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Supporting Information

Ag-Catalyzed Diastereoselective [6+3] Cycloaddition of Tropone with Homoserine Lactone-Derived Azomethine Ylides: Synthesis of Tricyclic Spiropiperidines

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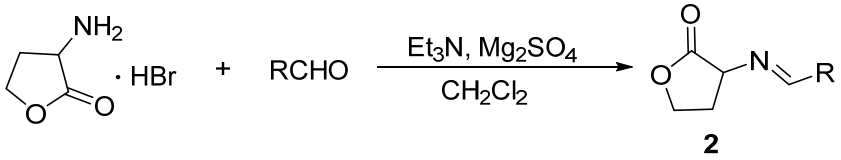
Contents

General Information

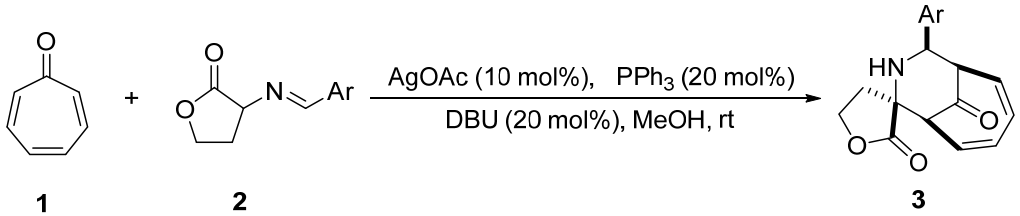
All reactions were performed under N_2 atmospheres in oven-dried glassware with magnetic stirring. Unless otherwise stated, all reagents were purchased from commercial suppliers and used without further purification. Diethyl ether employed in the reactions was freshly distilled from $CaCI_2$. Organic solutions were concentrated under reduced pressure on a rotary evaporator or an oil pump. Reactions were monitored through thin layer chromatography (TLC) on silica gel–precoated glass plates. Flash column chromatography was performed using Qingdao Haiyang flash silica gel (200–300 mesh). Infrared spectra were recorded using a Bruker Optics TENSOR 27 instrument. ^1H and ^{13}C NMR spectra were recorded in $CDCl_3$ using a 300 MHz NMR instrument (referenced internally to Me_4Si). Chemical shifts (δ, ppm) are relative to tetramethylsilane (TMS) with the resonance of the non-deuterated solvent or TMS as the internal standard. ^1H NMR data are reported as follows: chemical shift, multiplicity (s = singlet; d = doublet; q = quartet; m = multiplet; br = broad), coupling constant (Hz), and integral. Data for ^{13}C NMR spectra are reported in terms of chemical shift. Optical rotation was obtained on an Autopol V Plus polarimeter. Accurate mass measurements were performed using an Agilent instrument with the ESI-MS technique.

Preparation of α-Iminoesters 2



All α-iminoesters were prepared using the reported procedure. A suspension of α-amino-γ-butyrolactone hydrobromide (14.8 mmol), $MgSO_4$ (14.8 mmol) and Et_3N (14.8 mmol) in dry CH_2Cl_2 (36 mL) was stirred at room temperature for 1 h, and aldehyde (16.2 mmol) was added. The resulting mixture was stirred at room temperature for 12 h, and then was filtered. To the filtrate was added water (5 mL). The organic layer was separated and the aqueous phase was extracted with CH_2Cl_2 (10 mL). The combined organic layers were washed with brine, dried over $MgSO_4$ and evaporated under reduced pressure to afford α-iminoesters **2**, which was used in the next step without further purification.

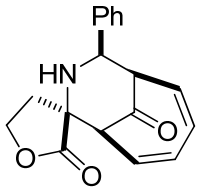
General Procedure for [6+3] cycloaddition between Tropone and Azomethine Ylides by AgOAc/PPh_3



Under nitrogen atmosphere, Ag catalyst (10 mol%, 0.03 mmol, 5.0 mg) and Ph_3P (20 mol%, 0.06 mmol, 15.8 mg) were dissolved in 1 mL of methanol. The resulting mixture was stirred at room temperature for about 1 hour, followed by addition of tropone **1** (0.3 mmol, 30 μL), α-iminoesters **2** (0.45mmol), DBU (20 mol%, 9.1 mg, 0.06 mmol) and methanol (2 mL). Upon the completion of the reaction as monitored by TLC, the mixture was concentrated in vacuo. The residue was purified through flash column chromatography (EtOAc/petroleum ether) to afford the corresponding product.

Characterization Data for the Cycloaddition Products 3

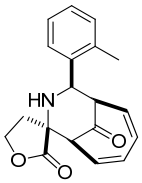
9-Phenyl-4',5'-dihydro-2'*H*-8-azaspiro[bicyclo[4.3.1]deca[2,4]diene-7,3'-furan]-2',10-dione (3a)



3a

Prepared according to the general procedure as described above in 92% yield. Reaction time = 12 h. It was purified by flash chromatography (EtOAc/PE = 1/10) to afford white solid, m.p. 102 – 103 °C. ^{1}H NMR analysis: >20:1 dr. ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.39 – 7.18 (m, 5H), 6.16 (dd, *J* = 11.4, 7.7 Hz, 1H), 6.06 – 5.87 (m, 1H), 5.59 (dd, *J* = 11.1, 8.2 Hz, 1H), 5.09 (dd, *J* = 11.3, 7.7 Hz, 1H), 4.83 (dd, *J* = 11.1, 3.8 Hz, 1H), 4.54 (ddd, *J* = 10.8, 8.8, 5.6 Hz, 1H), 4.39 (m, 1H), 3.73 (ddd, *J* = 7.7, 4.0, 2.4 Hz, 1H), 3.37 (dd, *J* = 8.2, 2.4 Hz, 1H), 2.43 (ddd, *J* = 13.3, 10.8, 8.5 Hz, 1H), 2.10 (ddd, *J* = 13.3, 5.6, 1.1 Hz, 1H), 1.97 (d, *J* = 11.2 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 203.1, 175.3, 138.0, 128.5, 128.0, 127.5, 126.2, 125.9, 124.1, 121.0, 67.2, 66.14, 60.4, 58.4, 56.0, 35.7; IR (film) ν_{max} 3323, 3030, 2980, 2929, 1750, 1603, 1480, 1379, 1264, 1193, 1062, 1031, 957, 873, 827, 802, 751, 661, 614, 512, 468; HRMS (ESI) calcd for $C_{18}H_{17}NO_3$ $[M + Na]^+$ 318.1101, found 318.1100.

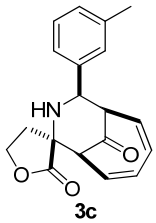
9-(o-Tolyl)-4',5'-dihydro-2'*H*-8-azaspiro[bicyclo[4.3.1]deca[2,4]diene-7,3'-furan]-2',10-dione (3b)



3b

Prepared according to the general procedure as described above in 56% yield. Reaction time = 12 h. It was purified by flash chromatography (EtOAc/PE = 1/10) to afford white solid, m.p. 114 – 115 °C. ^{1}H NMR analysis: >20:1 dr. ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.24 – 7.16 (m, 3H), 7.05 – 6.98 (m, 1H), 6.21 (dd, *J* = 11.3, 7.6 Hz, 1H), 6.08 (dd, *J* = 11.4, 7.7 Hz, 1H), 5.63 (dd, *J* = 11.3, 8.2 Hz, 1H), 5.05 (dd, *J* = 11.5, 7.8 Hz, 2H), 4.51 (m, 1H), 4.43 – 4.34 (m, 1H), 3.71 – 3.54 (m, 1H), 3.39 (dd, *J* = 8.2, 2.4 Hz, 1H), 2.50 – 2.42 (m, 1H), 2.38 (s, 3H), 2.15 – 2.02 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 203.3, 175.5, 135.8, 135.0, 130.9, 128.2, 127.3, 126.0, 125.9, 125.5, 124.2, 120.9, 67.1, 66.0, 56.7, 56.2, 56.0, 35.5, 29.6; IR (film) ν_{max} 3330, 3052, 2935, 1741, 1606, 1587, 1377, 1264, 1200, 1122, 1095, 1028, 876, 827, 775, 762, 696, 484; HRMS (ESI) calcd for $C_{19}H_{19}NO_3$ $[M + Na]^+$ 332.1257, found 332.1256.

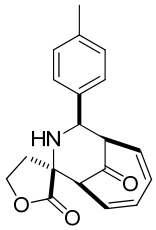
9-(m-Tolyl)-4',5'-dihydro-2'*H*-8-azaspiro[bicyclo[4.3.1]deca[2,4]diene-7,3'-furan]-2',10-dione (3c)



3c

Prepared according to the general procedure as described above in 74% yield. Reaction time = 12 h. It was purified by flash chromatography (EtOAc/PE = 1/10) to afford white solid, m.p. 120 – 121 °C. ^{1}H NMR analysis: >20:1 dr. ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.23 (t, *J* = 7.5 Hz, 1H), 7.04 (dd, J = 23.9, 7.9 Hz, 3H), 6.15 (m, 1H), 6.04 – 5.93 (m, 1H), 5.59 (dd, *J* = 11.4, 8.2 Hz, 1H), 5.11 (dd, *J* = 11.5, 7.7 Hz, 1H), 4.78 (dd, *J* = 11.2, 3.7 Hz, 1H), 4.61 – 4.49 (m, 1H), 4.38 (m 1H), 3.71 (ddd, *J* = 7.1, 3.9, 2.4 Hz, 1H), 3.34 (m, 1H), 2.42 (m, 1H), 2.35 (s, 3H), 2.11 (ddd, *J* = 13.3, 5.5, 1.0 Hz, 1H), 1.97 (d, *J* = 11.7 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 203.3, 175.4, 138.1, 138.0, 128.3, 128.2, 128.0, 127.0, 125.8, 124.1, 123.3, 120.9, 67.3, 66.2, 60.4, 58.4, 56.0, 35.6, 21.5; IR (film) ν_{max} 3295, 3044, 2912, 1785, 1623, 1499, 1400, 1325, 1277, 1208, 1093, 1041, 890, 845, 762, 700, 464; HRMS (ESI) calcd for $C_{19}H_{19}NO_3$ $[M + Na]^+$ 332.1257, found 332.1261.

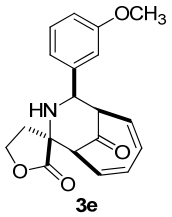
9-(p-Tolyl)-4',5'-dihydro-2'*H*-8-azaspiro[bicyclo[4.3.1]deca[2,4]diene-7,3'-furan]-2',10-dione (3d)



3d

Prepared according to the general procedure as described above in 76% yield. Reaction time = 12 h. It was purified by flash chromatography (EtOAc/PE = 1/10) to afford white solid, m.p. 104 – 105 °C. ^{1}H NMR analysis: >20:1 dr. ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.12 (q, *J* = 8.2 Hz, 4H), 6.15 (dd, *J* = 11.4, 7.7 Hz, 1H), 6.07 – 5.92 (m, 1H), 5.58 (dd, *J* = 11.3, 8.2 Hz, 1H), 5.13 (m, 1H), 4.78 (d, *J* = 5.6 Hz, 1H), 4.63 – 4.47 (m, 1H), 4.43 – 4.31 (m, 1H), 3.69 (ddd, *J* = 12.1, 7.3, 5.3 Hz, 1H), 3.35 (dd, *J* = 8.2, 2.3 Hz, 1H), 2.49 – 2.36 (m, 1H), 2.34 (s, 3H), 2.09 (ddd, *J* = 13.3, 5.5, 1.0 Hz, 1H), 1.95 (d, *J* = 10.5 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 203.4, 175.4, 137.2, 135.0, 129.1, 128.0, 126.1, 125.8, 124.1, 120.9, 67.3, 66.2 60.3, 58.5, 56.0, 35.6, 21.0; IR (film) ν_{max} 3375, 3030, 2900, 2853, 1740, 1583, 1520, 1464, 1270, 1219, 1192, 1095, 1028, , 819, 780, 715, 660, 483; HRMS (ESI) calcd for $C_{19}H_{19}NO_3$ $[M + Na]^+$ 332.1257, found 332.1258.

