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Efficient Synthesis of 2-Substituted Azoles：Radical C–H Alkylation of Azoles with Dicumyl Peroxide, Methylarenes and Cyclohexane under Metal-free Condition

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1.General information

All compounds are characterized by ^{1}H NMR, ^{13}C NMR and MS.Analytical thin-layer chromatography is performed on glass plates precoated with silica gel impregnated with a fluorescent indicator (254 nm), and the plates are visualized by exposure to ultraviolet light. ^{1}H NMR and ^{13}C NMR spectra are recorded on an AVANCE 500 Bruker spectrometer operating at 500 MHz and 125 MHz in $CDCl_3$, respectively, and chemical shifts are reported in ppm.GC analyses are performed on an Agilent 7890A instrument (Column: Agilent 19091J-413:30 m × 320 μm × 0.25 μm, H, FID detection). GC-MS data was recorded on a 5975C Mass Selective Detector,coupled with a 7890A Gas Chromatograph (Agilent Technologies).

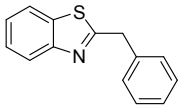
2.General procedure

General procedure for the preparation of substituted benzothiazole ： A 50 mL Schlenk tube was charged with 2-aminobenzothiazole derivative (6.5 mmol) and 10 mL of THF, and then isoamyl nitrite (14.3 mmol) was added slowly into the solution. The resultant mixture was refluxed for 30 minutes, and poured into ice-water, and the resultant aqueous mixture was extracted with ethyl acetate (3×30 mL). The organic extracts were combined and washed with brine, dried over $MgSO_4$, filtered, concentrated in vacuum and purified by column chromatography, giving the desired benzothiazoles in similar yields with the reported procedure.

General procedure for the synthesis of 2-benzylation azoles : To a mixture of benzothiazole (0.5 mmol) **1** and toluene derivative or cyclohexane **2** (2 mL) in a reaction tube was added DTBP (2.0 equiv). The reaction mixture was stirred for 24 h at 120 °C in air. The reaction mixture was extracted with ethyl acetate (15 mL × 3). The combined organic layers were washed with brine, dried over $MgSO_4$, and concentrated in vacuo. The residue was purified by column chromatography on silica gel to afford the desired products **3** or **4**.

General procedure for the synthesis of 2-methylation azoles : To a mixture of benzothiazole (0.5 mmol) **1** and HOAc (2 mL) in a reaction tube was added DCP (2.0 equiv). The reaction mixture was stirred for 12 h at 120 °C in air. The reaction mixture was extracted with ethyl acetate (15 mL × 3). The combined organic layers were washed with brine, dried over $MgSO_4$, and concentrated in vacuo. The residue was purified by column chromatography on silica gel to afford the desired products **5**.

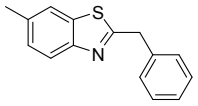
3.Characterization data



Formula: $C_{14}H_{11}NS$

Mass:225

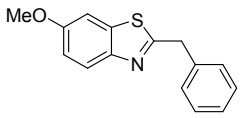
2-benzylbenzo[d]thiazole(3a): The crude product was purified by column chromatography on silica gel (petroleum ether/ethyl acetate = 4:1) to give **3a** as white solid (84.4mg, 75%). ^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.95 (d, *J* = 8.1 Hz, 1H), 7.73 (d, *J* = 7.9 Hz, 1H), 7.39 (t, *J* = 7.7 Hz, 1H), 7.34 – 7.23 (m, 6H), 4.39 (s, 2H). ^{13}C NMR (126 MHz, Chloroform-*d*) δ 170.2, 152.3, 136.2, 134.7, 128.2, 127.9, 126.4, 125.0, 123.9, 121.8, 120.6, 39.7. GC-MS (EI) *m/z*: 225.



Formula: $C_{15}H_{13}NS$

Mass: 239

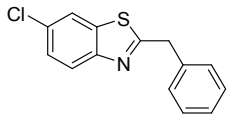
2-benzyl-6-methylbenzo[d]thiazole (**3b**): The crude product was purified by column chromatography on silica gel (petroleum ether/ethyl acetate = 9:1) to give **3b** as white solid (71.7 mg, 60%). ^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.79 (d, *J* = 8.3 Hz, 1H), 7.65 (d, *J* = 8.5 Hz, 1H), 7.49 (s, 1H), 7.29 – 7.27 (m, 3H), 7.19 – 7.17 (m, 1H), 7.11 – 7.09 (m, 1H), 4.34 (s, 2H), 2.38 (s, 3H). ^{13}C NMR (126 MHz, Chloroform-*d*) δ 169.0, 150.4, 134.9, 134.1, 129.9, 128.2, 127.9, 127.3, 126.5, 121.3, 120.3, 39.6, 20.5. GC-MS (EI) *m/z*: 239.



