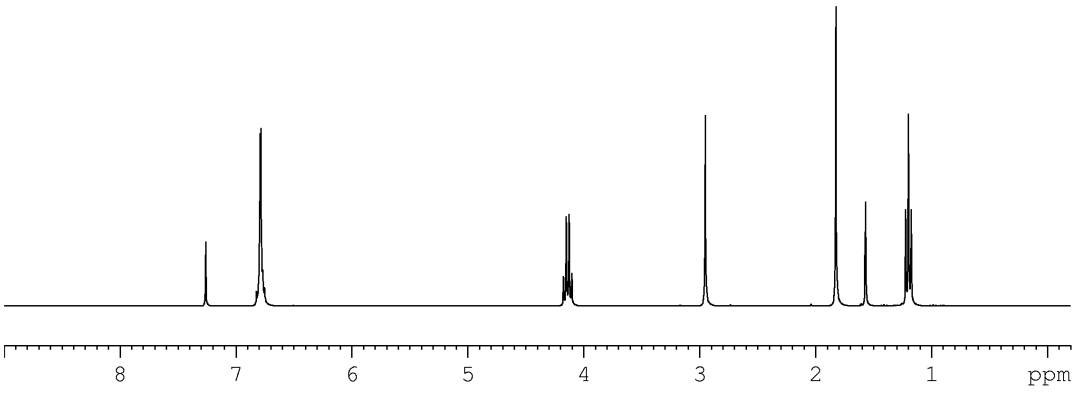

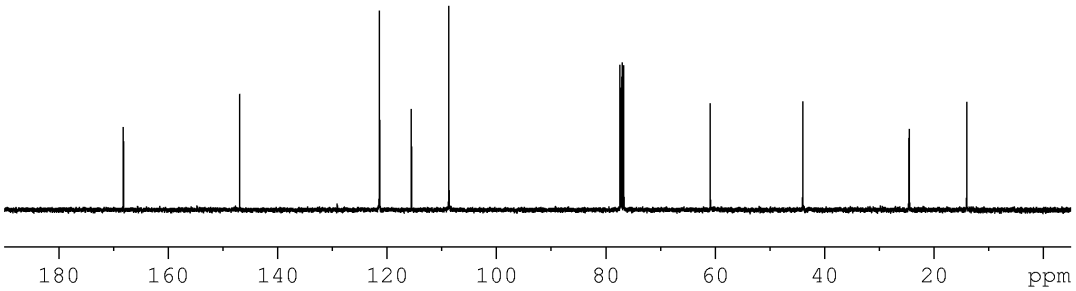

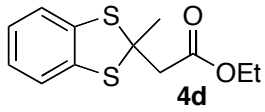

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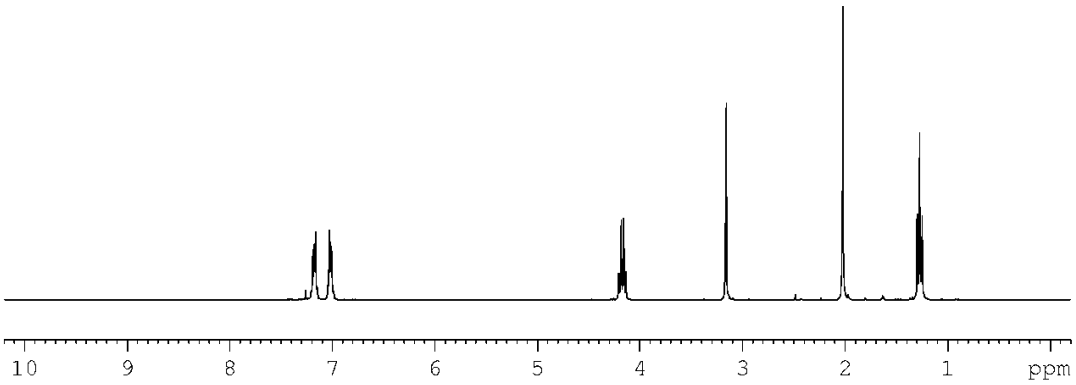

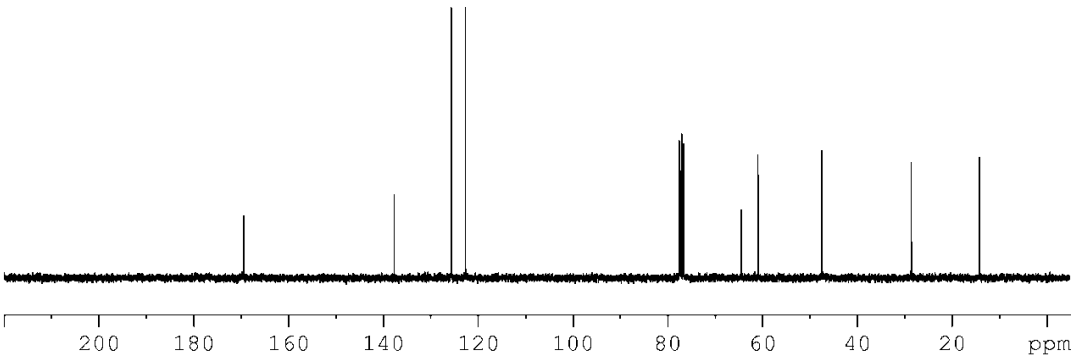

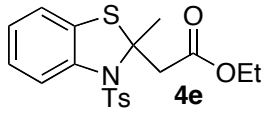
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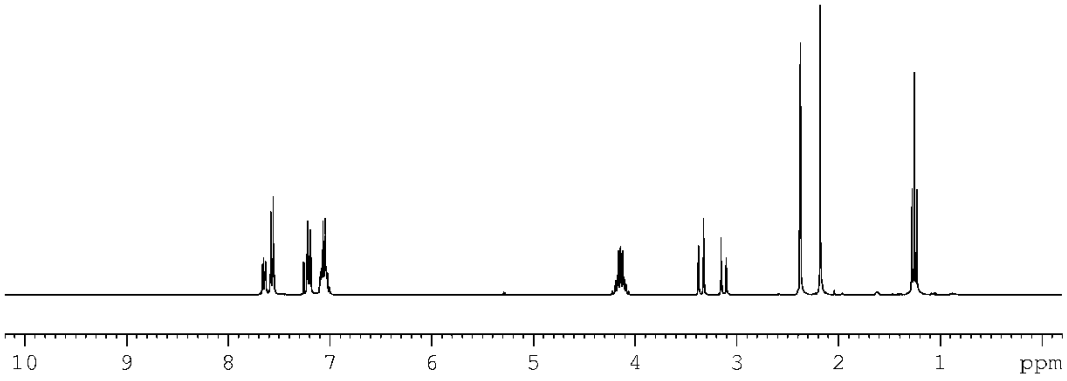
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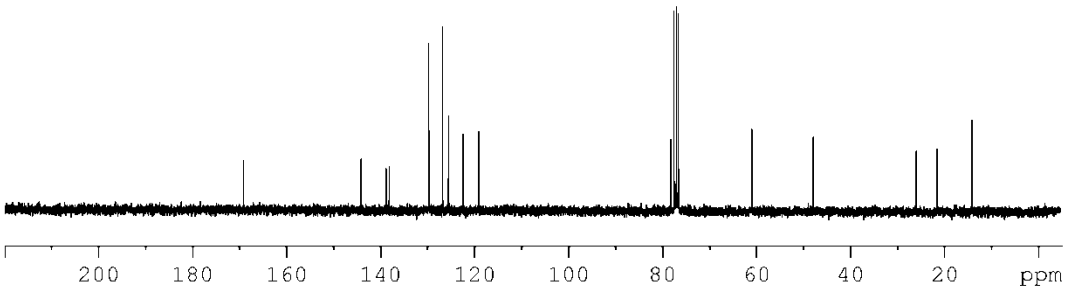
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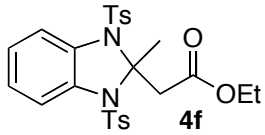
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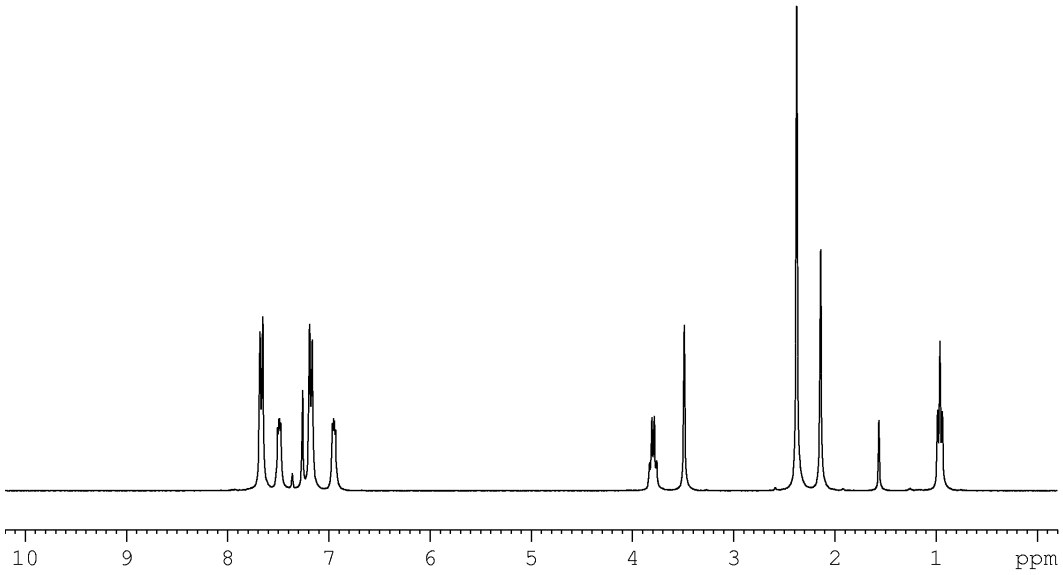
OEt
N
Ts

4f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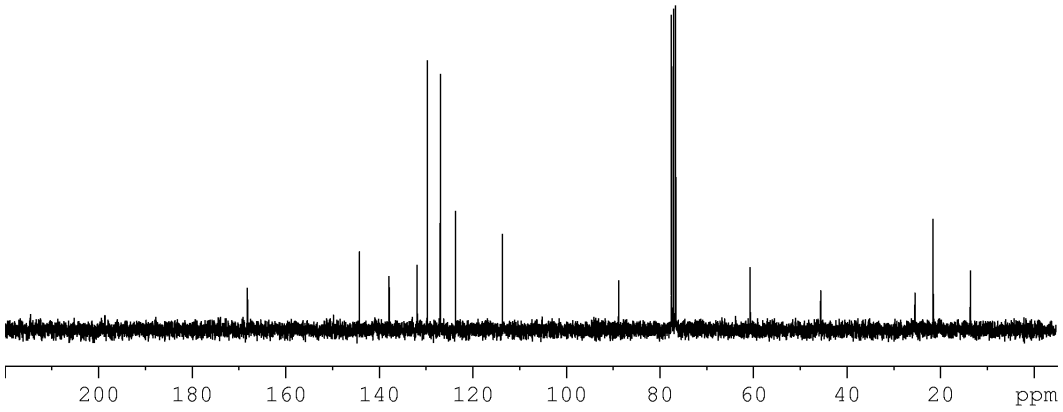
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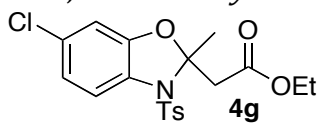
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O
OEt
N
Ts