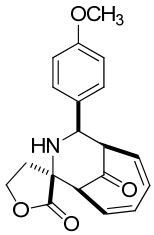
9-(3-Methoxyphenyl)-4',5'-dihydro-2'H-8-azaspiro[bicyclo[4.3.1]deca[2,4]diene-7,3'-furan]-2',10-dione (3e)



3e

Prepared according to the general procedure as described above in 68% yield. Reaction time = 12 h. It was purified by flash chromatography (EtOAc/PE = 1/10) to afford yellow semi-solid. ^{1}H NMR analysis: >20:1 dr. ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.26 (dd, J = 9.2, 6.6 Hz, 1H), 6.85 – 6.73 (m, 3H), 6.14 (dd, *J* = 11.4, 7.7 Hz, 1H), 5.99 (dd, *J* = 11.5, 7.7 Hz, 1H), 5.58 (dd, *J* = 11.4, 8.2 Hz, 1H), 5.12 (dd, *J* = 11.5, 7.7 Hz, 1H), 4.78 (dd, *J* = 11.5, 3.8 Hz, 1H), 4.53 (ddd, *J* = 10.8, 8.8, 5.6 Hz, 1H), 4.38 (m, 1H), 3.80 (s, 3H), 3.71 (ddd, *J* = 6.5, 3.8, 2.4 Hz, 1H), 3.35 (dd, *J* = 8.2, 2.3 Hz, 1H), 2.42 (ddd, *J* = 13.3, 10.8, 8.5 Hz, 1H), 2.13 – 2.03 (m, 1H), 1.95 (d, *J* = 11.7 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 203.2, 175.4, 159.7, 139.7, 129.5, 128.0, 125.9, 123.9, 120.9, 118.5, 112.5, 112.4, 67.2, 66.2, 60.3, 58.3, 56.0, 55.3, 35.6; IR (film) ν_{max} 3425, 3000, 2923, 2873, 1720, 1705, 1612, 1464, 1435, 1264, 1220, 1144, 1087, 1049, 785; HRMS (ESI) calcd for $C_{19}H_{19}NO_4$ $[M + Na]^+$ 348.1206, found 348.1201.

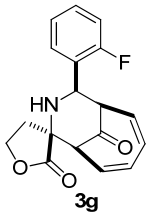
9-(4-Methoxyphenyl)-4',5'-dihydro-2'*H*-8-azaspiro[bicyclo[4.3.1]deca[2,4]diene-7,3'-furan]-2',10-dione (3f)



3f

Prepared according to the general procedure as described above in 52% yield. Reaction time = 16 h. It was purified by flash chromatography (EtOAc/PE = 1/10) to afford yellow semi-solid. ^{1}H NMR analysis: >20:1 dr. ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.13 (t, *J* = 5.7 Hz, 2H), 6.91 – 6.82 (m, 2H), 6.15 (dd, *J* = 11.4, 7.7 Hz, 1H), 6.00 (dd, *J* = 11.5, 7.7 Hz, 1H), 5.58 (dd, *J* = 11.4, 8.2 Hz, 1H), 5.17 – 5.08 (m, 1H), 4.80 – 4.71 (m, 1H), 4.53 (ddd, *J* = 10.8, 8.8, 5.6 Hz, 1H), 4.37 (m, 1H), 3.80 (s, 3H), 3.70 – 3.64 (m, 1H), 3.35 (dd, *J* = 8.2, 2.4 Hz, 1H), 2.43 (ddd, J = 13.3, 10.8, 8.5 Hz, 1H), 2.08 (dd, *J* = 13.4, 4.6 Hz, 1H), 1.91 (d, *J* = 11.9 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 203.3, 175.4, 158.9, 130.1, 128.0, 127.4, 125.8, 124.2, 120.9, 113.8, 67.2, 66.1, 60.0, 58.5, 56.0 55.3, 35.6; IR (film) ν_{max} 3295, 2957, 2942, 2850, 1740, 1720, 1601, 1475, 1442, 1300, 1219, 1197, 1128, 1045, 780; HRMS (ESI) calcd for $C_{19}H_{19}NO_4$ $[M + Na]^+$ 348.1206, found 348.1211.

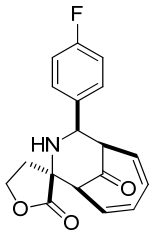
9-(2-Fluorophenyl)-4',5'-dihydro-2'*H*-8-azaspiro[bicyclo[4.3.1]deca[2,4]diene-7,3'-furan]-2',10-dione (3g)



3g

Prepared according to the general procedure as described above in 51% yield. Reaction time = 16 h. It was purified by flash chromatography (EtOAc/PE = 1/10) to afford orange semi-solid. ^{1}H NMR analysis: >20:1 dr. ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.32 – 7.22 (m, 1H), 7.17 – 7.01 (m, 3H), 6.18 (dd, *J* = 11.4, 7.7 Hz, 1H), 6.02 (dd, *J* = 11.5, 7.7 Hz, 1H), 5.60 (dd, *J* = 11.4, 8.2 Hz, 1H), 5.15 – 4.98 (m, 2H), 4.53 (ddd, *J* = 10.8, 8.8, 5.6 Hz, 1H), 4.39 (m, 1H), 3.82 – 3.74 (m, 1H), 3.38 (dd, *J* = 8.2, 2.3 Hz, 1H), 2.43 (ddd, *J* = 13.3, 10.8, 8.5 Hz, 1H), 2.22 – 2.06 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 202.7, 175.2, 160.0 (d, *J* = 245.3 Hz), 129.0(d, *J* = 9.0 Hz),128.1, 127.7 (d, *J* =3.8Hz), 126.2, 125.2(d, *J* = 12.8Hz), 124.0, 123.9, 121.0, 115.7(d, *J* = 21.8Hz), 67.1, 66.2, 56.8, 56.8, 56.1, 35.8; IR (film) ν_{max} 3325, 2927, 2867, 1780, 1500, 1457, 1400, 1219, 1196, 1110, 1028, 876, 705, 667; HRMS (ESI) calcd for $C_{18}H_{16}FNO_3$ $[M + Na]^+$ 336.1006, found 336.1010.

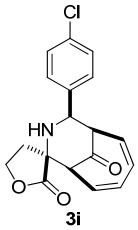
9-(4-Fluorophenyl)-4',5'-dihydro-2'*H*-8-azaspiro[bicyclo[4.3.1]deca[2,4]diene-7,3'-furan]-2',10-dione (3h)



3h

Prepared according to the general procedure as described above in 74% yield. Reaction time = 12 h. It was purified by flash chromatography (EtOAc/PE = 1/10) to afford orange semi-solid. ^{1}H NMR analysis: >20:1 dr. ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.21 (m, 2H), 7.11 – 7.01 (m, 2H), 6.18 (dd, *J* = 11.4, 7.6 Hz, 1H), 6.03 (dd, *J* = 11.5, 7.7 Hz, 1H), 5.62 (dd, *J* = 11.4, 8.2 Hz, 1H), 5.10 (dd, *J* = 11.5, 7.7 Hz, 1H), 4.82 (d, *J* = 7.0 Hz, 1H), 4.55 (ddd, *J* = 9.8, 8.4, 5.2 Hz, 1H), 4.41 (ddd, *J* = 12.0, 6.6, 2.3 Hz, 1H), 3.75 – 3.67 (m, 1H), 3.38 (dd, *J* = 8.2, 2.3 Hz, 1H), 2.46 (ddd, *J* = 13.3, 10.7, 8.5 Hz, 1H), 2.16 – 2.05 (m, 1H), 1.93 (d, *J* = 11.3 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 202.9, 175.3, 162.0(d, *J* = 244.5Hz), 133.8 (d, *J* = 3.0Hz), 128.0, 127.9, 127.8, 126.1, 123.8, 121.1, 113.4(d, *J* =75Hz), 67.1, 66.1, 59.8, 58.2, 55.9, 35.6; IR (film) ν_{max} 3500, 2930, 1800, 1720, 1612, 1526, 1463, 1383, 1259, 1195, 1167, 1100, 1035, 850, 802, 765, 700, 660, 541, 525; HRMS (ESI) calcd for $C_{18}H_{16}FNO_3$ $[M + Na]^+$ 336.1006, found 336.1003.

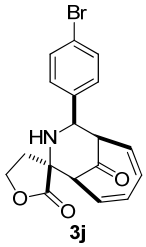
9-(4-Chlorophenyl)-4',5'-dihydro-2'*H*-8-azaspiro[bicyclo[4.3.1]deca[2,4]diene-7,3'-furan]-2',10-dione (3i)



3i

Prepared according to the general procedure as described above in 76% yield. Reaction time = 12 h. It was purified by flash chromatography (EtOAc/PE = 1/10) to afford orange semi-solid. ^{1}H NMR analysis: >20:1 dr. ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.37 – 7.31 (m, 2H), 7.22 – 7.14 (m, 2H), 6.17 (dd, *J* = 11.4, 7.7 Hz, 1H), 6.02 (dd, *J* = 11.5, 7.7 Hz, 1H), 5.61 (dd, *J* = 11.3, 8.2 Hz, 1H), 5.14 – 5.02 (m, 1H), 4.82 (dd, *J* = 11.4, 3.9 Hz, 1H), 4.55 (ddd, *J* = 10.7, 8.9, 5.6 Hz, 1H), 4.41 (tt, *J* = 4.6, 2.3 Hz, 1H), 3.77 – 3.65 (m, 1H), 3.37 (dd, *J* = 8.2, 2.3 Hz, 1H), 2.45 (ddd, *J* = 13.4, 10.7, 8.5 Hz, 1H), 2.12 (ddd, *J* = 13.4, 5.6, 1.2 Hz, 1H), 1.93 (d, *J* = 11.6 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 202.8, 175.3, 136.6, 133.3, 128.6, 128.0, 127.6, 126.2, 123.6, 121.1, 67.1, 66.2, 59.8, 58.0, 55.9, 35.5; IR (film) ν_{max} 3502, 2930, 1715, 1647, 1500, 1397, 1276, 1210, 1195, 1093, 851, 744, 697, 678, 483; HRMS (ESI) calcd for $C_{18}H_{16}ClNO_3$ $[M + Na]^+$ 352.0711, found 352.0705.