Formula: $C_{15}H_{13}NOS$

Mass: 255

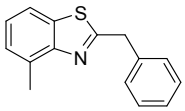
2-benzyl-6-methoxybenzo[d]thiazole (**3c**): The crude product was purified by column chromatography on silica gel (petroleum ether/ethyl acetate = 9:1) to give **3c** as white solid (88.0 mg, 69%).^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.78 (d, *J* = 8.9 Hz, 1H), 7.29 – 7.26 (m, 3H), 7.18 – 7.18 (m, 3H), 6.97 (d, *J* = 6.4 Hz, 1H), 4.31 (s, 2H), 3.77 (s, 3H). ^{13}C NMR (126 MHz, Chloroform-*d*) δ 167.5, 151.6, 136.0, 128.2, 127.9, 126.3, 124.6, 123.1, 122.3, 114.1, 103.3, 54.8, 39.6. GC-MS (EI) *m/z*: 255.



Fornula: $C_{14}H_{10}ClNO$

Mass:259

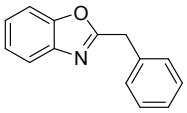
2-benzyl-6-chlorobenzo[d]thiazole (**3d**): The crude product was purified by column chromatography on silica gel (petroleum ether/ethyl acetate = 5:1) to give **3d** as white solid (97.1 mg, 75%).^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.81 (d, *J* = 8.7 Hz, 1H), 7.68 (d, *J* = 2.0 Hz, 1H), 7.34 – 7.22 (m, 6H), 4.34 (s, 2H). ^{13}C NMR (126 MHz, Chloroform-*d*) δ 170.8, 150.9, 135.9,129.7, 128.2, 128.0, 127.6, 126.5, 125.8, 122.6, 120.2, 39.6. GC-MS (EI) *m/z*: 259.



Formula: $C_{15}H_{13}NS$

Mass: 239

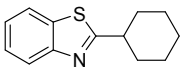
2-benzyl-4-methylbenzo[d]thiazole (**3e**): The crude product was purified by column chromatography on silica gel (petroleum ether/ethyl acetate = 9:1) to give **3e** as white solid (63.3mg, 53%). ^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.53 (d, *J* = 7.3 Hz, 1H), 7.32 – 7.24 (m, 4H), 7.18 – 7.16 (m, 3H), 4.38 (s, 2H), 2.68 (s, 3H). ^{13}C NMR (126 MHz, Chloroform-*d*) δ 168.5, 148.7, 128.2, 127.8, 127.3, 126.8, 126.3, 125.6,124.6, 123.7, 117.9, 39.8, 17.6. GC-MS (EI) *m/z*: 239.



Fornula: $C_{14}H_{11}NO$

Mass:209

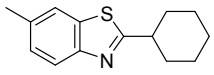
2-benzylbenzo[d]oxazole(**3f**): The crude product was purified by column chromatography on silica gel (petroleum ether/ethyl acetate =4:1) to give **3f** as yellow solid (71.1mg, 68%). ^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.63 – 7.58 (m, 1H), 7.40 – 7.17 (m, 8H), 4.20 (s, 2H). ^{13}C NMR (126 MHz, Chloroform-*d*) δ 164.2, 150.1, 140.4, 133.8, 128.0, 127.9, 126.4, 123.7, 123.2, 118.9, 109.5, 34.3. GC-MS (EI) *m/z*: 209.



Formula:$C_{13}H_{15}NS$

Mass:217

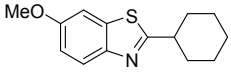
2-cyclohexylbenzo[d]thiazole (**3g**): The crude product was purified by column chromatography on silica gel (petroleum ether/ethyl acetate =4:1) to give **3g** as yellow solid (90.1mg, 83%). ^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.97 (d, *J* = 8.1 Hz, 1H), 7.84 (d, *J* = 8.0 Hz, 1H), 7.44 (t, *J* = 8.2 Hz, 1H), 7.33 (t, *J* = 7.6 Hz, 1H), 3.11 (tt, *J* = 11.7, 3.6 Hz, 1H), 2.21 (d, *J* = 15.5 Hz, 2H), 1.92 – 1.86 (m, 2H), 1.77 (d, *J* = 14.1 Hz, 1H), 1.69 – 1.60 (m, 2H), 1.50 – 1.40 (m, 2H), 1.37 – 1.28 (m, 1H). ^{13}C NMR (126 MHz, DMSO-d_6) δ 177.13, 153.24, 134.62, 126.50, 125.25, 122.80, 122.61, 42.83, 33.32, 25.94, 25.68. GC-MS (EI) *m/z*: 217.