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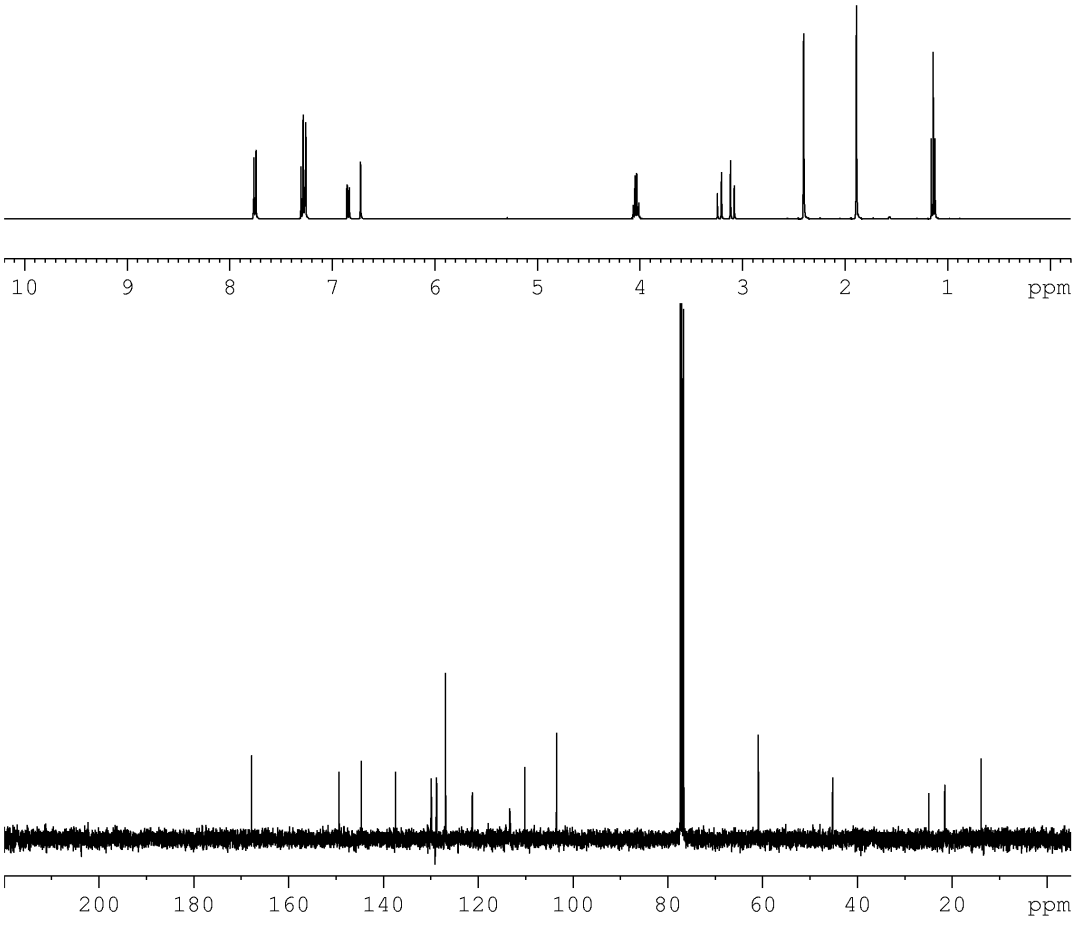
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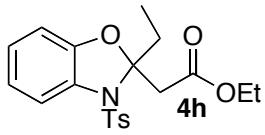

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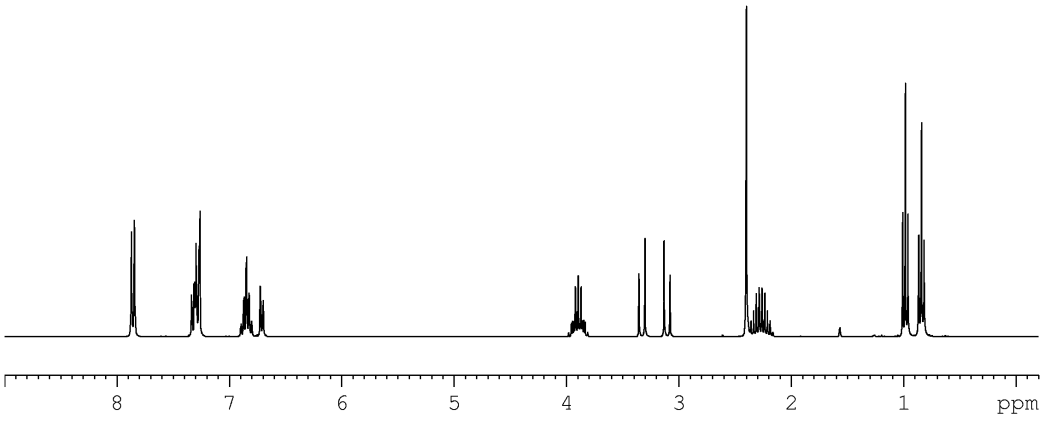

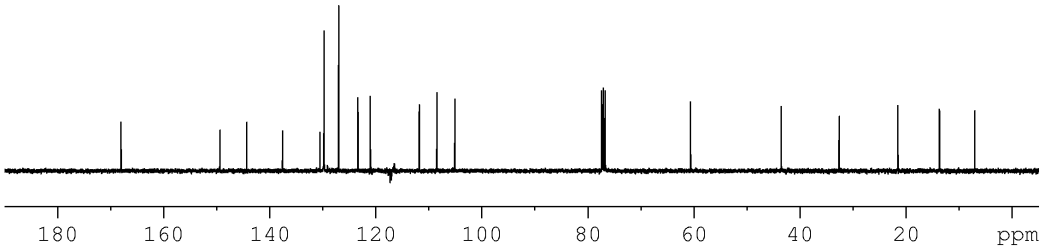

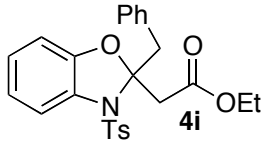
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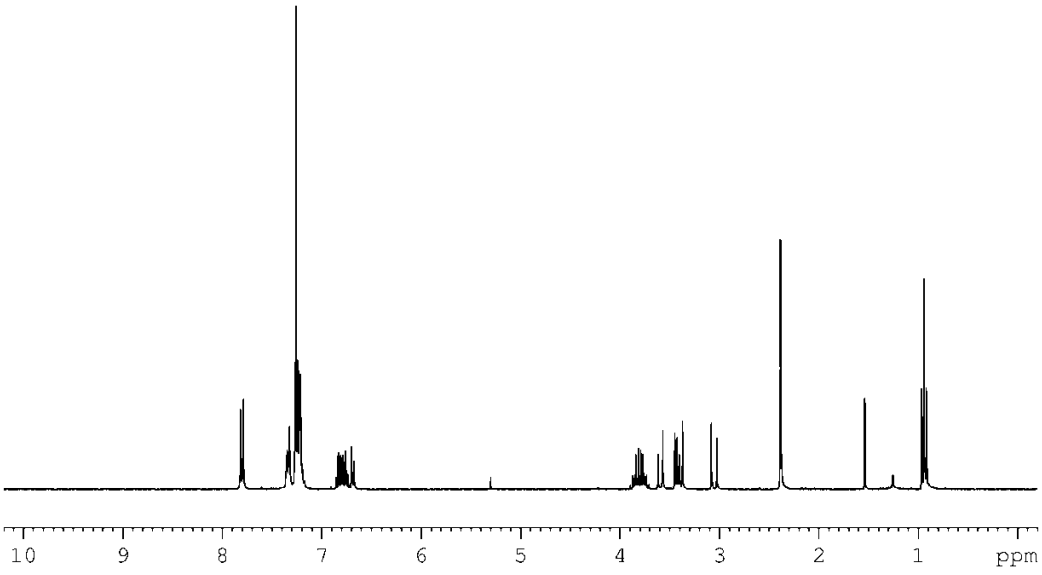
OEt

4i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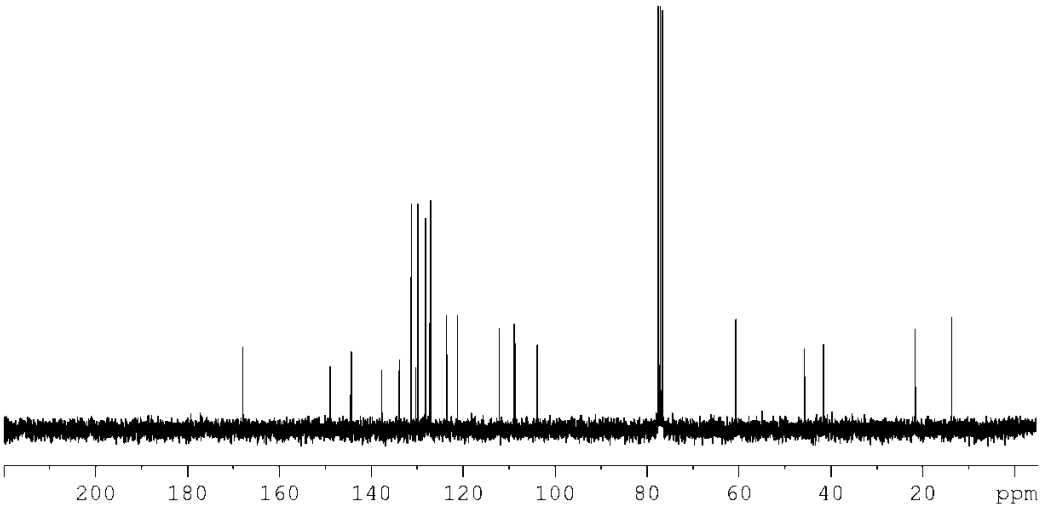
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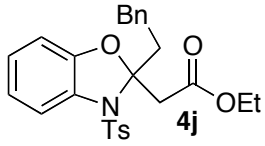
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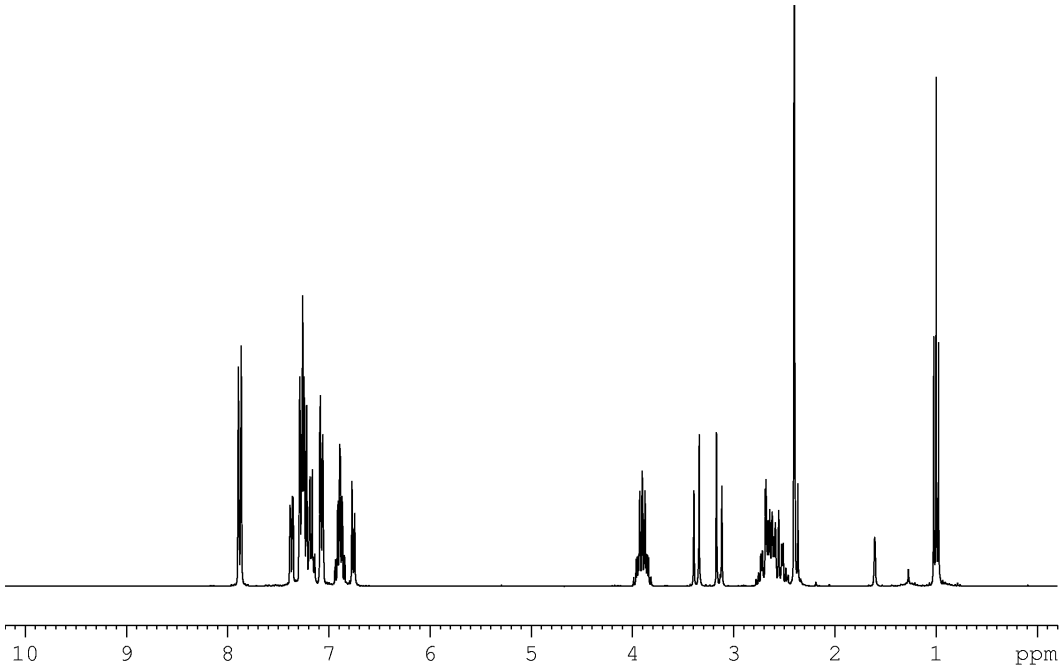
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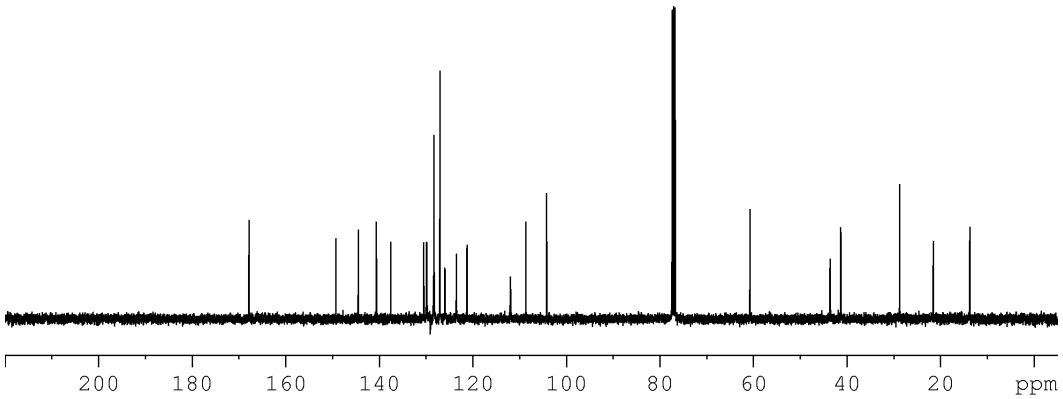
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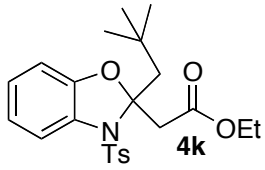
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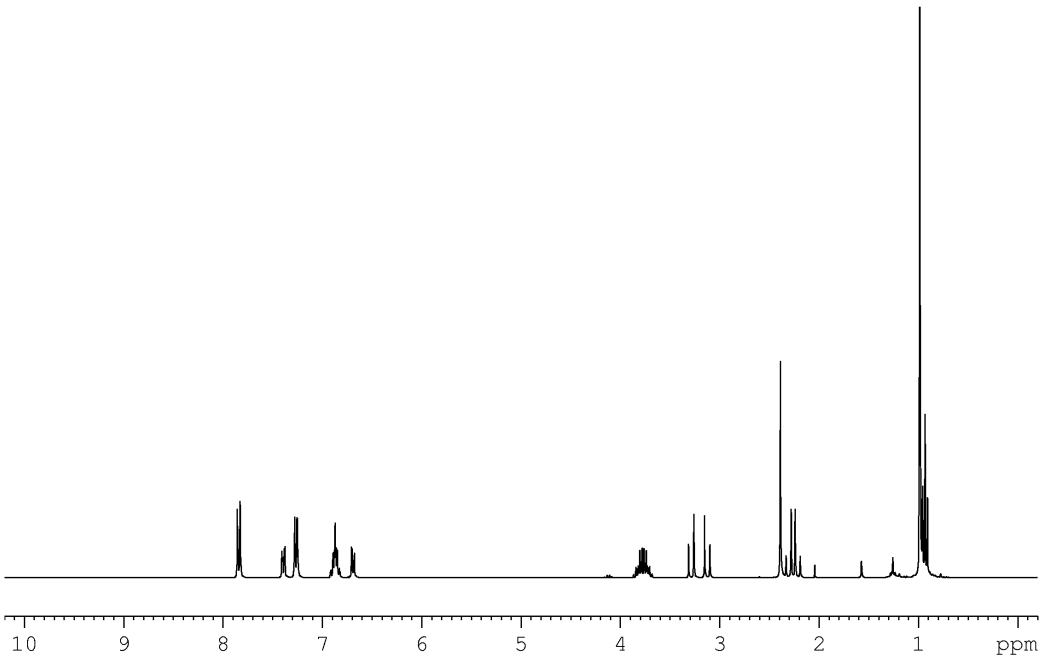
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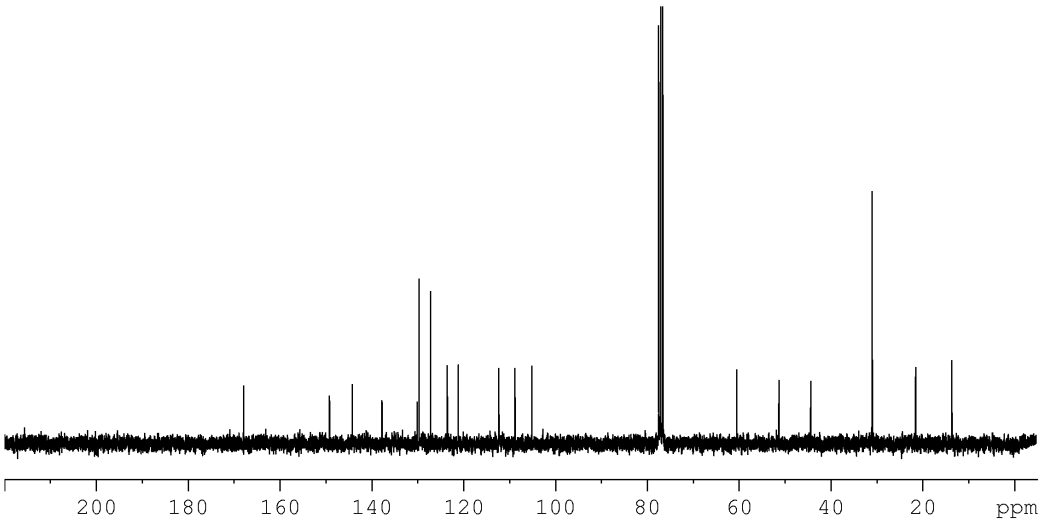
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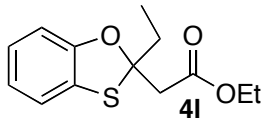