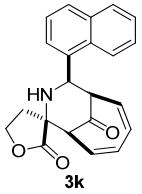
9-(4-Bromophenyl)-4',5'-dihydro-2'*H*-8-azaspiro[bicyclo[4.3.1]deca[2,4]diene-7,3'-furan]-2',10-dione (3j)



3j

Prepared according to the general procedure as described above in 61% yield. Reaction time = 16 h. It was purified by flash chromatography (EtOAc/PE = 1/10) to afford orange semi-solid. ^{1}H NMR analysis: >20:1 dr. ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.55 – 7.45 (m, 2H), 7.12 (d, *J* = 8.4 Hz, 2H), 6.17 (dd, *J* = 11.4, 7.7 Hz, 1H), 6.07 – 5.95 (m, 1H), 5.61 (dd, *J* = 11.4, 8.2 Hz, 1H), 5.09 (dd, *J* = 11.5, 7.7 Hz, 1H), 4.80 (dd, *J* = 11.5, 4.0 Hz, 1H), 4.64 – 4.49 (m, 1H), 4.41 (tt, *J* = 8.9, 4.4 Hz, 1H), 3.74 – 3.66 (m, 1H), 3.38 (dd, *J* = 8.2, 2.3 Hz, 1H), 2.53 – 2.33 (m, 1H), 2.11 (ddd, *J* = 12.0, 6.0, 4.9 Hz, 1H), 1.93 (d, *J* = 11.7 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 202.7, 175.3, 137.1, 131.6, 128.0, 127.8, 126.2, 123.6, 121.4, 121.1, 67.1, 66.2, 59.9, 57.9, 55.9, 35.5; IR (film) ν_{max} 3321, 2896, 2851, 1840, 1703, 1500, 1468, 1320,1274, 1198, 1088, 1029, 894, 827, 776, 689, 656, 477; HRMS (ESI) calcd for $C_{18}H_{16}ClNO_3$ $[M + Na]^+$ 396.0206, found 396.0203.

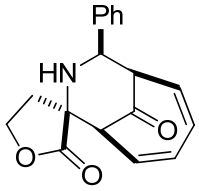
9-(Naphthalen-1-yl)-4',5'-dihydro-2'*H*-8-azaspiro[bicyclo[4.3.1]deca[2,4]diene-7,3'-furan]-2',10-dione (3k)



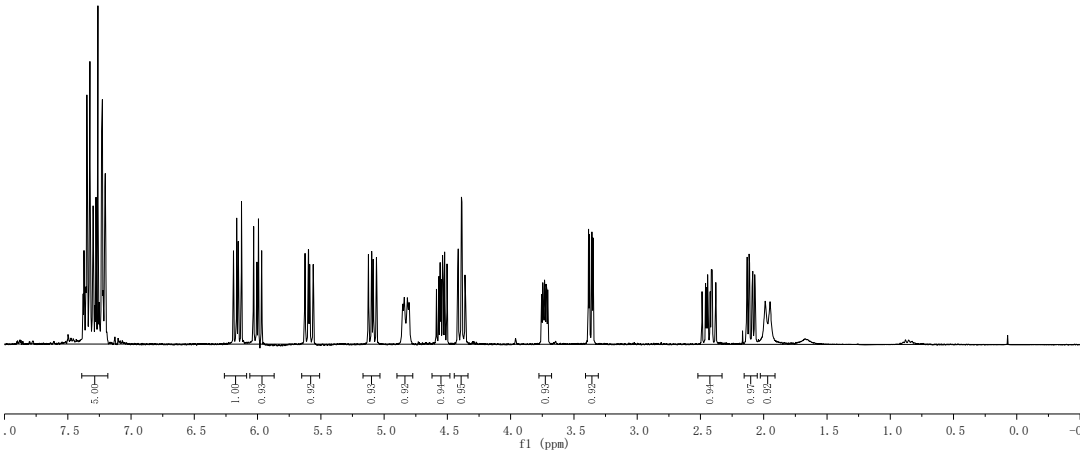
3k

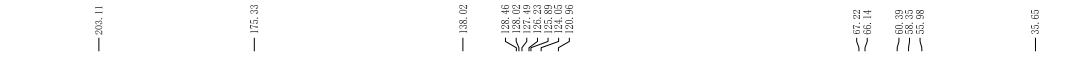
Prepared according to the general procedure as described above in 67% yield. Reaction time = 12 h. It was purified by flash chromatography (EtOAc/PE = 1/10) to afford yellow semi-solid. ^{1}H NMR analysis: >20:1 dr. ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.06 (d, *J* = 8.4 Hz, 1H), 7.93 – 7.87 (m, 1H), 7.82 (d, *J* = 8.2 Hz, 1H), 7.57 (m, 2H), 7.49 – 7.41 (m, 1H), 7.21 (d, *J* = 7.2 Hz, 1H), 6.22 (dd, *J* = 11.4, 7.7 Hz, 1H), 6.08 – 5.95 (m, 1H), 5.75 – 5.59 (m, 2H), 4.84 (dd, *J* = 11.4, 7.8 Hz, 1H), 4.55 (ddd, J = 10.7, 8.9, 5.7 Hz, 1H), 4.42 (m, 1H), 3.91 (tt, *J* = 7.2, 3.5 Hz, 1H), 3.46 (dd, *J* = 8.2, 2.3 Hz, 1H), 2.57 – 2.41 (m, 1H), 2.31 – 2.14 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 203.3, 175.6, 133.8, 133.4, 129.9, 128.90, 128.2, 128.1, 126.8, 125.9, 125.6, 124.6, 124.2, 123.3, 122.6, 121.0, 67.3, 66.1, 57.3, 56.2, 35.6, 30.0; IR (film) ν_{max} 3300, 2975, 1845，1732, 1645, 1425, 1331, 1261, 1161, 1030, 955, 836, 705, 6783, 658,442；HRMS (ESI) calcd for $C_{22}H_{19}NO_3$ $[M + Na]^+$ 368.1257, found 368.1252.

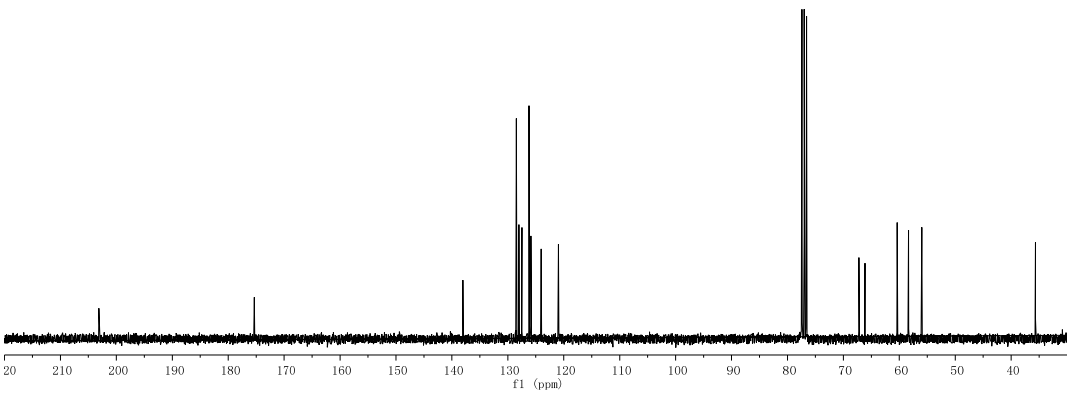
^{1}H and ^{13}C NMR Spectra of the Products 3