Formula:$C_{14}H_{17}NS$

Mass:231

2-cyclohexyl-6-methylbenzo[d]thiazole(**3h**): The crude product was purified by column chromatography on silica gel (petroleum ether/ethyl acetate =4:1) to give **3h** as yellow solid (94.7mg, 82%). ^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.76 (d, *J* = 8.3 Hz, 1H), 7.54 (s, 1H), 7.16 (d, *J* = 7.4 Hz, 1H), 3.04 – 2.94 (m, 1H), 2.38 (s, 3H), 2.11 (d, *J* = 15.5 Hz, 2H), 1.80 (d, *J* = 13.3 Hz, 2H), 1.70 – 1.50 (m, 3H), 1.42 – 1.20 (m, 3H). ^{13}C NMR (126 MHz, Chloroform-*d*) δ 150.2, 133.7, 133.5, 126.3, 121.1, 120.4, 42.4, 32.5, 25.1, 24.9, 20.5. GC-MS (EI) *m/z*: 231.

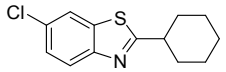


Formula: $C_{14}H_{17}NOS$

Mass: 247

2-cyclohexyl-6-methoxybenzo[d]thiazole(**3i**): The crude product was purified by

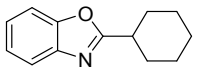
column chromatography on silica gel (petroleum ether/ethyl acetate =4:1) to give **3i** as yellow solid (106.2mg, 86%). ^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.76 (d, *J* = 8.9 Hz, 1H), 7.22 (d, *J* = 2.5 Hz, 1H), 6.95 (dd, *J* = 8.9, 2.5 Hz, 1H), 3.77 (s, 3H), 3.07 – 2.86 (m, 1H), 2.10 (d, *J* = 15.3 Hz, 2H), 1.79 (d, *J* = 13.3 Hz, 2H), 1.70 – 1.48 (m, 3H), 1.39 – 1.18 (m, 3H). ^{13}C NMR (126 MHz, Chloroform-*d*) δ 174.1, 156.3, 146.6, 134.8, 122.0, 113.9, 103.3, 54.8, 42.4, 32.5, 25.1, 24.9. GC-MS (EI) *m/z*: 247.



Fornula: $C_{13}H_{14}ClNS$

Mass:251

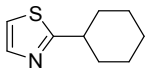
6-chloro-2-cyclohexylbenzo[d]thiazole (**3j**): The crude product was purified by column chromatography on silica gel (petroleum ether/ethyl acetate =5:1) to give **3j** as yellow solid (110.4mg, 88%).^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.77 (d, *J* = 8.7 Hz, 1H), 7.72 (d, *J* = 2.0 Hz, 1H), 7.31 (dd, *J* = 8.7, 2.1 Hz, 1H), 3.05 – 2.93 (m, 1H), 2.13 – 2.07 (d, *J* = 15.5 Hz, 2H), 1.80 (d, *J* = 13.3 Hz, 2H), 1.70 – 1.51 (m, 3H), 1.38 – 1.19 (m, 3H). ^{13}C NMR (126 MHz, Chloroform-*d*) δ 177.1, 150.7, 134.8, 129.4, 125.6, 122.3, 120.2, 42.4, 32.4, 25.1, 24.8. GC-MS (EI) *m/z*: 251.



Formula:$C_{13}H_{15}NO$

Mass:201

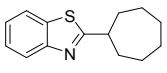
2-cyclohexylbenzo[d]oxazole(**3k**): The crude product was purified by column chromatography on silica gel (petroleum ether/ethyl acetate =5:1) to give **3k** as yellow solid (78.4mg, 78%). ^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.65 – 7.56 (m, 1H), 7.44 – 7.37 (m, 1H), 7.23 – 7.15 (m, 2H), 2.98 – 2.78 (m, 1H), 2.10 (d, *J* = 16.2 Hz, 2H), 1.80 (d, *J* = 13.3 Hz, 2H), 1.71 – 1.58 (m, 3H), 1.40 – 1.22 (m, 3H). ^{13}C NMR (126 MHz, Chloroform-*d*) δ 169.5, 149.6, 140.3, 123.4, 123.0, 118.6, 109.3, 37.0, 29.5, 24.8, 24.7. GC-MS (EI) *m/z*: 201.



Fornula: $C_9H_{13}NS$

Mass:167

2-cyclohexylthiazole(**3l**): The crude product was purified by column chromatography on silica gel (petroleum ether/ethyl acetate =5:1) to give **3l** as yellow solid (48.4mg, 58%).^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.60 (d, *J* = 3.3 Hz, 1H), 7.10 (d, *J* = 3.3 Hz, 1H), 2.97 – 2.90 (m, 1H), 2.07 (d, *J* = 12.9 Hz, 2H), 1.77 (d, *J* = 13.2 Hz, 2H), 1.68 – 1.64 (m, 1H), 1.50 – 1.41 (m, 2H), 1.38 – 1.31 (m, 3H), 1.24 – 1.20 (m, 2H). ^{13}C NMR (126 MHz, Chloroform-*d*) δ 176.2, 140.9, 116.6, 41.5, 32.8, 25.1, 24.9. GC-MS (EI) *m/z*: 167.