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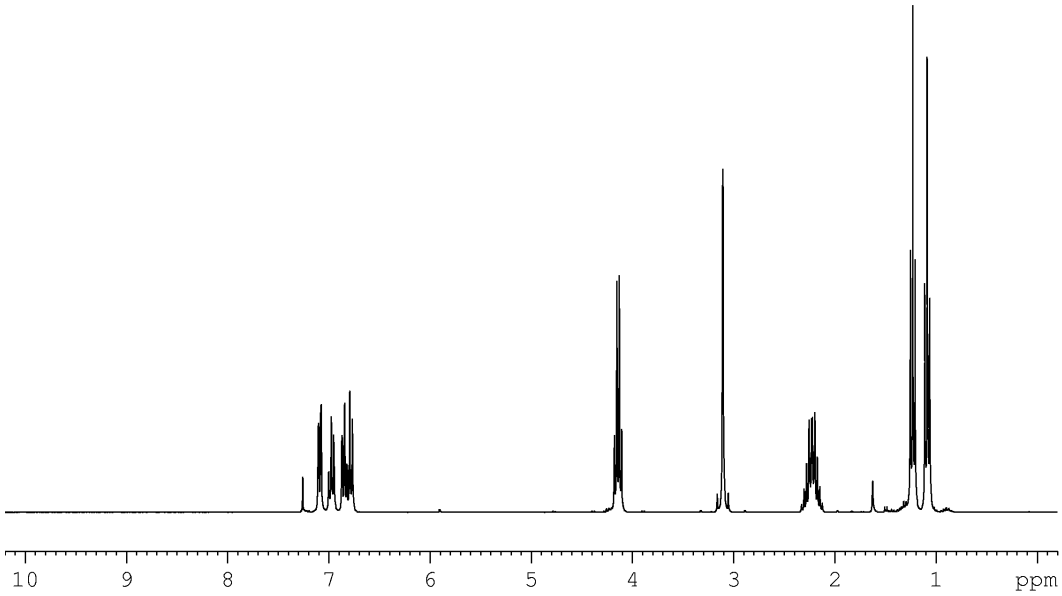

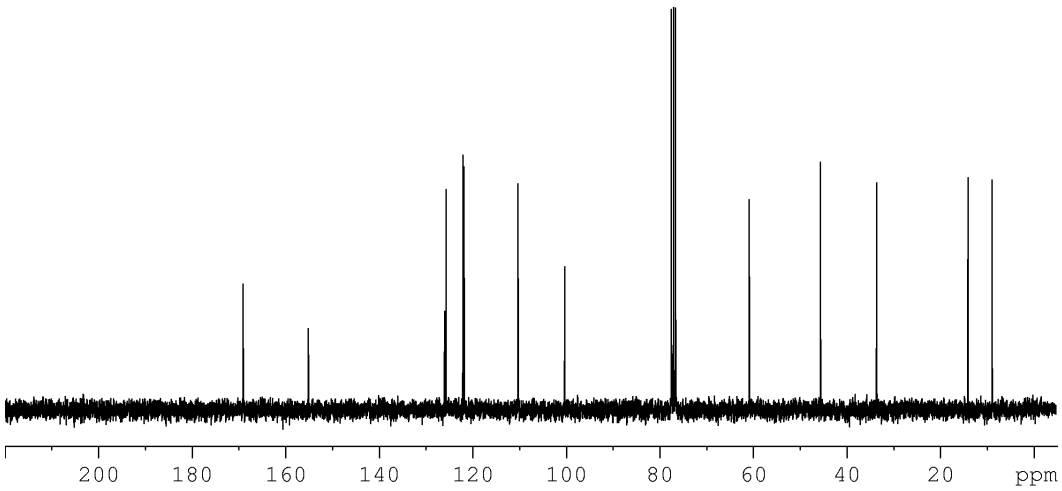

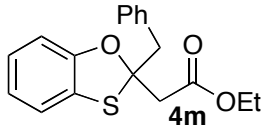

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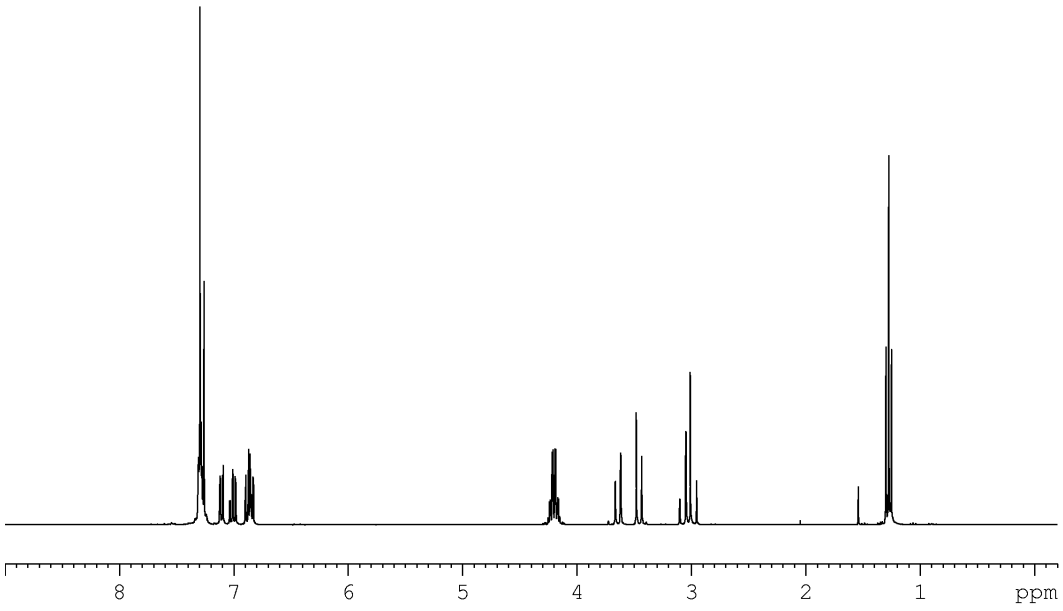