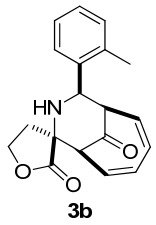


3a

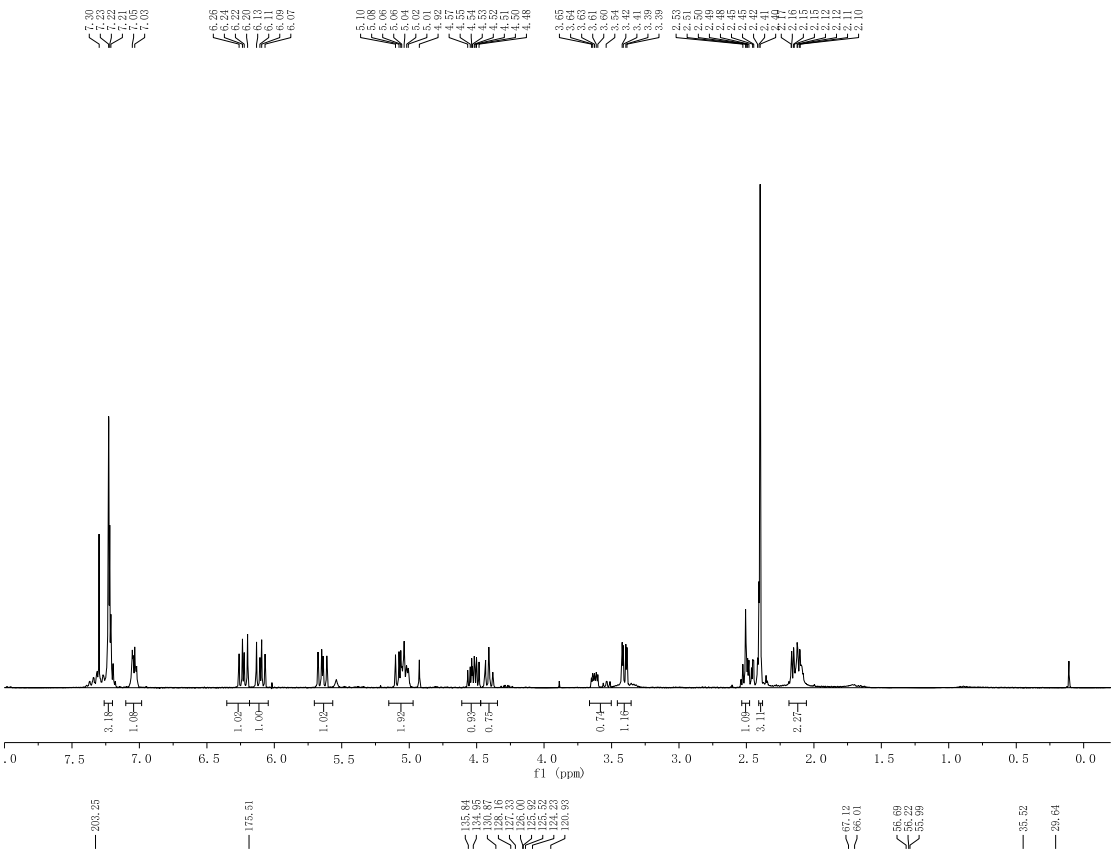


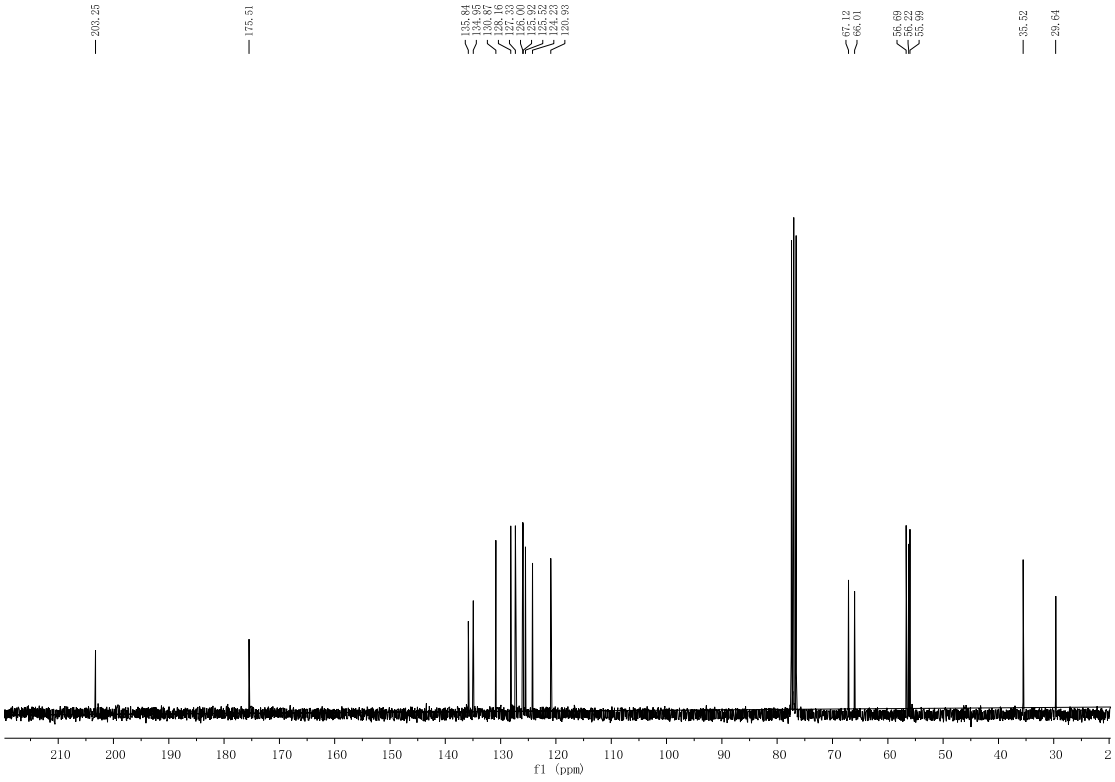


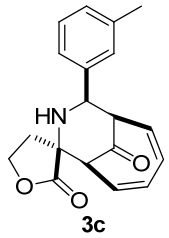




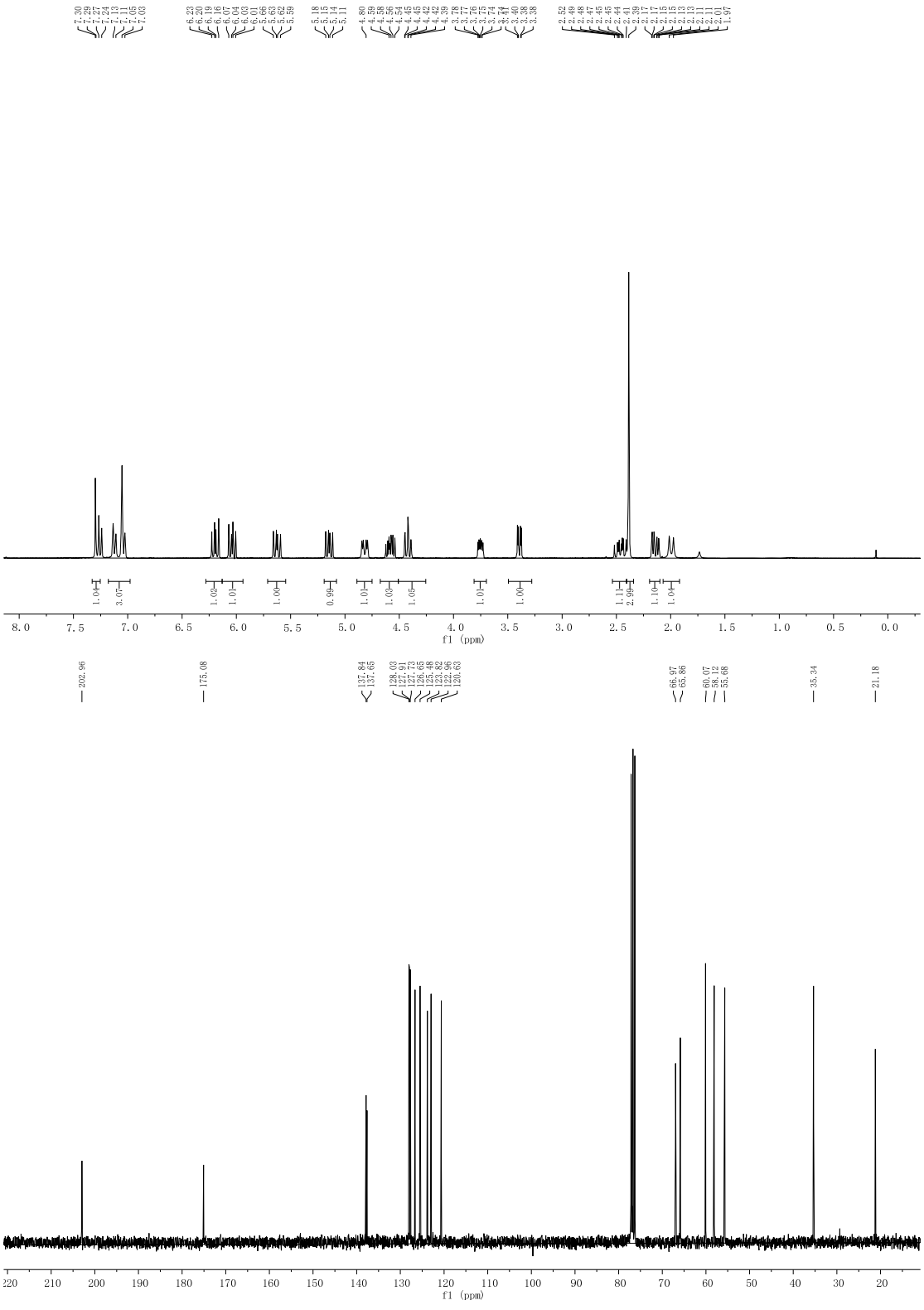
3b

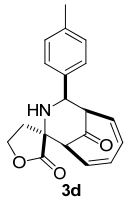




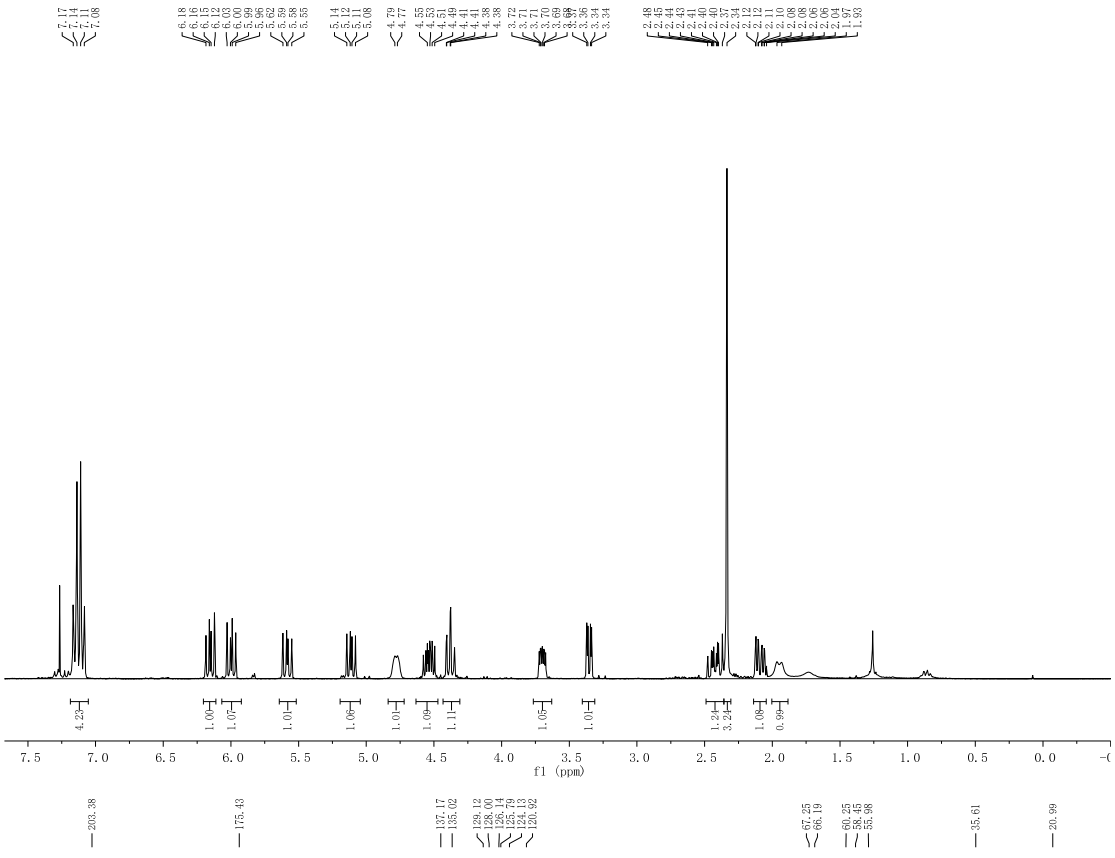


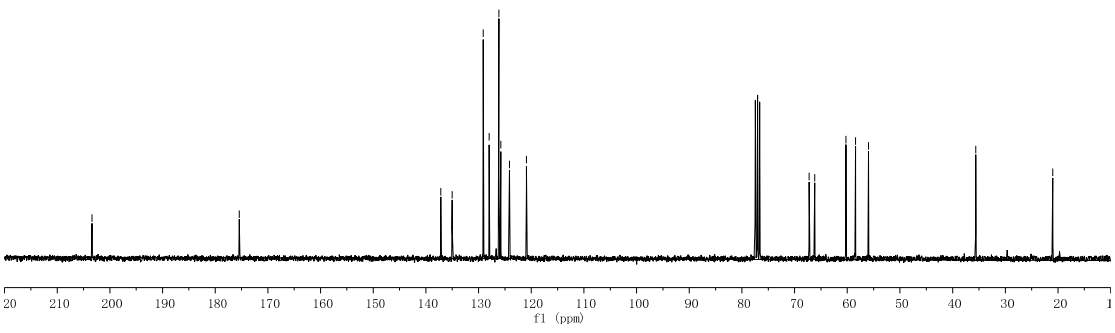
3c

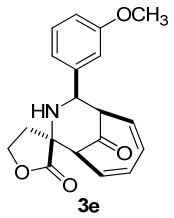




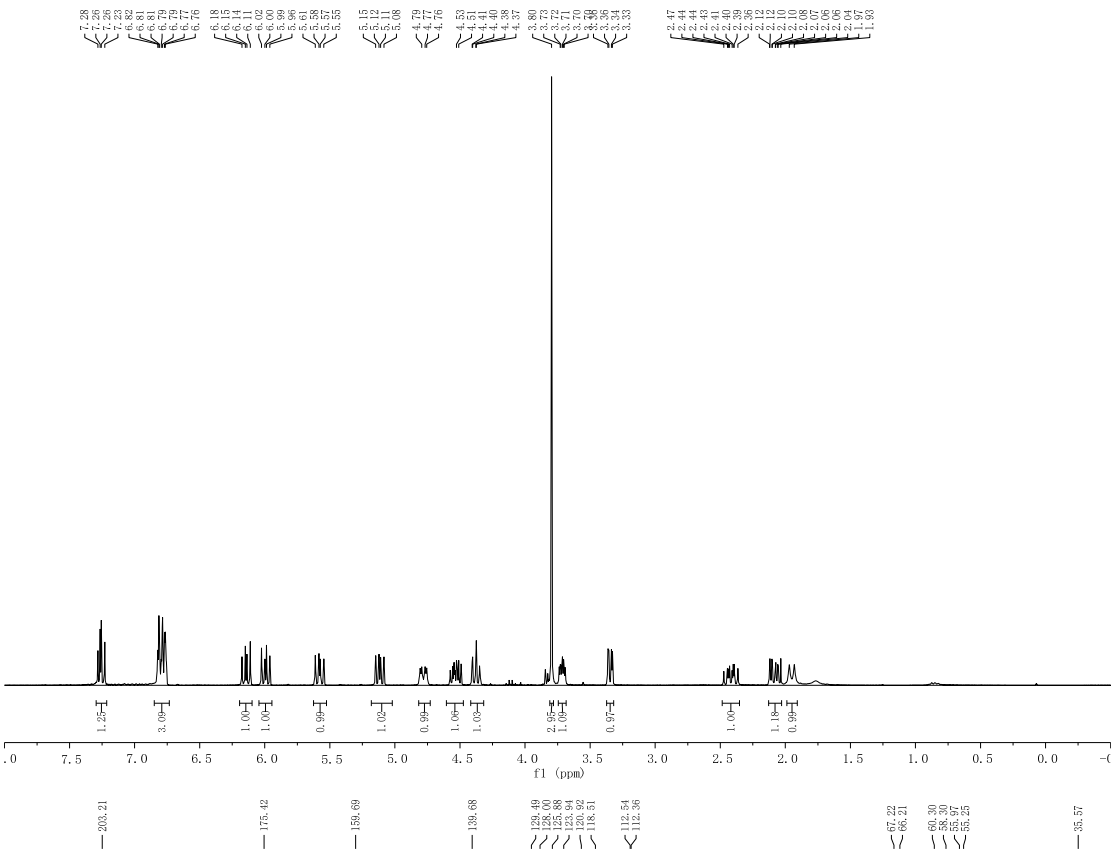
3d

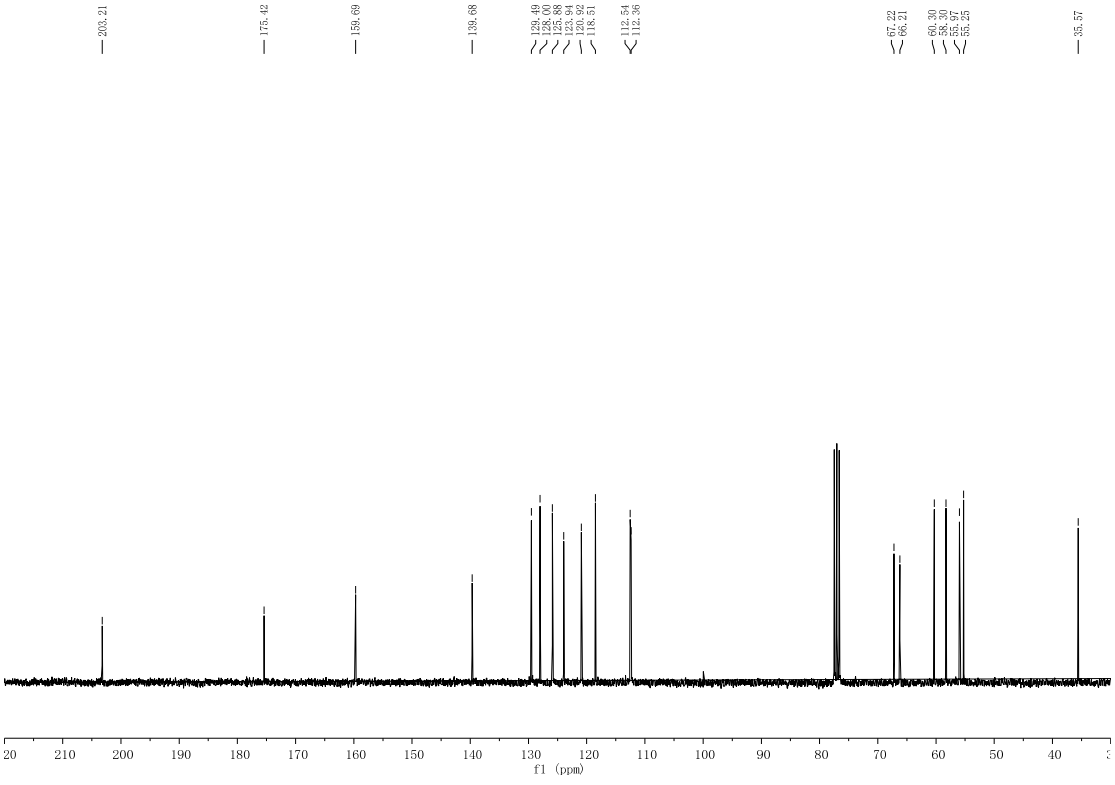


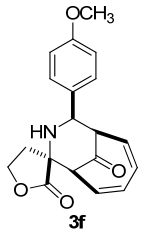




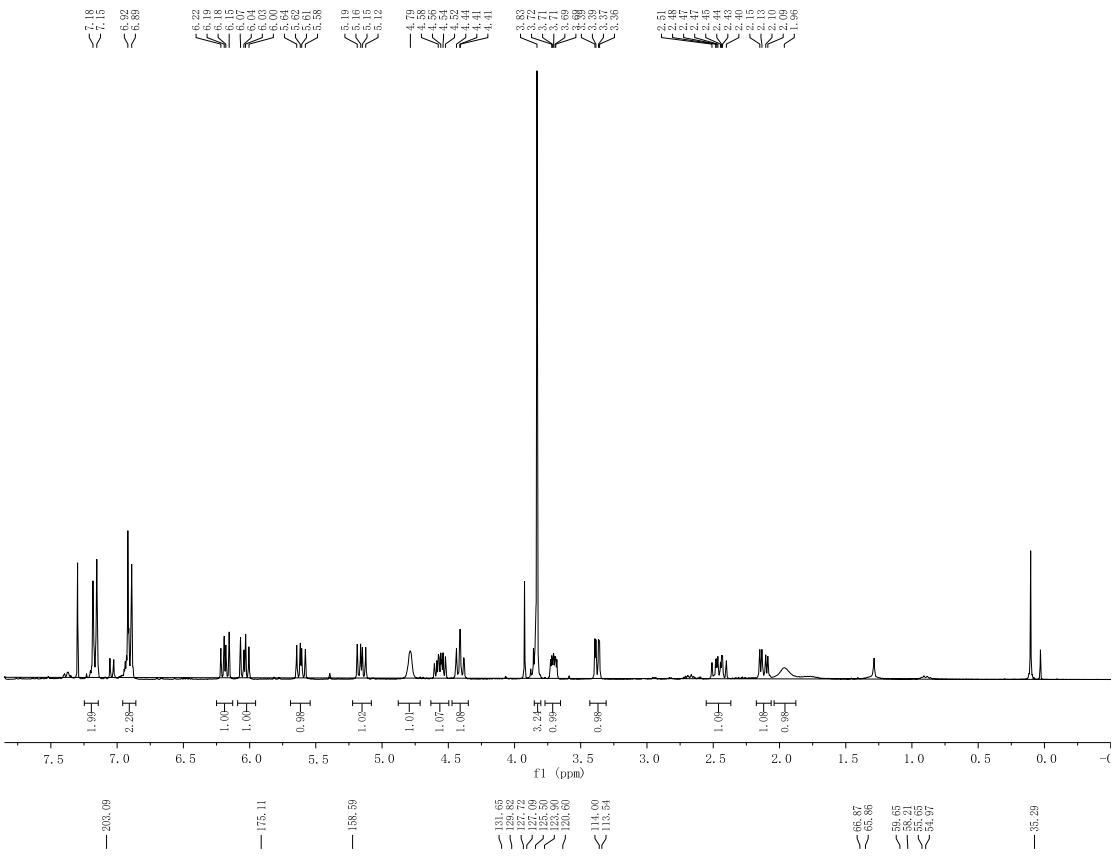
3e






OCH3
HN
O
O
O

3f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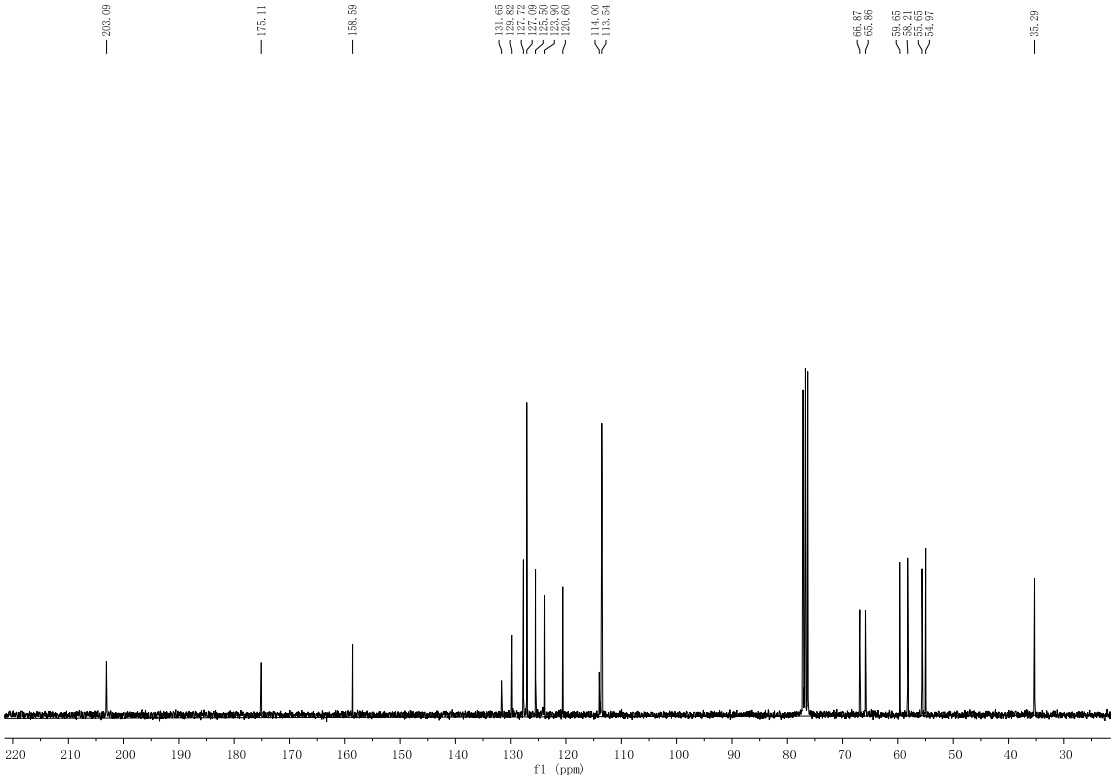
7.15
6.92
6.89
6.22
6.19
6.18
6.15
6.07