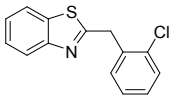


Formula: $C_{14}H_{17}NS$

Mass: 231

2-cycloheptylbenzo[d]thiazole (**3m**): The crude product was purified by column chromatography on silica gel (petroleum ether/ethyl acetate =5:1) to give **3m** as yellow solid (88.9mg, 77%). ^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.98 (d, *J* = 7.8 Hz, 1H), 7.85 (d, *J* = 7.6 Hz, 1H), 7.49 – 7.40 (m, 1H), 7.38 – 7.29 (m, 1H), 3.38 – 3.22 (m, 1H), 2.31 – 2.16 (m, 2H), 1.95 – 1.81 (m, 4H), 1.74 – 1.60 (m, 6H). ^{13}C NMR

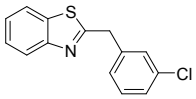
(126 MHz, Chloroform-*d*) δ 177.8, 152.0, 133.7, 124.8, 123.5, 121.6, 120.5, 44.6, 34.4, 27.1, 25.6. GC-MS (EI) *m/z*: 231.



Formula:$C_{14}H_{10}ClNS$

Mass:259

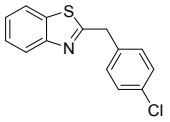
2-(2-chlorobenzyl)benzo[d]thiazole(**4a**): The crude product was purified by column chromatography on silica gel (petroleum ether/ethyl acetate =4:1) to give **4a** as white solid (84.2mg, 65%). ^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.93 (d, *J* = 8.2 Hz, 1H), 7.72 (d, *J* = 8.0 Hz, 1H), 7.41 – 7.32 (m, 3H), 7.27 (t, *J* = 7.6 Hz, 1H), 7.21 – 7.17 (m, 2H), 4.52 (s, 2H). ^{13}C NMR (126 MHz, Chloroform-*d*) δ 168.7, 152.3, 134.6, 134.1, 130.4, 128.9, 128.0, 127.1, 126.3, 125.0, 123.9, 121.8, 120.6, 37.2. GC-MS (EI) *m/z*: 259.



Formula:$C_{14}H_{10}ClNS$

Mass:259

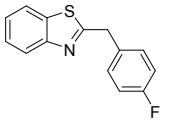
2-(3-chlorobenzyl)benzo[d]thiazole(**4b**): The crude product was purified by column chromatography on silica gel (petroleum ether/ethyl acetate =4:1) to give **4b** as white solid (88.1mg, 68%). ^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.94 (d, *J* = 8.2 Hz, 1H), 7.74 (d, *J* = 7.9 Hz, 1H), 7.40 (t, *J* = 8.2 Hz, 1H), 7.31 – 7.26 (m, 2H), 7.22 – 7.17 (m, 3H), 4.34 (s, 2H). ^{13}C NMR (126 MHz, Chloroform-*d*) δ 168.8, 152.3, 138.1, 134.7, 133.7, 129.1, 128.3, 126.6, 126.3, 125.2, 124.1, 121.9, 120.6, 39.2. GC-MS (EI) *m/z*: 259.



Formula:$C_{14}H_{10}ClNS$

Mass:259

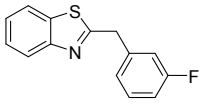
2-(4-chlorobenzyl)benzo[d]thiazole(**4c**): The crude product was purified by column chromatography on silica gel (petroleum ether/ethyl acetate =4:1) to give **4c** as white solid (98.4mg, 76%). ^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.92 (d, *J* = 8.2 Hz, 1H), 7.73 (d, *J* = 8.0 Hz, 1H), 7.39 (t, *J* = 7.7 Hz, 1H), 7.29 (t, *J* =4.0 Hz, 1H), 7.27 – 7.20 (m, 4H), 4.34 (s, 2H). ^{13}C NMR (126 MHz, Chloroform-*d*) δ 169.3, 152.3, 134.6, 132.3, 129.5, 128.1, 127.5, 125.1, 124.0, 121.9, 120.6, 38.9. GC-MS (EI) *m/z*: 259.



Formula: $C_{14}H_{10}FNS$

Mass:243

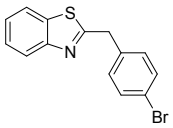
2-(4-fluorobenzyl)benzo[d]thiazole(**4d**): The crude product was purified by column chromatography on silica gel (petroleum ether/ethyl acetate =4:1) to give **4d** as white solid(87.5mg, 72%). ^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.93 (d, *J* = 8.2 Hz, 1H), 7.73 (d, *J* = 8.0 Hz, 1H), 7.39 (t, *J* = 8.1 Hz, 1H), 7.30 – 7.24 (m, 3H), 6.99 – 6.94 (m, 2H), 4.34 (s, 2H). ^{13}C NMR (126 MHz, Chloroform-*d*) δ 189.2, 169.8, 160.2, 134.6, 131.9, 129.7, 125.1, 124.0, 121.9, 120.6, 114.7, 38.8. GC-MS (EI) *m/z*: 243.