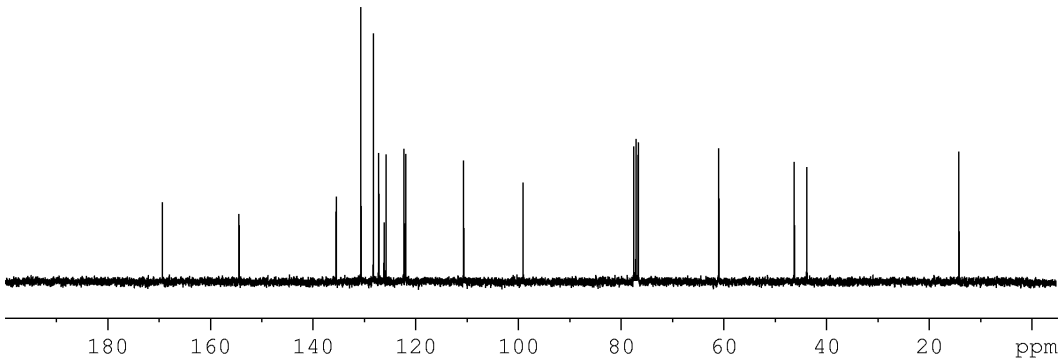

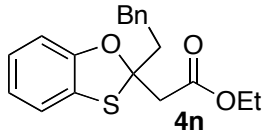
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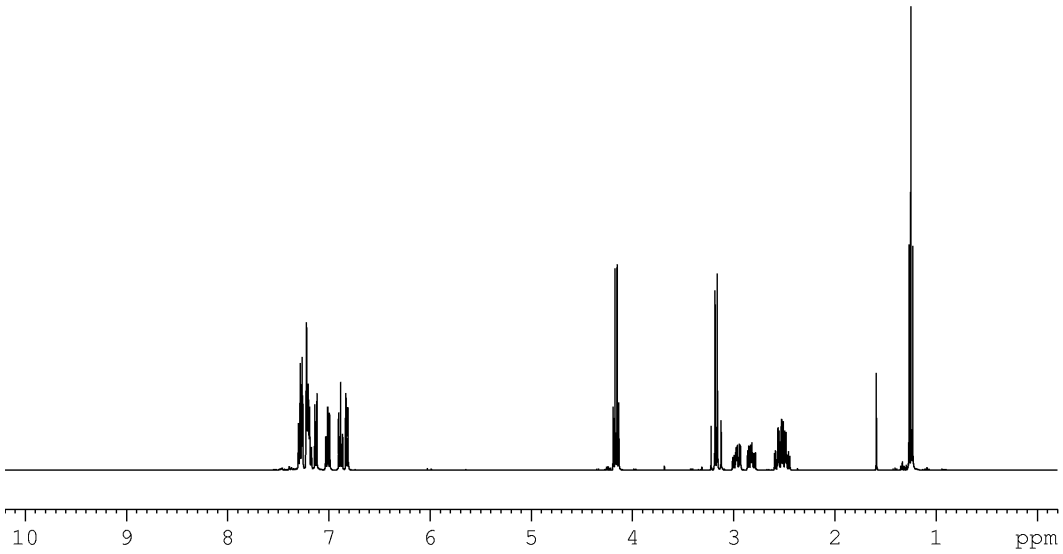
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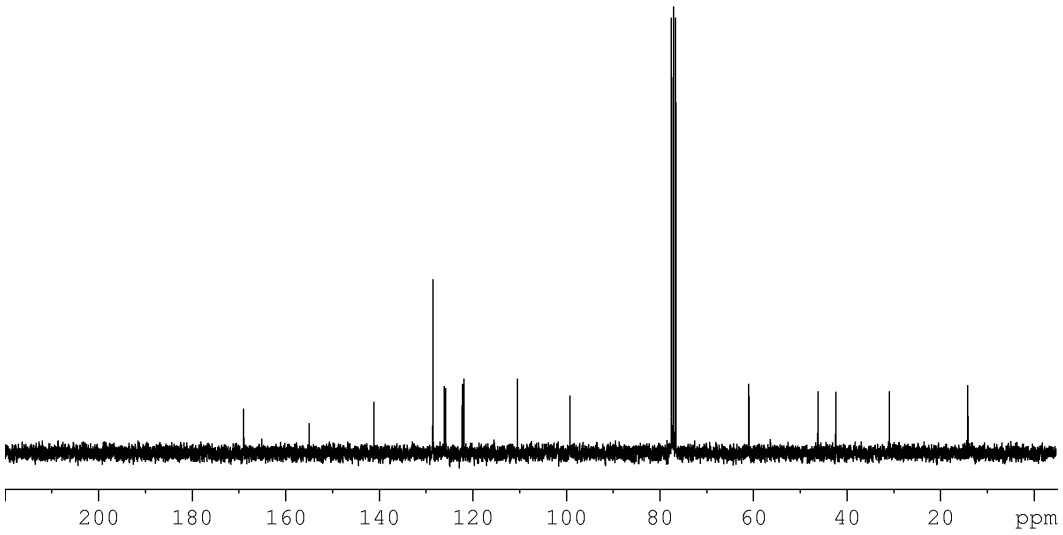
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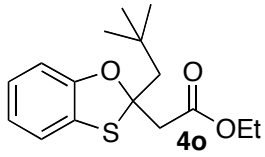

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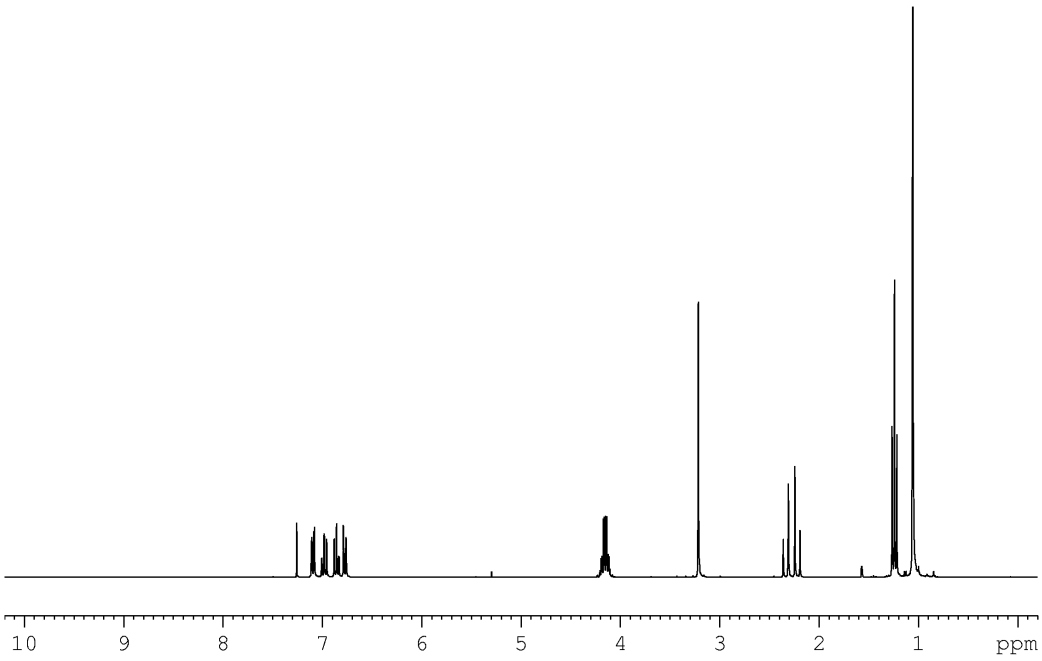

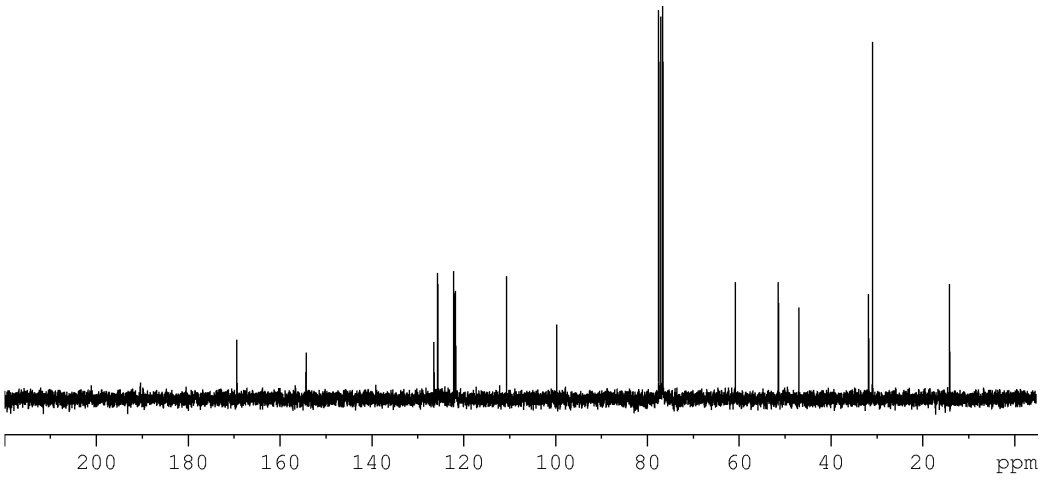

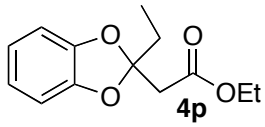

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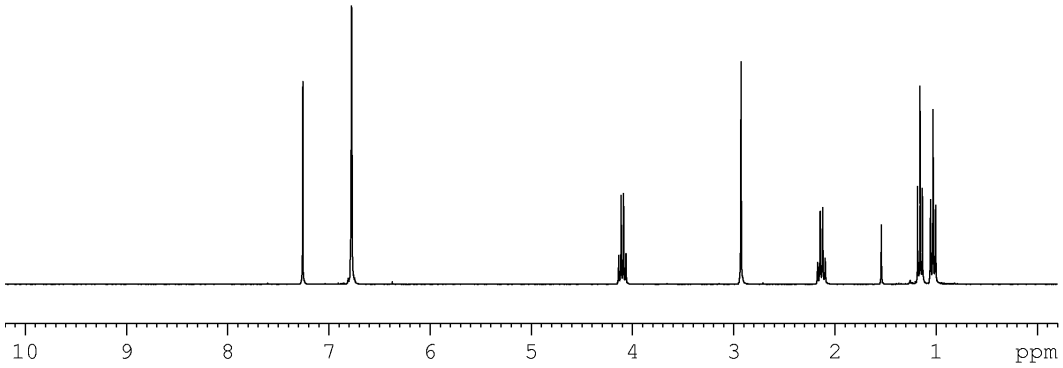