6.04
6.03
6.00
5.64
5.62
5.61
5.58
5.19
5.16
5.15
5.12
4.79
4.58
4.56
4.54
4.52
4.44
4.41
4.41
3.83
3.72
3.71
3.71
3.69
3.39
3.37
3.36
2.51
2.48
2.47
2.47
2.45
2.44
2.43
2.40
2.15
2.13
2.10
2.09
1.96
1.99
2.28
1.00
1.00
0.98
1.02
1.01
1.07
1.08
3.24
0.99
0.98
1.09
1.08
0.98
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
f1 (ppm)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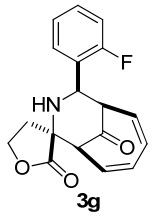
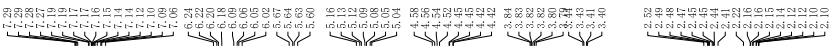
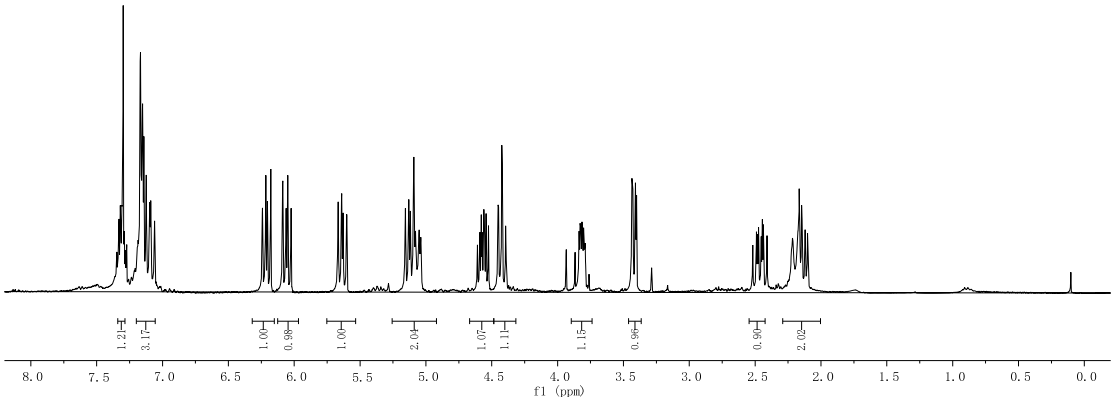
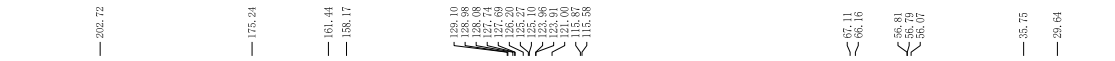
175.11
158.59
131.65
129.82
127.72
127.09
125.50
123.90
120.60
114.00
113.54
66.87
65.86
59.65
58.21
55.65
54.97
35.29
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
f1 (ppm)