Formula: $C_{14}H_{10}FNS$

Mass: 243

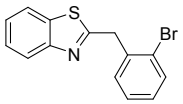
2-(3-fluorobenzyl)benzo[d]thiazole(**4e**): The crude product was purified by column chromatography on silica gel (petroleum ether/ethyl acetate =4:1) to give **4e** as white solid (82.6mg, 68%). ^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.94 (d, *J* = 8.2 Hz, 1H), 7.74 (d, *J* = 8.0 Hz, 1H), 7.38 (t, *J* = 7.5 Hz, 1H), 7.32 – 7.22 (m, 2H), 7.08 (d, *J* = 7.6 Hz, 1H), 7.01 (d, *J* = 9.5 Hz, 1H), 6.92 (t, *J* = 9.6 Hz, 1H), 4.36 (s, 2H). ^{13}C NMR (126 MHz, Chloroform-*d*) δ 169.0, 161.0, 152.2, 138.5, 135.0, 129.4, 128.4, 125.1, 123.8, 121.9, 120.6, 115.3, 113.3, 39.2. GC-MS (EI) *m/z*: 243.



Formula: $C_{14}H_{10}BrNS$

Mass:303

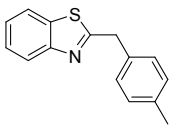
2-(4-bromobenzyl)benzo[d]thiazole(**4f**): The crude product was purified by column chromatography on silica gel (petroleum ether/ethyl acetate =4:1) to give **4f** as white solid (106.1mg, 70%). ^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.92 (d, *J* = 8.2 Hz, 1H), 7.74 (d, *J* = 8.0 Hz, 1H), 7.42 – 7.37 (m, 3H), 7.28 (t, *J* = 7.3 Hz, 1H), 7.19 – 7.17 (m, 2H), 4.32 (s, 2H). ^{13}C NMR (126 MHz, Chloroform-*d*) δ 169.1, 152.3, 135.2, 134.6, 131.0, 129.9, 125.1, 124.0, 121.9, 120.4, 39.0. GC-MS (EI) *m/z*: 303.



Formula: $C_{14}H_{10}BrNS$

Mass: 303

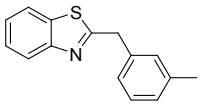
2-(2-bromobenzyl)benzo[d]thiazole (**4g**): The crude product was purified by column chromatography on silica gel (petroleum ether/ethyl acetate =4:1) to give **4g** as white solid (93.9mg, 62%). ^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.94 (d, *J* = 8.1 Hz, 1H), 7.73 (d, *J* = 8.0 Hz, 1H), 7.55 (d, *J* = 8.0 Hz, 1H), 7.41 – 7.33 (m, 2H), 7.30 – 7.22 (m, 2H), 7.11 (t, *J* = 7.7 Hz, 1H), 4.53 (s, 2H). ^{13}C NMR (126 MHz, Chloroform-*d*) δ 168.8, 152.3, 135.9, 134.6, 132.2, 130.5, 128.2, 126.9, 125.0, 123.9, 122.1, 121.9, 120.6, 39.8. GC-MS (EI) *m/z*: 303.



Formula: $C_{15}H_1NS$

Mass:239

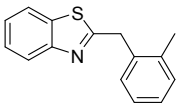
2-(4-methylbenzyl)benzo[d]thiazole (**4h**): The crude product was purified by column chromatography on silica gel (petroleum ether/ethyl acetate =4:1) to give **4h** as white solid (86.0mg, 72%). ^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.93 (d, *J* = 8.2 Hz, 1H), 7.71 (d, *J* = 8.0 Hz, 1H), 7.38 (t, *J* = 7.7 Hz, 1H), 7.26 (t, *J* = 7.6 Hz, 1H), 7.20 (d, *J* = 7.6 Hz, 2H), 7.10 (d, *J* = 7.8 Hz, 2H), 4.34 (s, 2H), 2.28 (s, 3H). ^{13}C NMR (126 MHz, Chloroform-*d*) δ 170.8, 152.3, 136.1, 134.7, 133.2, 128.6, 128.1, 125.0, 123.8, 121.8, 120.6, 39.3, 20.2. GC-MS (EI) *m/z*: 239.



Formula: $C_{15}H_{13}NS$

Mass:239

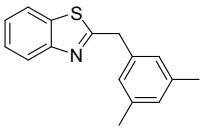
2-(3-methylbenzyl)benzo[d]thiazole (**4i**): The crude product was purified by column chromatography on silica gel (petroleum ether/ethyl acetate =4:1) to give **4i** as white solid (84.8mg, 71%). ^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.93 (d, *J* = 8.2 Hz, 1H), 7.70 (d, *J* = 8.0 Hz, 1H), 7.39 (t, *J* = 7.7 Hz, 1H), 7.29 – 7.24 (m, 2H), 7.19 – 7.13 (m, 3H), 4.38 (s, 2H), 2.28 (s, 3H). ^{13}C NMR (126 MHz, Chloroform-*d*) δ 137.6, 136.1, 134.8, 128.9, 127.8, 127.1, 125.2, 125.0, 123.8, 121.8, 120.6. GC-MS (EI) *m/z*: 239.