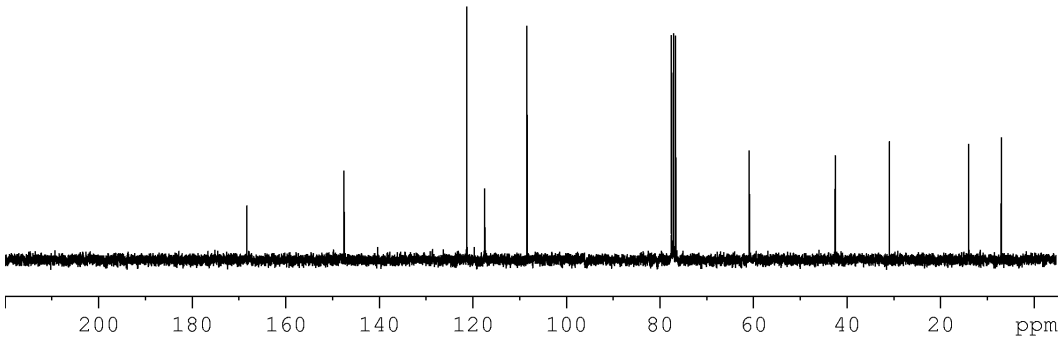

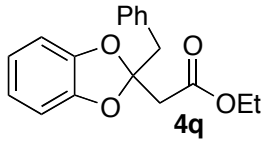
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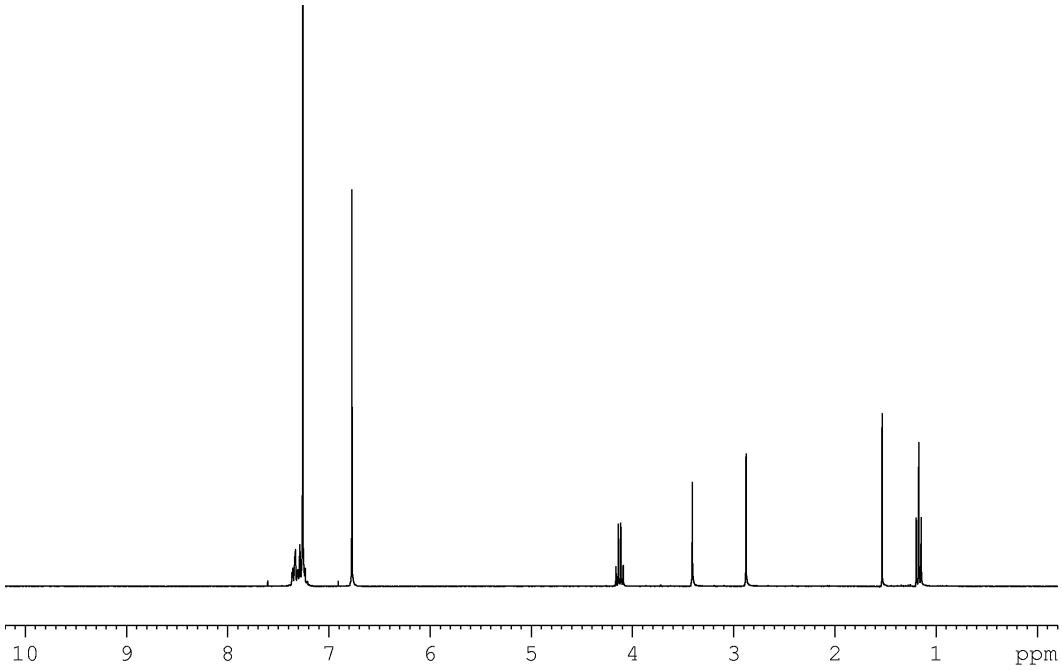
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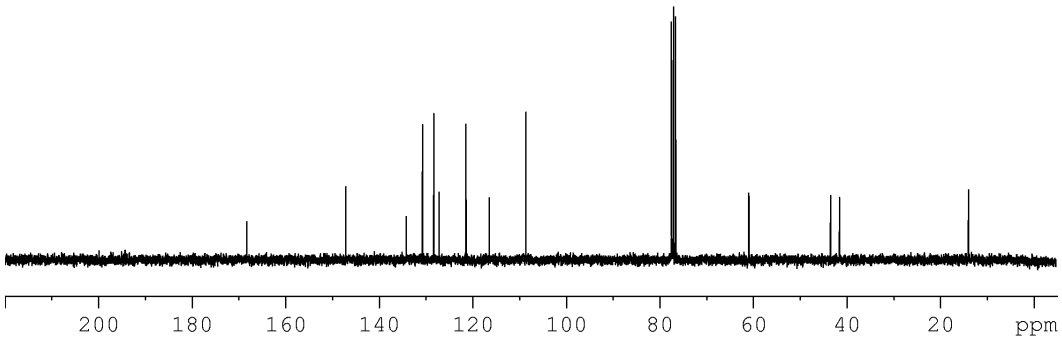
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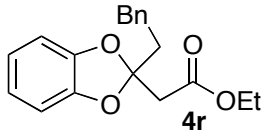
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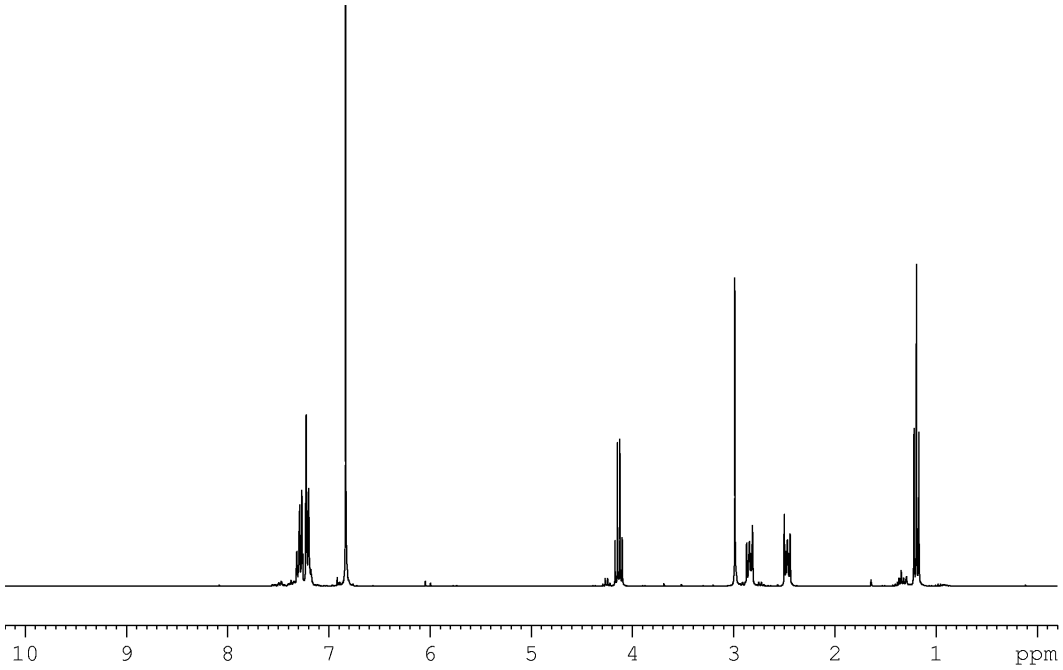
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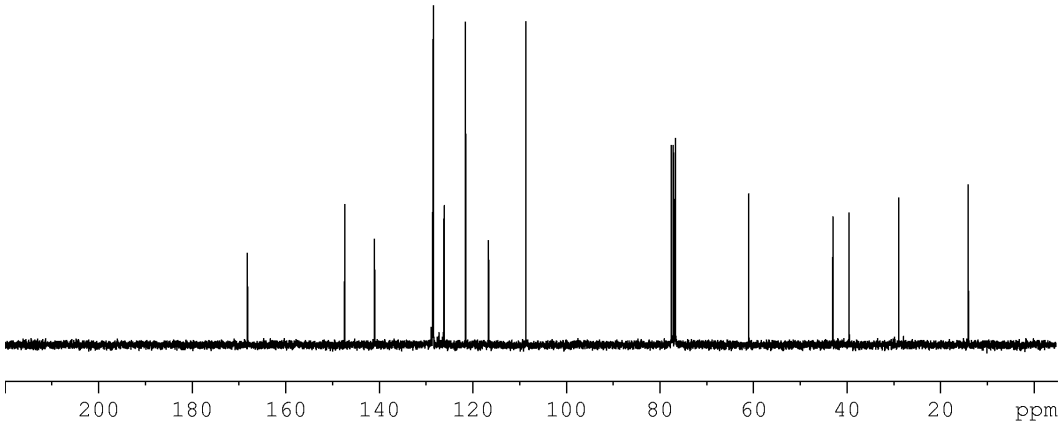
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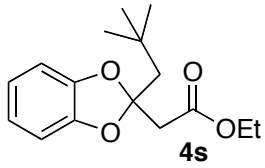

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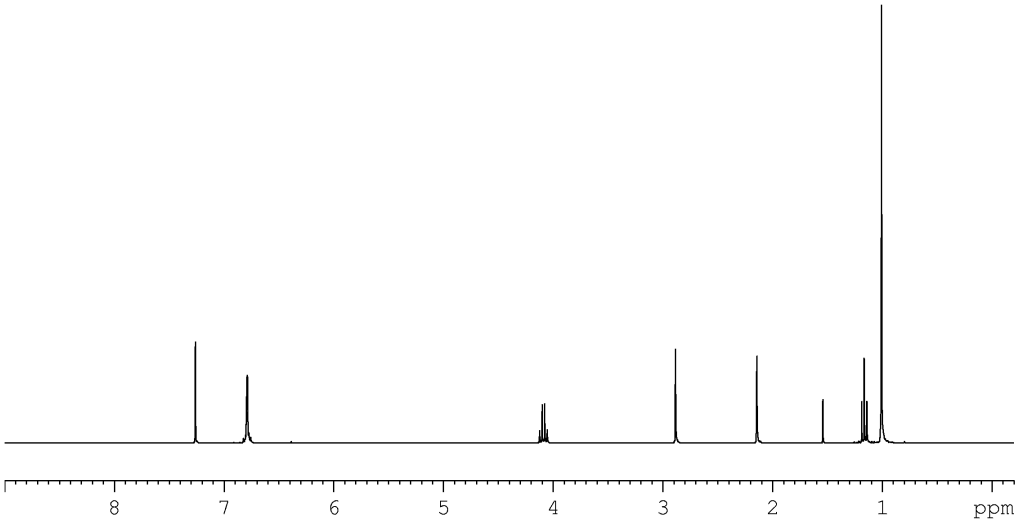

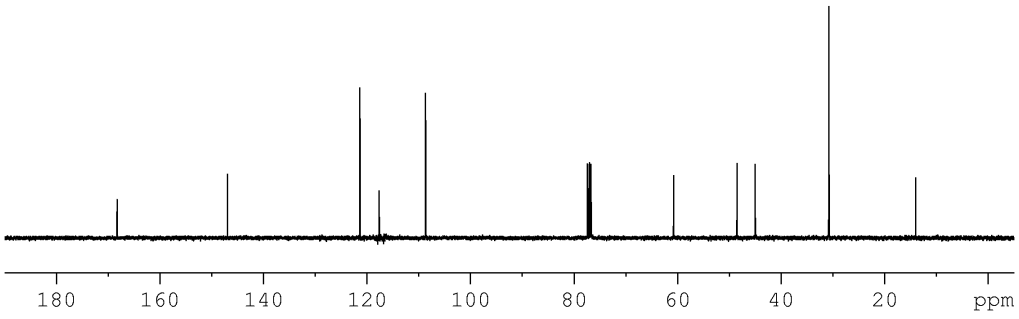

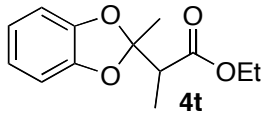

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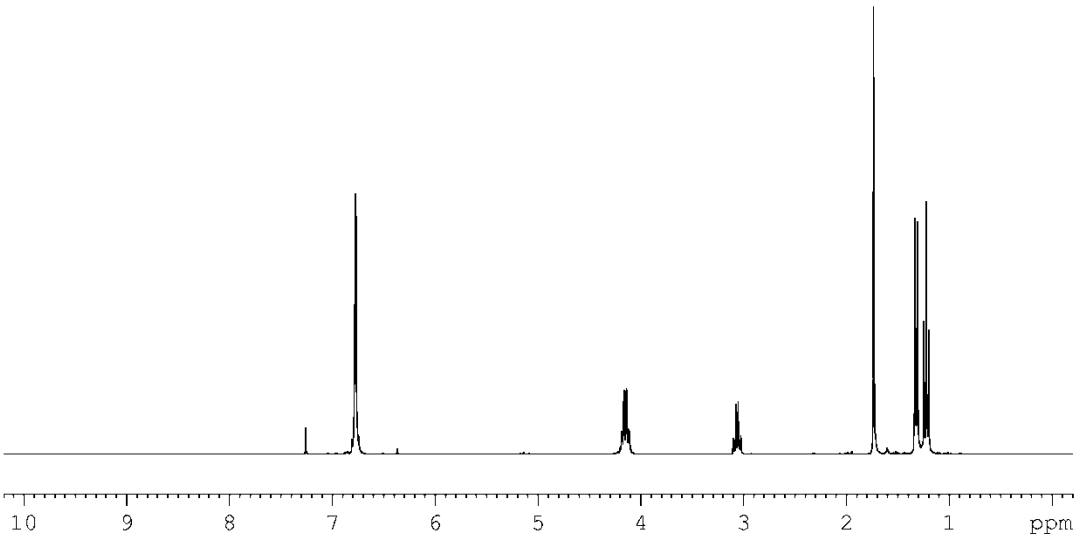

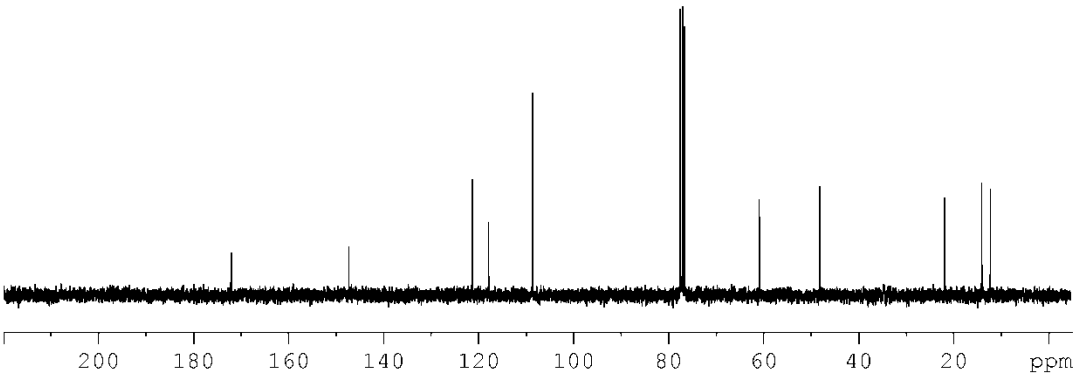

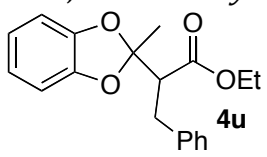

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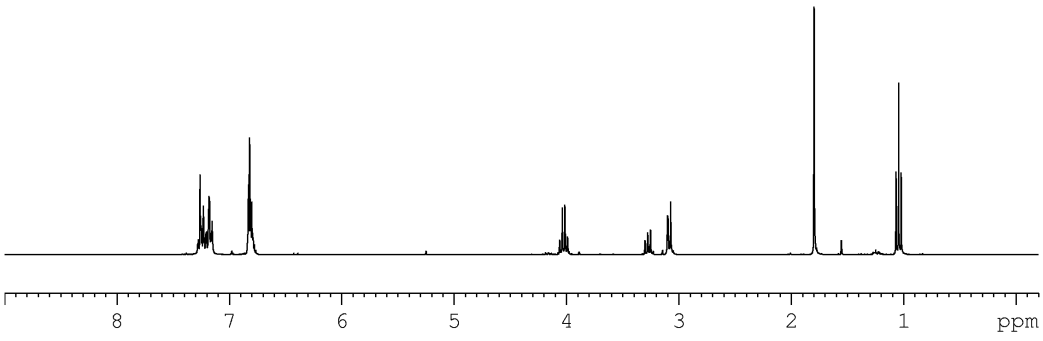