F
HN
O
O
O

3g




1.21
3.17
1.00
0.98
1.00
2.04
1.07
1.11
1.18
0.98
0.90
2.02
f1 (ppm)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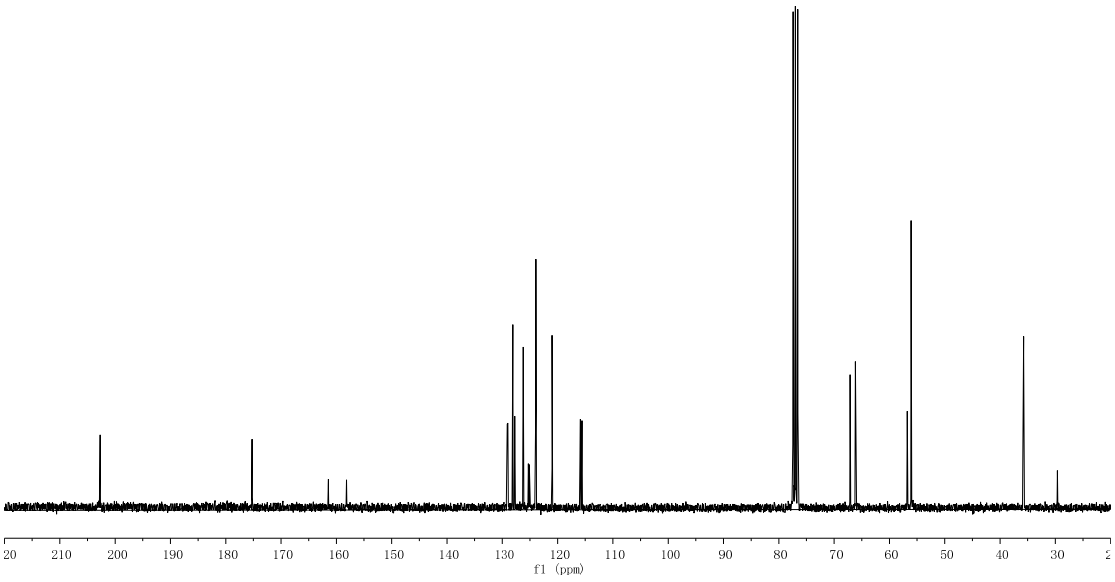
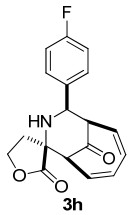
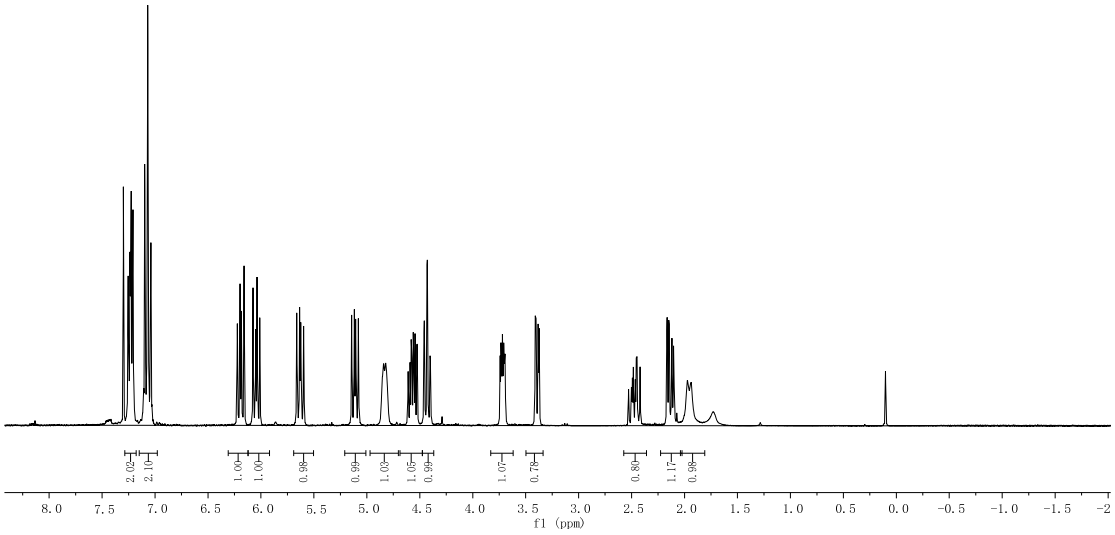
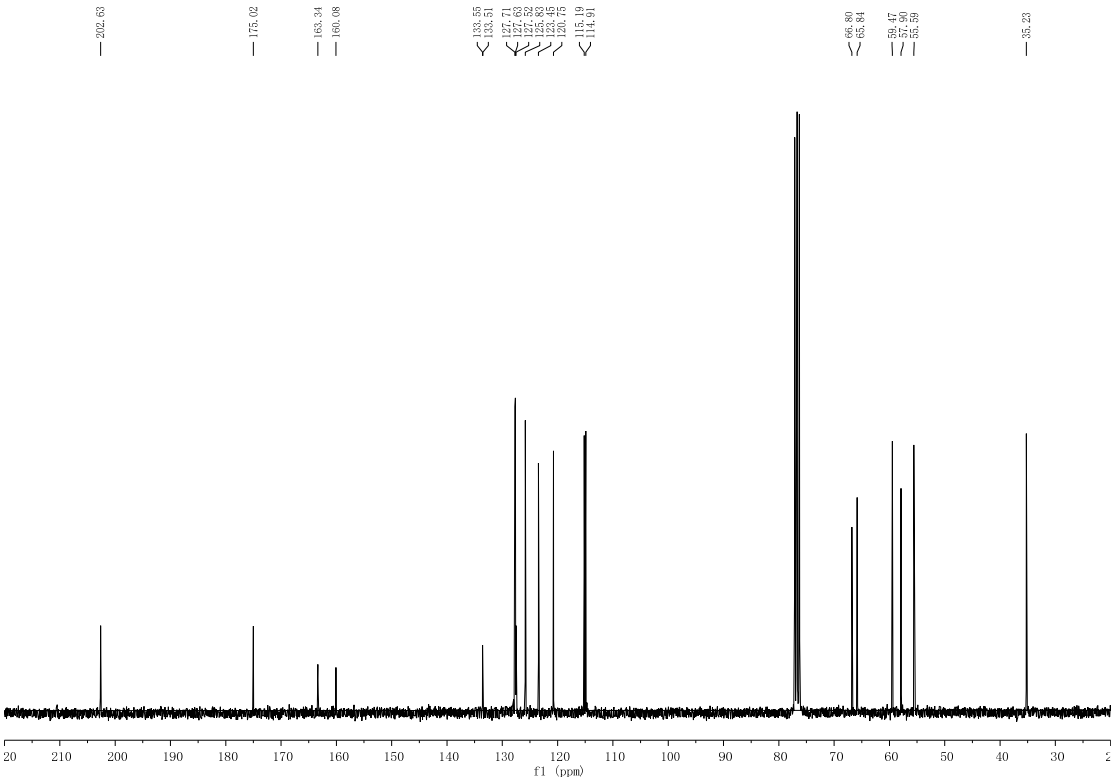
175.24
161.44
158.17
129.10
128.98
128.08
127.74
127.69
126.20
125.27
125.10
123.96
123.91
121.00
115.87
115.58
67.11
66.16
56.81
56.79
56.07
35.75
29.64


f1 (ppm)


F
HN
O
O
O

3h


2.02
2.10
1.00
1.00
0.98
0.99
1.03
1.05
0.99
1.07
0.78
0.80
1.17
0.98
f1 (ppm)


202.63
175.02
163.34
160.08
133.55
133.51
127.71
127.63
127.52
125.83
123.45
120.75
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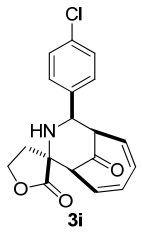
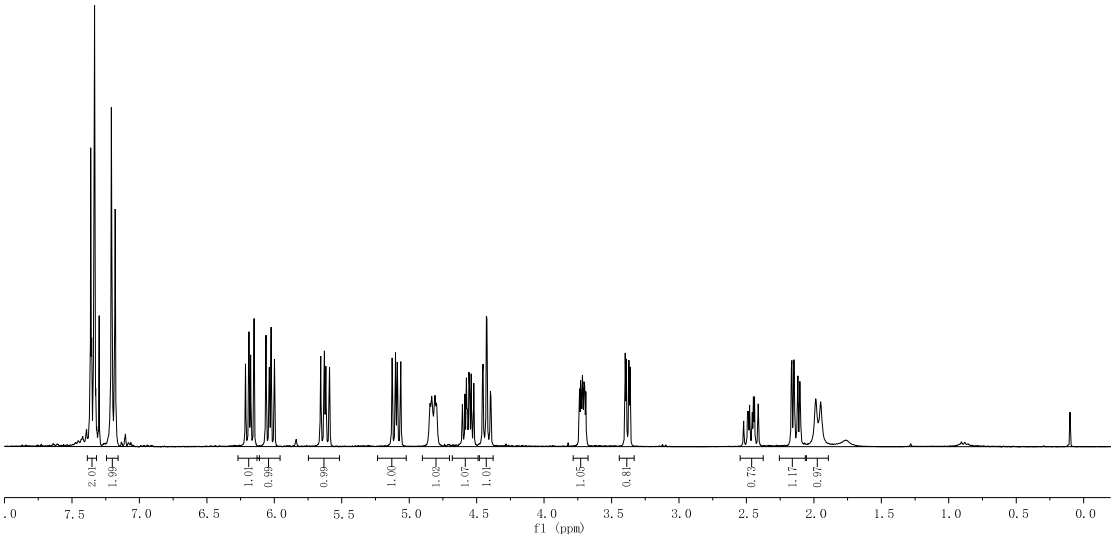
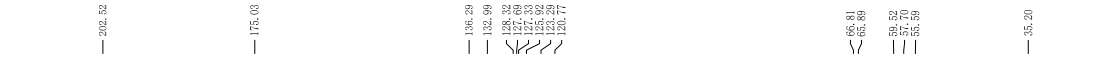
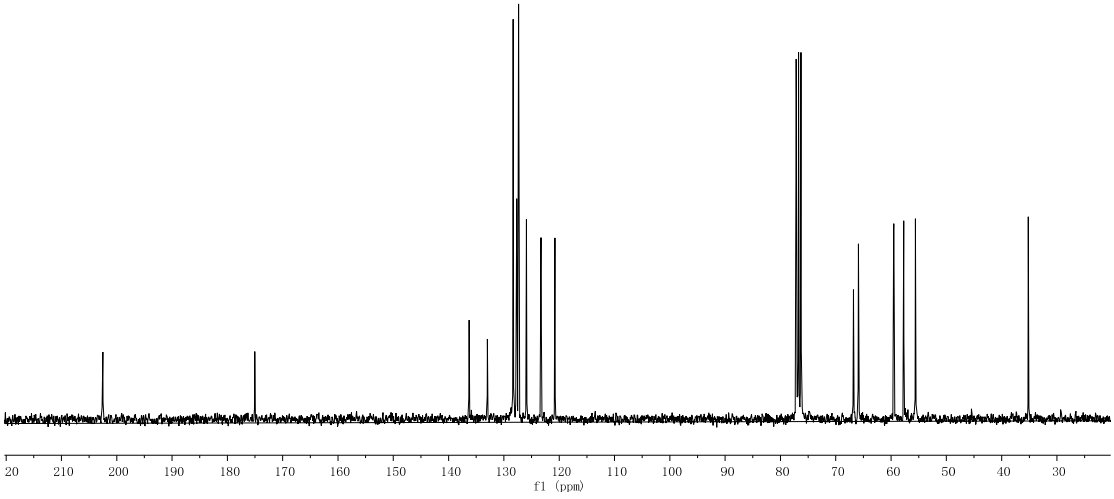
59.47
57.90
55.59
35.23
f1 (ppm)