Formula: $C_{15}H_{13}NS$

Mass: 239

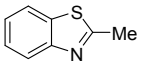
2-(2-methylbenzyl)benzo[d]thiazole (**4j**): The crude product was purified by column chromatography on silica gel (petroleum ether/ethyl acetate =4:1) to give **4j** as white solid (89.6mg, 75%). ^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.92 (d, *J* = 8.2 Hz, 1H), 7.70 (d, *J* = 8.0 Hz, 1H), 7.38 (t, *J* = 7.6 Hz, 1H), 7.25 (d, *J* = 8.1 Hz, 2H), 7.17 (dd, *J* = 8.9, 6.4 Hz, 3H), 4.38 (s, 2H), 2.27 (s, 3H). ^{13}C NMR (126 MHz, Chloroform-*d*) δ 170.5, 152.5, 135.9, 134.6, 129.7, 129.2, 126.9, 125.5, 125.0, 123.8, 121.7, 120.5, 37.6, 18.7. GC-MS (EI) *m/z*: 239.



Formula: $C_{16}H_{15}NS$

Mass: 253

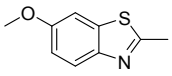
2-(3,5-dimethylbenzyl)benzo[d]thiazole(**4k**): The crude product was purified by column chromatography on silica gel (petroleum ether/ethyl acetate =4:1) to give **4k** as white solid (97.4mg, 77%). ^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.92 (d, *J* = 8.2 Hz, 1H), 7.71 (d, *J* = 8.0 Hz, 1H), 7.37 (t, *J* = 7.7 Hz, 1H), 7.25 (t, *J* = 7.6 Hz, 1H), 6.87 (d, *J* = 28.8 Hz, 3H), 4.28 (s, 2H), 2.22 (s, 6H). ^{13}C NMR (126 MHz, Chloroform-*d*) δ 152.3, 137.5, 136.1, 128.0, 126.0, 124.9, 123.8, 121.8, 120.5, 39.6, 20.3. GC-MS (EI) *m/z*: 253.



Formula: C_8H_7NS

Mass: 149

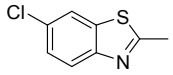
2-(3,5-dimethylbenzyl)benzo[d]thiazole(**5a**): The crude product was purified by column chromatography on silica gel (petroleum ether/ethyl acetate =4:1) to give **5a** as white solid (55.9mg, 75%). ^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.95 (d, *J* = 8.2 Hz, 1H), 7.79 (d, *J* = 8.0 Hz, 1H), 7.42 (t, *J* = 7.7 Hz, 1H), 7.31 (t, *J* = 7.6 Hz, 1H), 2.81 (s, 3H). ^{13}C NMR (126 MHz, Chloroform-*d*) δ 165.9, 152.4, 134.7, 124.9, 123.7, 121.4, 120.4, 19.1. GC-MS (EI) *m/z*: 149.



Formula: C_9H_9NOS

Mass: 179

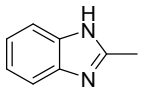
6-methoxy-2-methylbenzo[d]thiazole(**5b**): The crude product was purified by column chromatography on silica gel (petroleum ether/ethyl acetate =4:1) to give **5b** as white solid (56.4mg, 63%). ^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.82 (d, *J* = 8.9 Hz, 1H), 7.28 (d, *J* = 2.5 Hz, 1H), 7.03 (dd, *J* = 8.9, 2.5 Hz, 1H), 3.86 (s, 3H), 2.78 (s, 3H). ^{13}C NMR (126 MHz, Chloroform-*d*) δ 163.4, 156.4, 146.9, 135.9, 121.8, 114.0, 103.2, 54.8, 19.0. GC-MS (EI) *m/z*: 179.



Formula: C_8H_6ClNS

Mass: 183

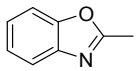
6-chloro-2-methylbenzo[d]thiazole (**5c**): The crude product was purified by column chromatography on silica gel (petroleum ether/ethyl acetate =4:1) to give **5c** as white solid (64.1mg, 70%). ^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.84 (d, *J* = 8.7 Hz, 1H), 7.79 (d, *J* = 2.0 Hz, 1H), 7.40 (dd, *J* = 8.7, 2.1 Hz, 1H), 2.82 (s, 3H). ^{13}C NMR (126 MHz, Chloroform-*d*) δ 166.5, 151.0, 135.9, 129.6, 125.7, 122.1, 120.1, 19.2. GC-MS (EI) *m/z*: 183.