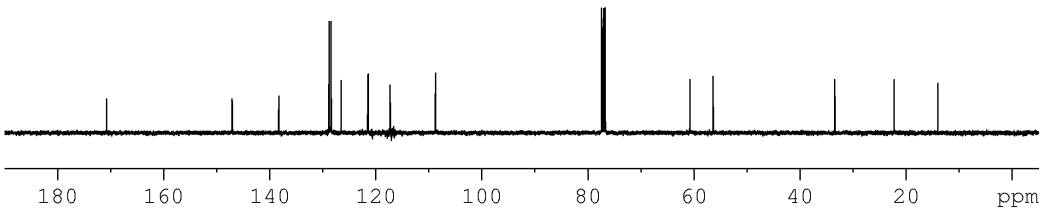

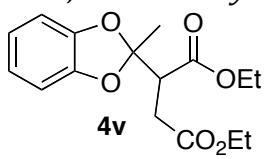
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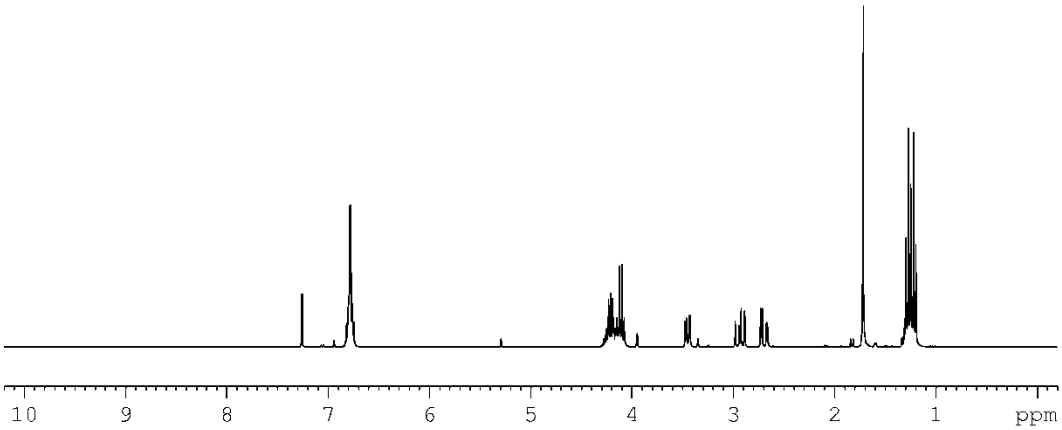
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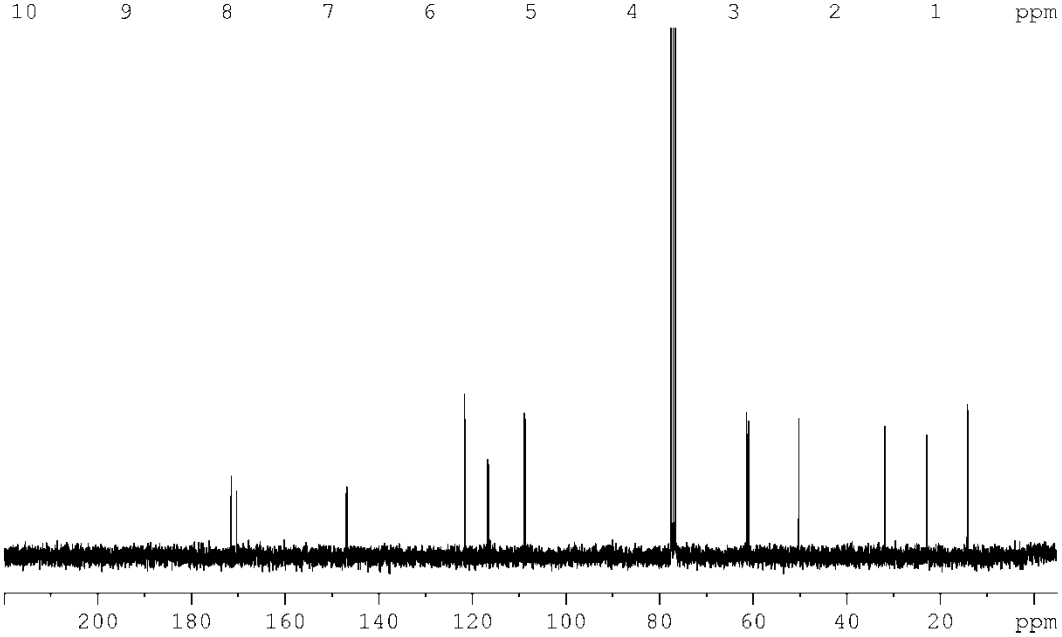
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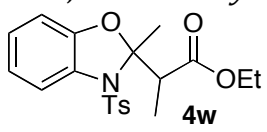
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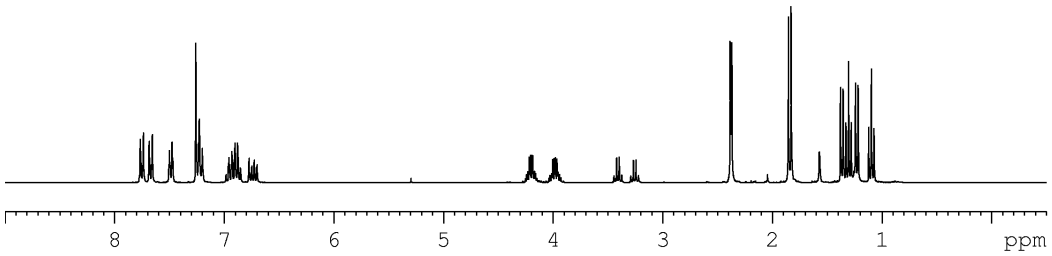
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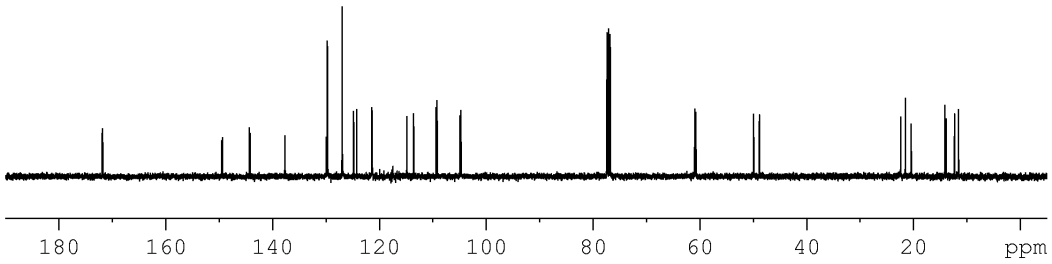
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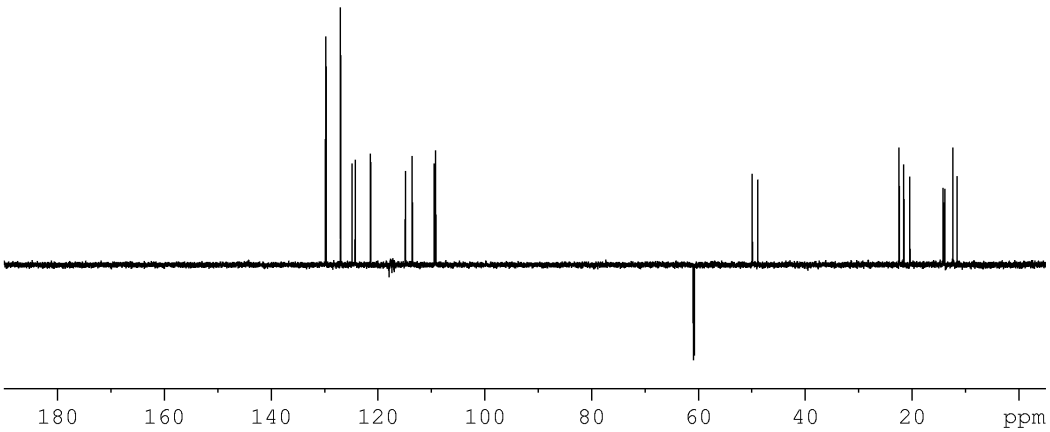
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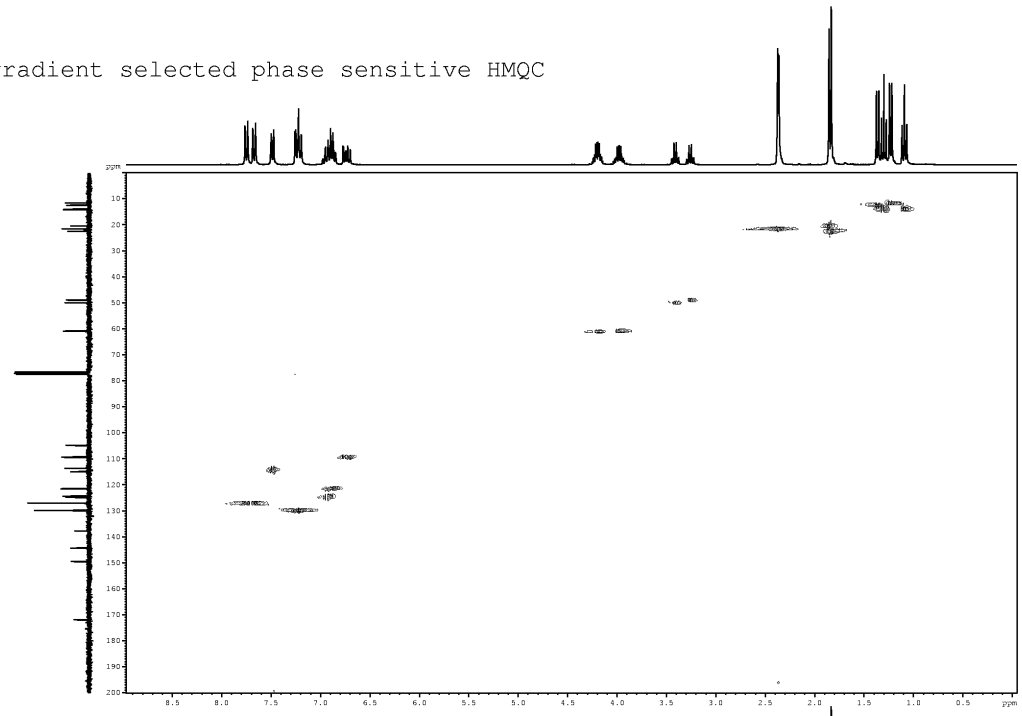
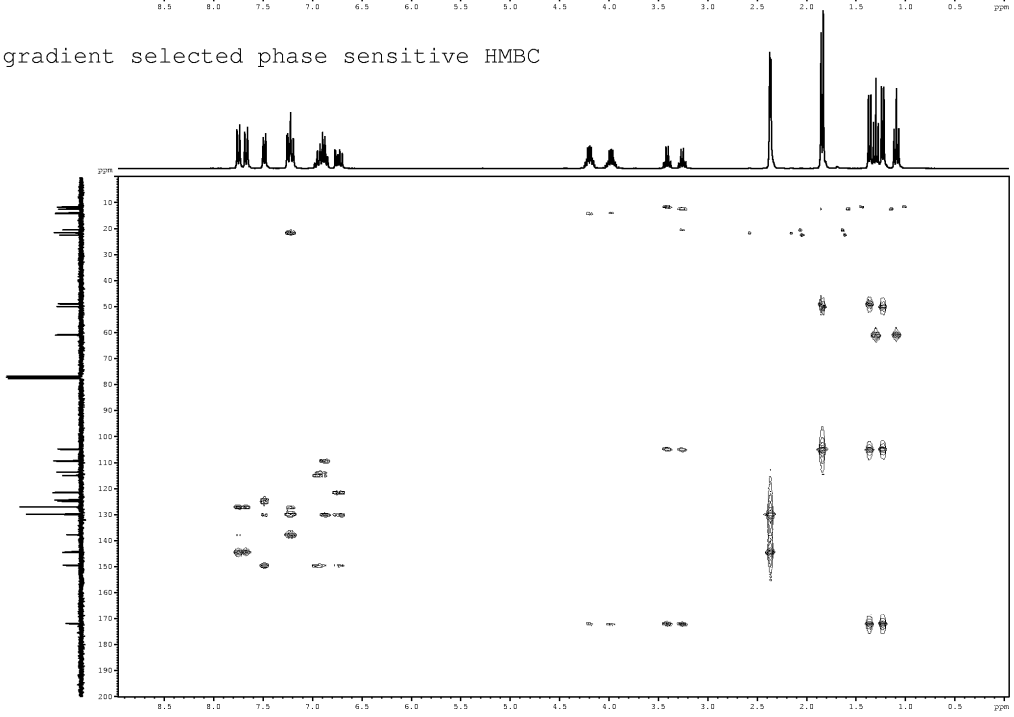
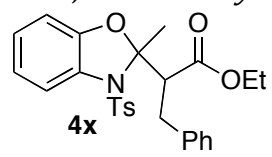
gradient selected phase sensitive HMQC