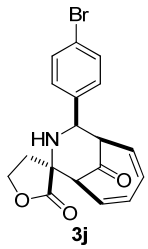

Cl
HN
O
O
O

3i

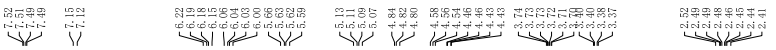

2.01
1.99
1.01
0.99
0.99
1.00
1.02
1.07
1.01
1.05
0.81
0.72
1.17
0.97
f1 (ppm)

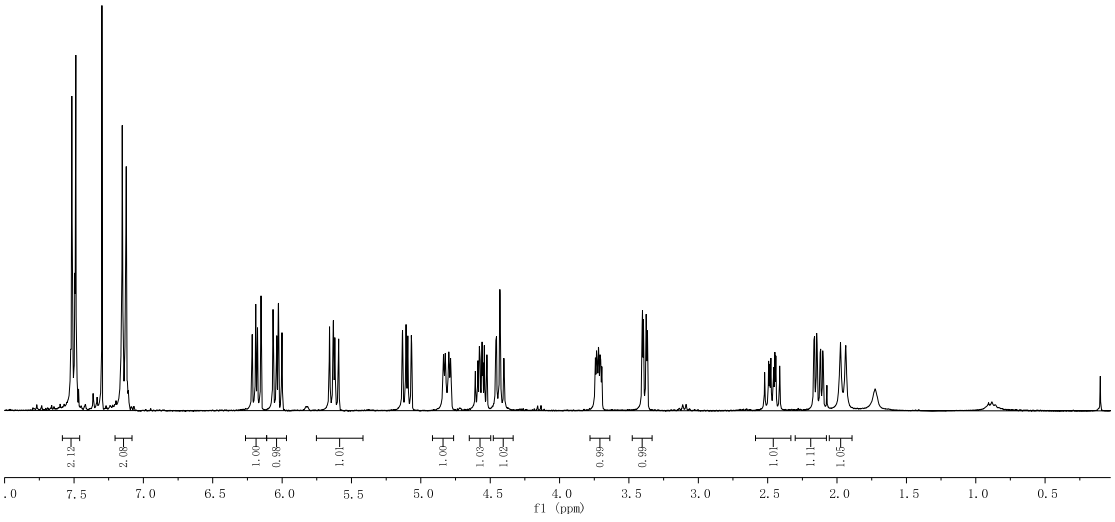


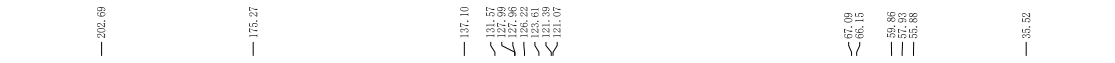

f1 (ppm)

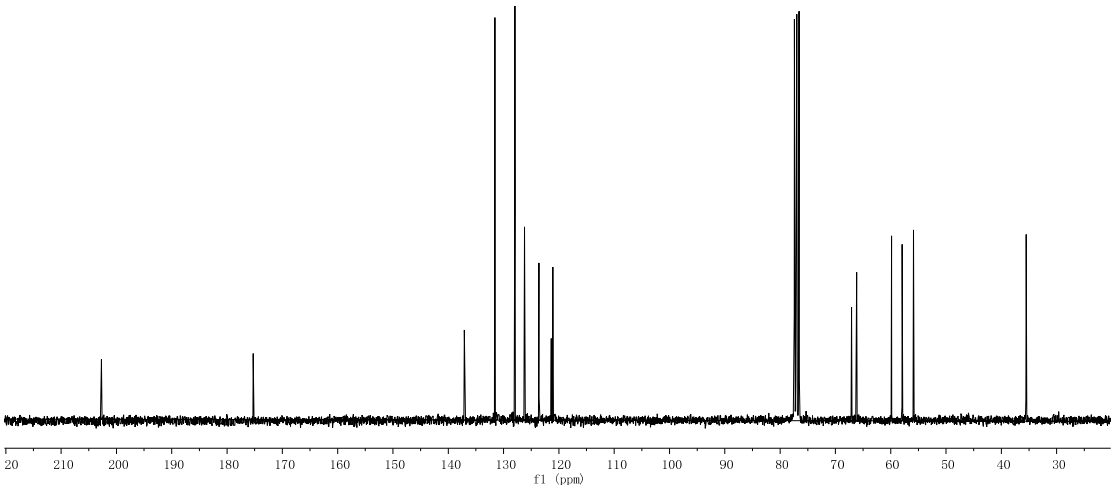


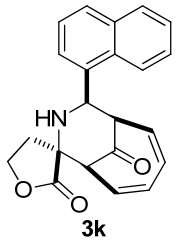
3j



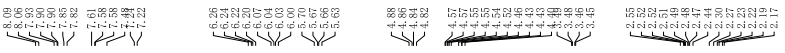


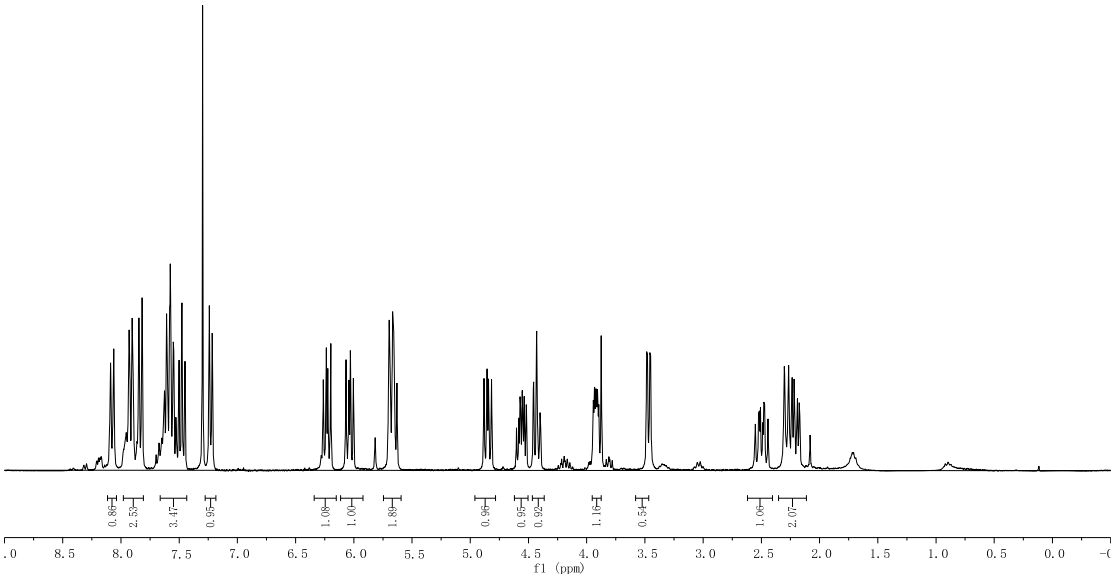





HN
O
O
O

3k

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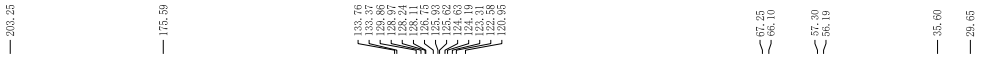
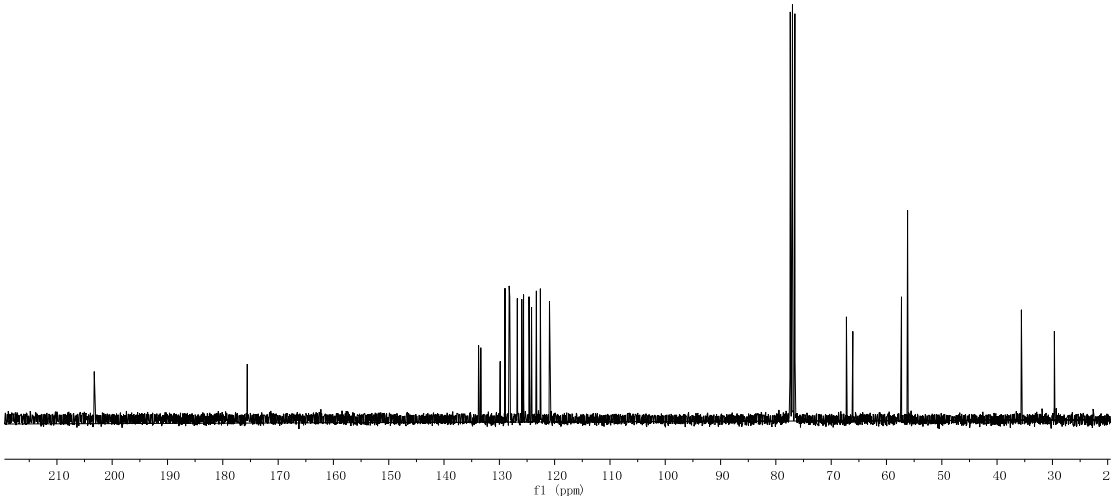
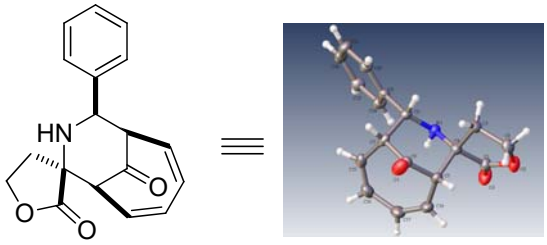
1.00
1.80
0.98
0.95
0.92
1.16
0.54
1.06
2.07
f1 (ppm)




f1 (ppm)

X-Ray Crystallographic Data of 3a

Crystallographic data for **3a** have been deposited with the Cambridge Crystallographic Data Centre as supplementary numbers CCDC 1473250. These data can be obtained free of charge via www.ccdc.cam.ac.uk/data_request/cif, or by emailing data_request@ccdc.cam.ac.uk, or by contacting The Cambridge Crystallographic Data Centre, 12, Union Road, Cambridge CB2 1EZ, UK; fax: +44 1223 336033.