Formula: $C_8H_8N_2$

Mass: 132

2-methyl-1H-benzo[d]imidazole (**5d**): The crude product was purified by column chromatography on silica gel (petroleum ether/ethyl acetate =4:1) to give **5d** as white solid (43.6mg, 66%). ^{1}H NMR (500 MHz, DMSO-d_6) δ 12.11 (s, 1H), 7.39 (dd, *J* = 6.0, 3.4 Hz, 2H), 7.04 (dd, *J* = 5.9, 3.2 Hz, 2H), 2.43 (s, 3H). ^{13}C NMR (126 MHz, DMSO-d_6) δ 155.7, 150.7, 120.5, 114.3, 14.1. GC-MS (EI) *m/z*: 132.

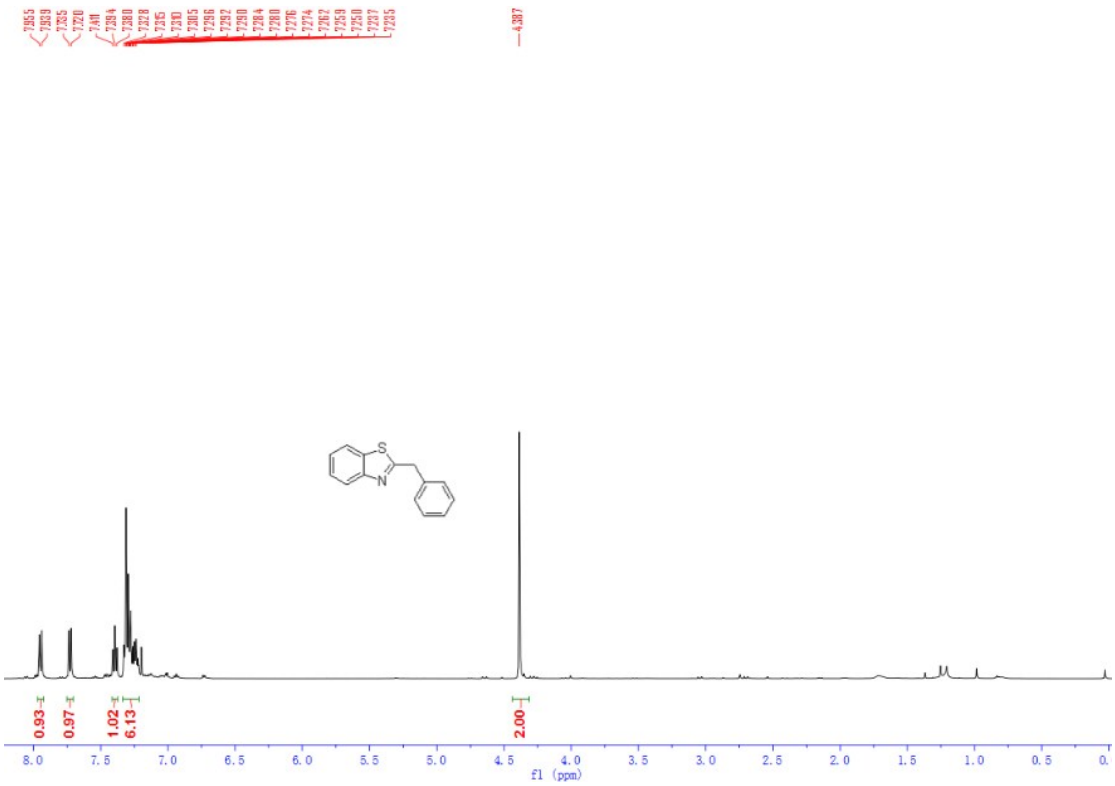