gradient selected phase sensitive HMBC

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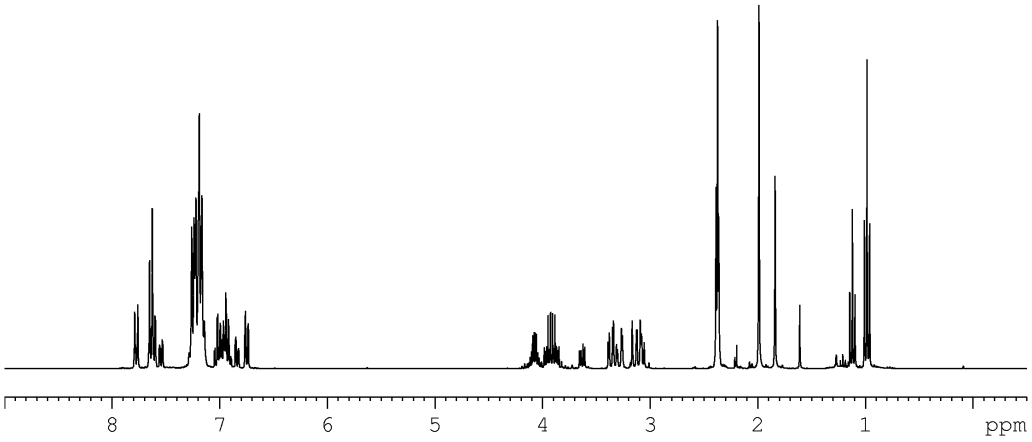
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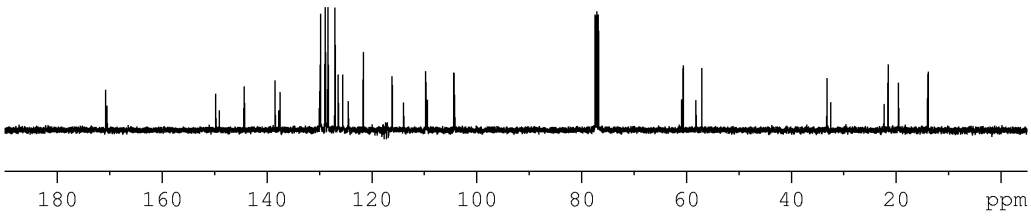
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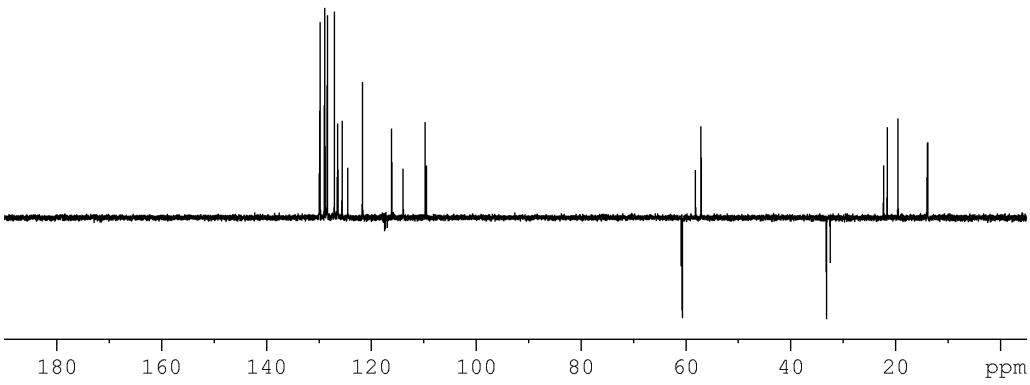
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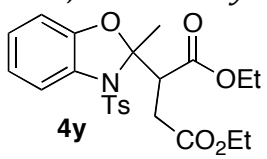
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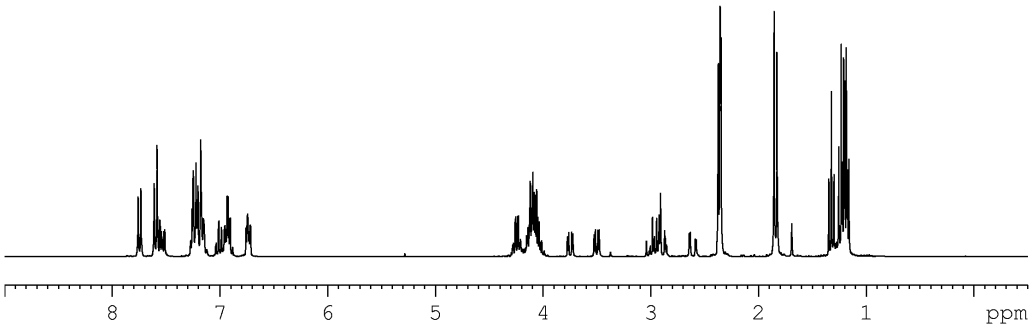
4y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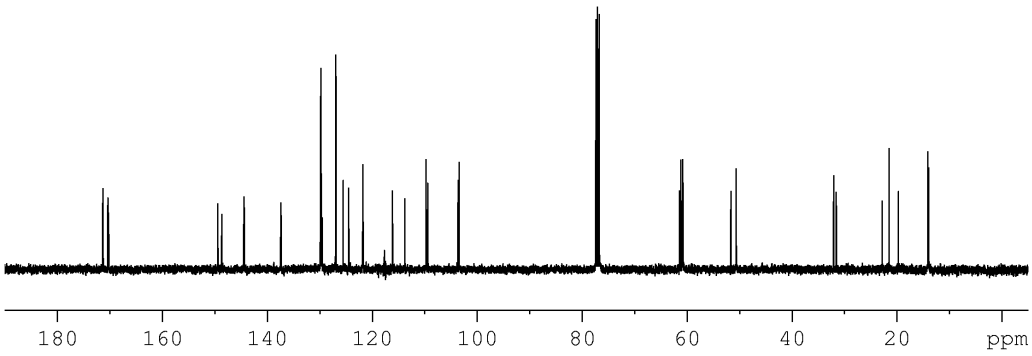
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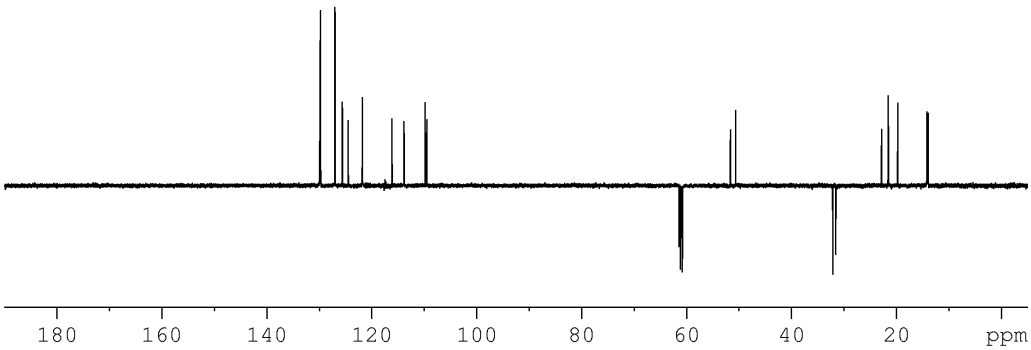
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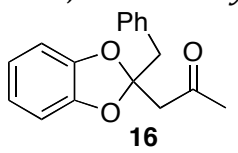

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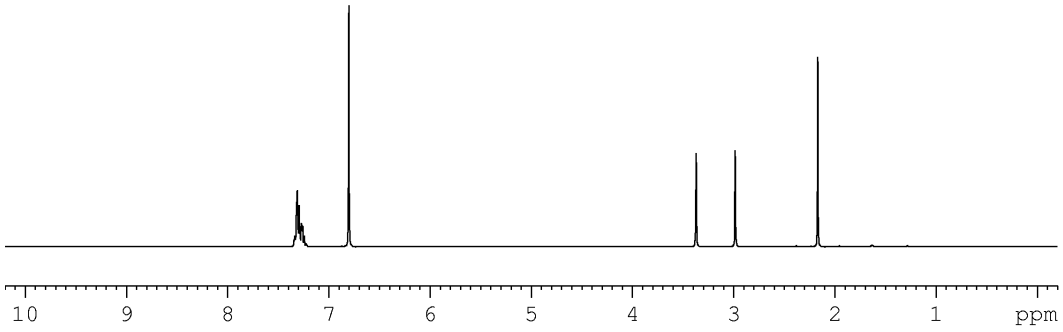

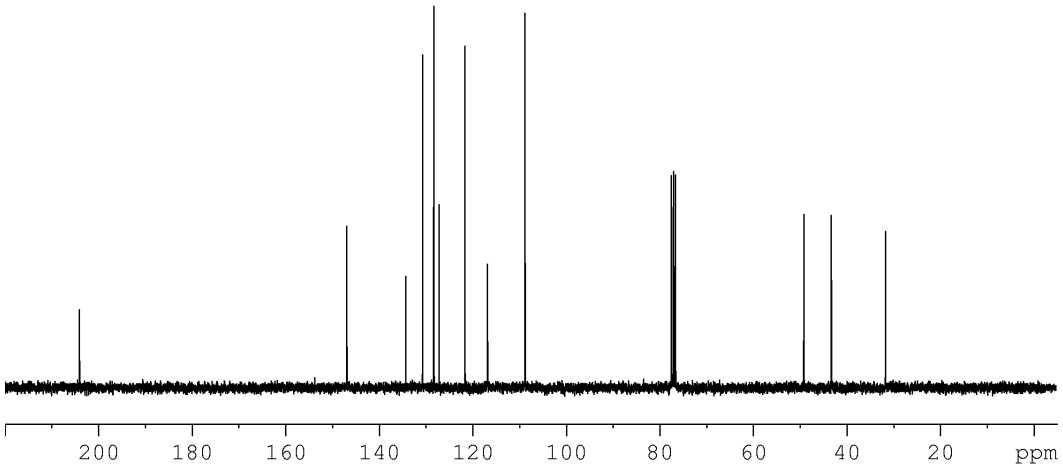

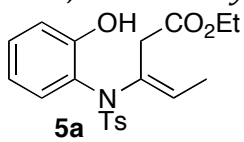

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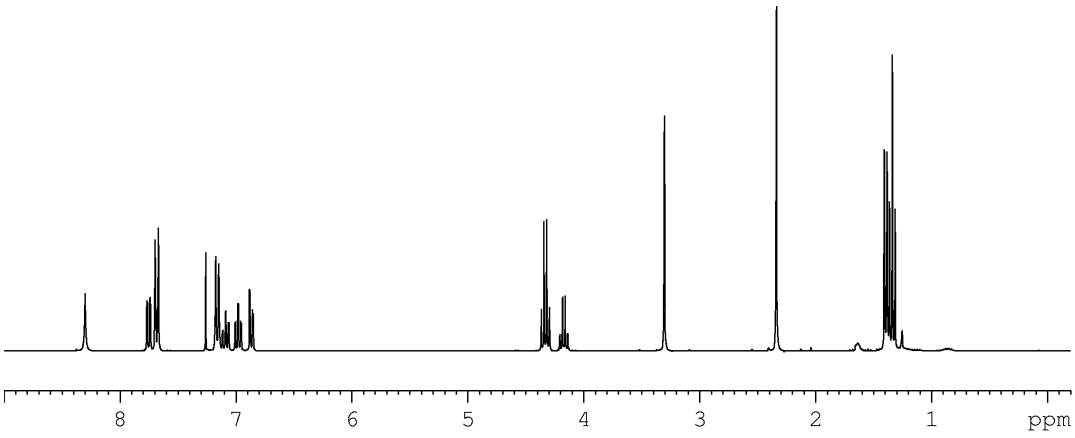