3a

Table 1. Crystal data and structure refinement for **3a**.

Identification code	**3a**	
Empirical formula	C18 H17 N O3	
Formula weight	295.32	
Temperature	173.1500 K	
Wavelength	0.71073 Å	
Crystal system	Orthorhombic	
Space group	P b c a	
Unit cell dimensions	a = 11.483(2) Å	= 90°.
	b = 10.012(2) Å	= 90°.
	c = 25.315(5) Å	= 90°.
Volume	2910.5(10) $Å^3$	
Z	8	
Density (calculated)	1.348 Mg/m^3	
Absorption coefficient	0.092 mm^{-1}	
F(000)	1248	
Crystal size	0.38 x 0.24 x 0.07 mm^3	
Theta range for data collection	3.219 to 27.470°.	
Index ranges	-14<=h<=14, -12<=k<=4, -31<=l<=32	
Reflections collected	11086	
Independent reflections	3307 [R(int) = 0.0382]	
Completeness to theta = 26.000°	99.6 %	
Absorption correction	Semi-empirical from equivalents	
Max. and min. transmission	1.0000 and 0.8165	
Refinement method	Full-matrix least-squares on F^2	
Data / restraints / parameters	3307 / 0 / 203	
Goodness-of-fit on F^2	1.217	
Final R indices [I>2sigma(I)]	R1 = 0.0692, wR2 = 0.1149	
R indices (all data)	R1 = 0.0828, wR2 = 0.1199	
Extinction coefficient	n/a	
Largest diff. peak and hole	0.209 and -0.242 $e.Å^{-3}$	

Table 2. Atomic coordinates (x 10^4) and equivalent isotropic displacement parameters ($Å^2$ x 10^3) for **3a**. U(eq) is defined as one third of the trace of the orthogonalized U^{ij} te nsor.

	x	y	z	U(eq)
O1	4504(2)	-1248(2)	4395(1)	38(1)
O2	6147(1)	-980(2)	2480(1)	33(1)
O3	5063(2)	841(2)	2353(1)	40(1)
N1	5695(2)	1608(2)	3398(1)	23(1)
C1	5558(2)	102(2)	2651(1)	27(1)
C2	6738(2)	-1626(2)	2922(1)	32(1)
C3	6744(2)	-578(2)	3359(1)	29(1)
C4	5629(2)	208(2)	3250(1)	23(1)
C5	4551(2)	-529(2)	3501(1)	24(1)
C6	4596(2)	-313(2)	4092(1)	25(1)
C7	4763(2)	1100(2)	4281(1)	25(1)
C8	5785(2)	1786(2)	3970(1)	22(1)
C9	5888(2)	3238(2)	4126(1)	22(1)
C10	6480(2)	3566(2)	4590(1)	27(1)
C11	6566(2)	4881(2)	4756(1)	32(1)
C12	6043(2)	5892(2)	4467(1)	31(1)
C13	5446(2)	5573(2)	4011(1)	30(1)
C14	5367(2)	4262(2)	3841(1)	27(1)
C15	3652(2)	1882(2)	4243(1)	31(1)
C16	2793(2)	1755(2)	3893(1)	35(1)
C17	2689(2)	853(3)	3444(1)	38(1)
C18	3410(2)	-94(2)	3271(1)	33(1)

Table 3. Bond lengths [Å] and angles [°] for **3a**.

O1-C6	1.215(2)
O2-C1	1.348(2)
O2-C2	1.461(3)
O3-C1	1.200(2)
N1-C4	1.453(2)
N1-C8	1.462(2)
C1-C4	1.523(3)
C2-C3	1.524(3)
C3-C4	1.528(3)
C4-C5	1.574(3)
C5-C6	1.515(3)
C5-C18	1.498(3)
C6-C7	1.506(3)
C7-C8	1.571(3)
C7-C15	1.499(3)
C8-C9	1.511(3)
C9-C10	1.395(3)
C9-C14	1.390(3)
C10-C11	1.385(3)
C11-C12	1.386(3)
C12-C13	1.381(3)
C13-C14	1.384(3)
C15-C16	1.333(3)
C16-C17	1.456(3)
C17-C18	1.333(3)
C1-O2-C2	109.98(15)
C4-N1-C8	112.15(15)
O2-C1-C4	110.47(17)
O3-C1-O2	122.08(18)
O3-C1-C4	127.46(19)
O2-C2-C3	104.68(16)

C2-C3-C4	102.70(17)
N1-C4-C1	109.11(16)
N1-C4-C3	113.94(17)
N1-C4-C5	112.90(16)
C1-C4-C3	100.84(16)
C1-C4-C5	109.10(16)
C3-C4-C5	110.20(16)
C6-C5-C4	107.80(15)
C18-C5-C4	113.25(17)
C18-C5-C6	111.84(17)
O1-C6-C5	120.77(18)
O1-C6-C7	122.33(18)
C7-C6-C5	116.89(17)
C6-C7-C8	110.25(16)
C15-C7-C6	111.18(17)
C15-C7-C8	112.06(16)
N1-C8-C7	112.98(16)
N1-C8-C9	112.44(16)
C9-C8-C7	110.32(16)
C10-C9-C8	119.00(17)
C14-C9-C8	122.68(18)
C14-C9-C10	118.24(18)
C11-C10-C9	120.95(19)
C10-C11-C12	120.2(2)
C13-C12-C11	119.2(2)
C12-C13-C14	120.8(2)
C13-C14-C9	120.63(19)
C16-C15-C7	128.5(2)
C15-C16-C17	129.7(2)
C18-C17-C16	130.3(2)
C17-C18-C5	128.5(2)

Symmetry transformations used to generate equivalent atoms:

Table 4. Anisotropic displacement parameters ($Å^2$ x 10^3) for **3a**. The anisotropic displacement factor exponent takes the form: $-2\ ^2[\ h^2\ a^{*2}U^{11} + ...\ + 2\ h\ k\ a^*\ b^*\ U^{12}\ ]$

	U^{11}	U^{22}	U^{33}	U^{23}	U^{13}	U^{12}
O1	58(1)	28(1)	30(1)	6(1)	-3(1)	-9(1)
O2	41(1)	32(1)	26(1)	-2(1)	4(1)	9(1)
O3	53(1)	43(1)	24(1)	2(1)	-2(1)	17(1)
N1	26(1)	22(1)	22(1)	1(1)	-1(1)	0(1)
C1	29(1)	28(1)	25(1)	-2(1)	2(1)	3(1)
C2	33(1)	29(1)	36(1)	0(1)	2(1)	8(1)
C3	23(1)	29(1)	34(1)	0(1)	-2(1)	3(1)
C4	24(1)	23(1)	22(1)	0(1)	-1(1)	1(1)
C5	25(1)	23(1)	24(1)	-3(1)	-2(1)	-3(1)
C6	26(1)	25(1)	24(1)	2(1)	0(1)	-2(1)
C7	34(1)	24(1)	18(1)	0(1)	-1(1)	-5(1)
C8	24(1)	22(1)	22(1)	0(1)	-4(1)	1(1)
C9	19(1)	22(1)	24(1)	1(1)	1(1)	-3(1)
C10	28(1)	25(1)	27(1)	2(1)	-4(1)	1(1)
C11	34(1)	34(1)	29(1)	-6(1)	-6(1)	-3(1)
C12	34(1)	23(1)	36(1)	-6(1)	2(1)	-3(1)
C13	31(1)	24(1)	35(1)	4(1)	-3(1)	1(1)
C14	29(1)	24(1)	29(1)	2(1)	-5(1)	-2(1)
C15	34(1)	27(1)	31(1)	-5(1)	12(1)	-4(1)
C16	24(1)	34(1)	48(1)	-4(1)	7(1)	3(1)
C17	24(1)	52(2)	38(1)	-4(1)	-6(1)	2(1)
C18	26(1)	45(1)	29(1)	-7(1)	-5(1)	-3(1)

Table 5. Hydrogen coordinates (x 10^4) and isotropic displacement parameters ($Å^2$ x 10^3) for **3a**.

	x	y	z	U(eq)
H2A	7526	-1876	2826	39
H2B	6319	-2419	3034	39
H3A	7425	-8	3334	35
H3B	6724	-990	3705	35
H5	4640	-1487	3433	29

H7	4986	1064	4655	30
H8	6506	1346	4082	27
H10	6823	2893	4789	32
H11	6975	5085	5063	39
H12	6094	6775	4580	37
H13	5093	6247	3816	36
H14	4962	4065	3533	33
H15	3549	2542	4497	37
H16	2165	2328	3943	43
H17	2012	955	3247	46
H18	3174	-544	2968	40
H1	5070(20)	2030(20)	3263(9)	43(7)

Table 6. Torsion angles [°] for **3a**.

O1-C6-C7-C8	132.2(2)
O1-C6-C7-C15	-102.9(2)
O2-C1-C4-N1	144.11(17)
O2-C1-C4-C3	23.9(2)
O2-C1-C4-C5	-92.1(2)
O2-C2-C3-C4	30.8(2)
O3-C1-C4-N1	-36.0(3)
O3-C1-C4-C3	-156.2(2)
O3-C1-C4-C5	87.8(3)
N1-C4-C5-C6	-54.1(2)
N1-C4-C5-C18	70.1(2)
N1-C8-C9-C10	-151.47(18)
N1-C8-C9-C14	31.7(3)
C1-O2-C2-C3	-16.7(2)
C1-C4-C5-C6	-175.63(16)
C1-C4-C5-C18	-51.4(2)
C2-O2-C1-O3	175.3(2)
C2-O2-C1-C4	-4.8(2)
C2-C3-C4-N1	-148.81(17)
C2-C3-C4-C1	-32.1(2)
C2-C3-C4-C5	83.10(19)
C3-C4-C5-C6	74.5(2)
C3-C4-C5-C18	-161.20(17)
C4-N1-C8-C7	-55.9(2)

C4-N1-C8-C9	178.42(16)
C4-C5-C6-O1	-130.2(2)
C4-C5-C6-C7	49.6(2)
C4-C5-C18-C17	-93.3(3)
C5-C6-C7-C8	-47.5(2)
C5-C6-C7-C15	77.4(2)
C6-C5-C18-C17	28.7(3)
C6-C7-C8-N1	48.4(2)
C6-C7-C8-C9	175.25(16)
C6-C7-C15-C16	-31.7(3)
C7-C8-C9-C10	81.4(2)
C7-C8-C9-C14	-95.4(2)
C7-C15-C16-C17	-1.4(4)
C8-N1-C4-C1	-179.04(16)
C8-N1-C4-C3	-67.2(2)
C8-N1-C4-C5	59.5(2)
C8-C7-C15-C16	92.1(3)
C8-C9-C10-C11	-178.04(19)
C8-C9-C14-C13	177.37(19)
C9-C10-C11-C12	1.1(3)
C10-C9-C14-C13	0.6(3)
C10-C11-C12-C13	-0.5(3)
C11-C12-C13-C14	-0.1(3)
C12-C13-C14-C9	0.0(3)
C14-C9-C10-C11	-1.1(3)
C15-C7-C8-N1	-76.0(2)
C15-C7-C8-C9	50.9(2)
C15-C16-C17-C18	1.4(4)
C16-C17-C18-C5	1.3(4)
C18-C5-C6-O1	104.7(2)
C18-C5-C6-C7	-75.5(2)

Symmetry transformations used to generate equivalent atoms:

Table 7. Hydrogen bonds for **3a** [Å and °].

D-H..A	d(D-H)	d(H...A)	d(D...A)	<(DHA)