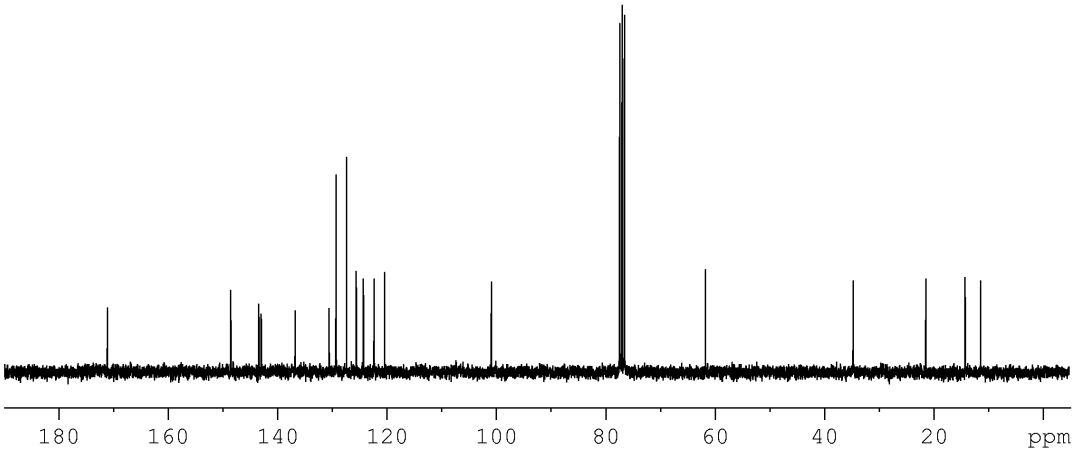

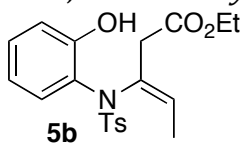

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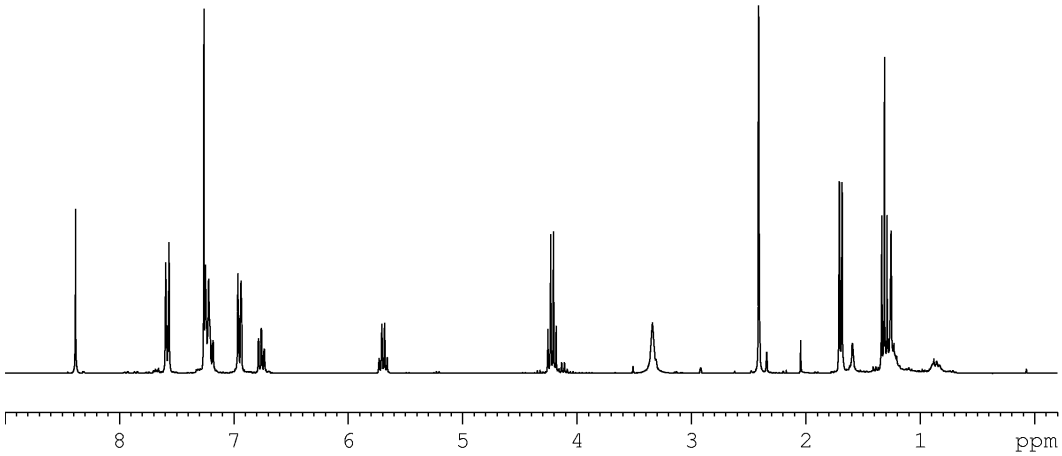

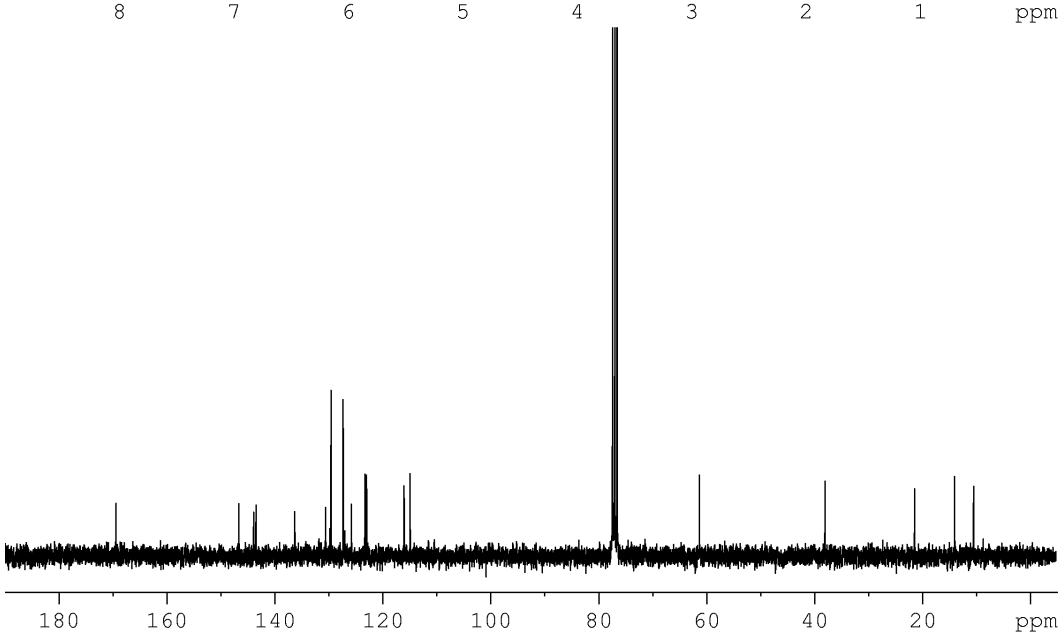

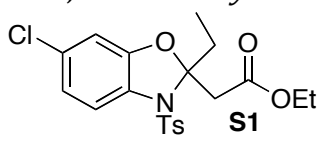

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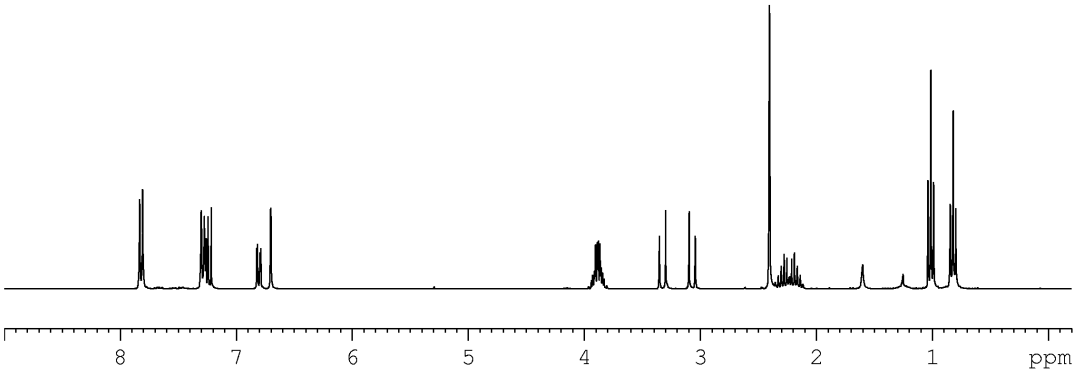

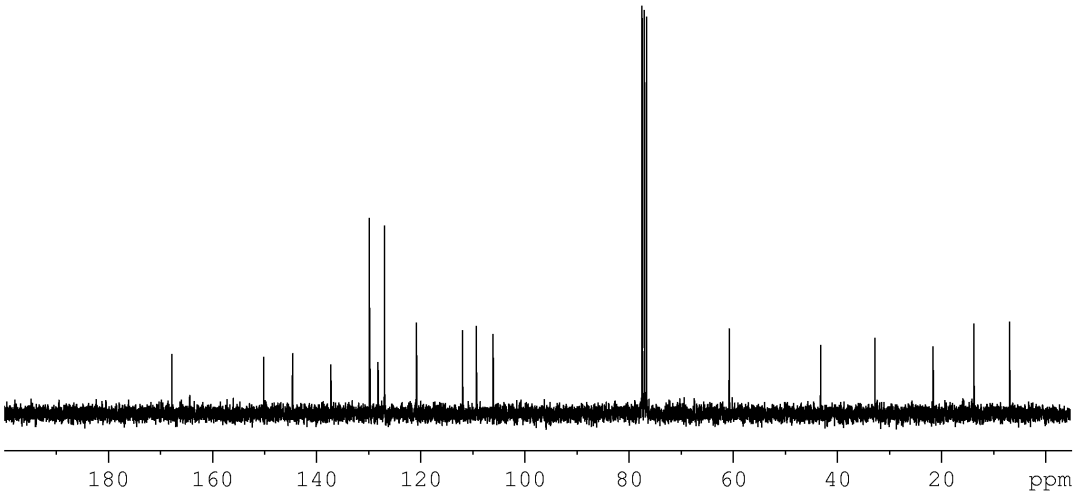

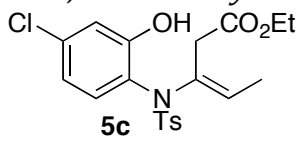

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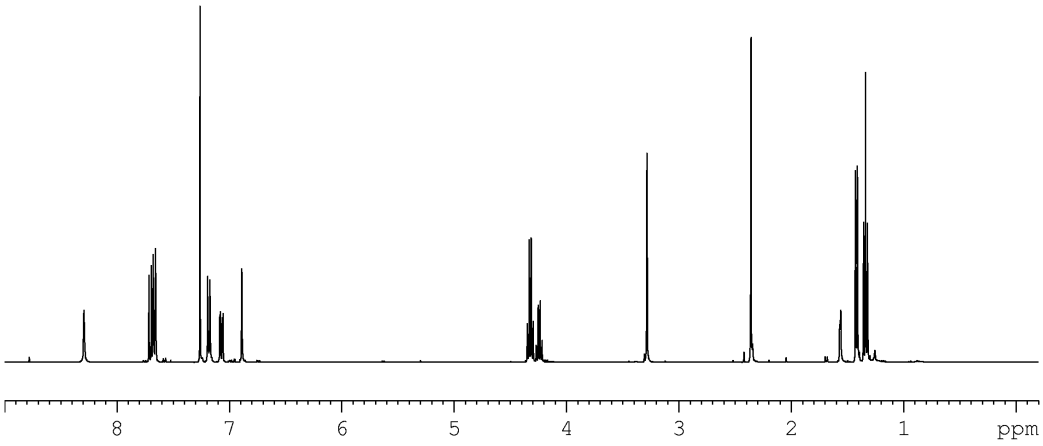

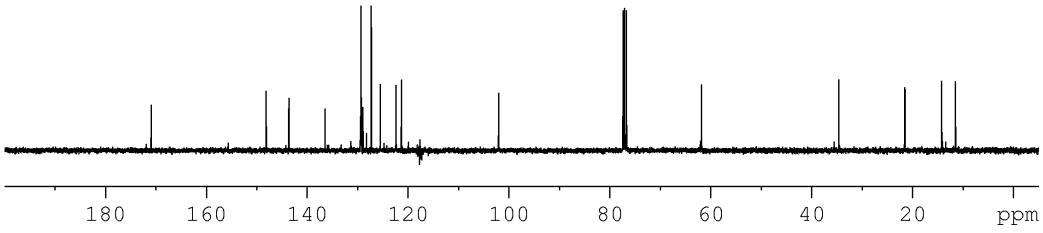

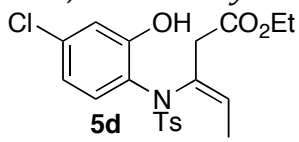

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