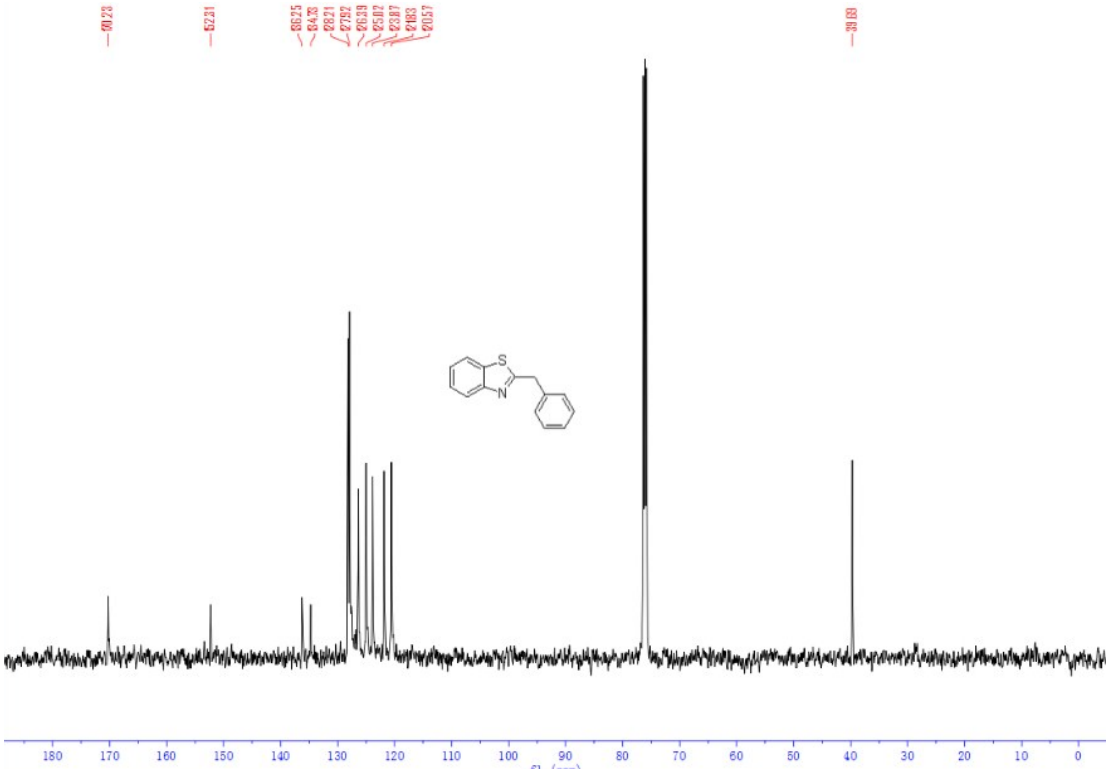
Formula: C_8H_7NO

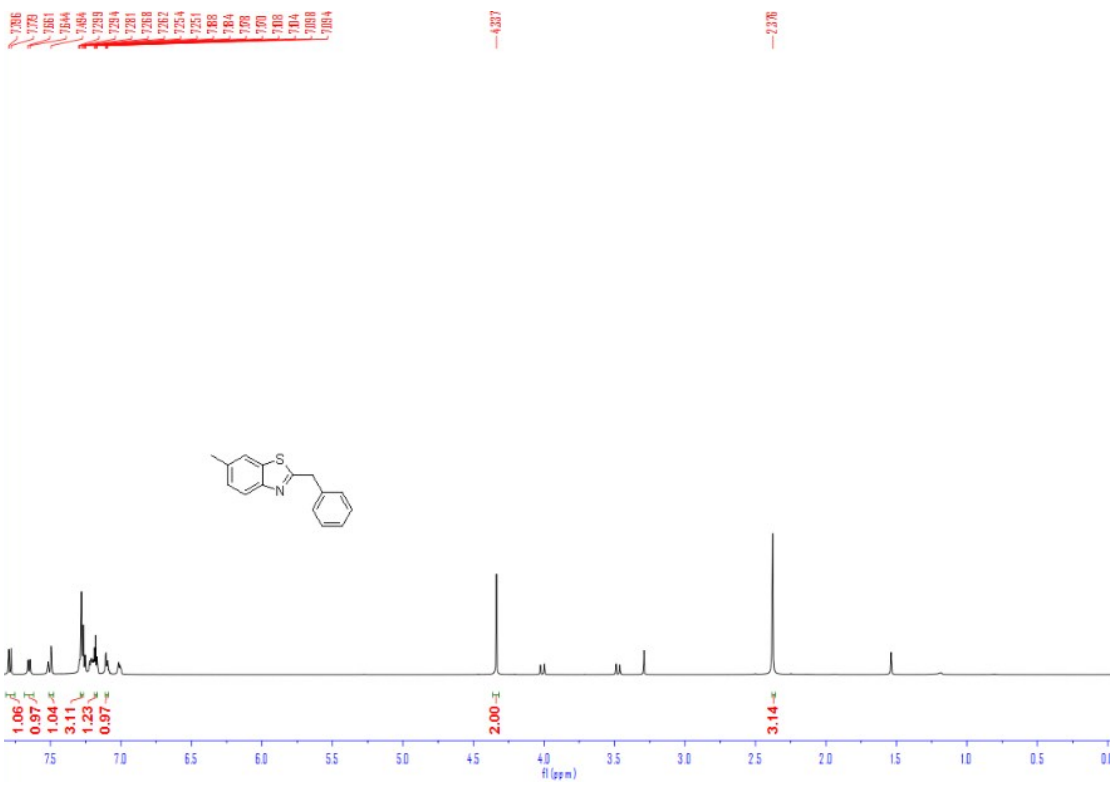
Mass: 133

2-methylbenzo[d]oxazole(**5e**): The crude product was purified by column chromatography on silica gel (petroleum ether/ethyl acetate =4:1) to give **5e** as white solid (45.2mg, 68%). ^{1}H NMR (500 MHz, Chloroform-*d*) δ 7.7 – 7.6 (m, 1H), 7.5 – 7.4 (m, 1H), 7.3 – 7.2 (m, 2H), 2.6 (s, 3H). ^{13}C NMR (126 MHz, Chloroform-*d*) δ 162.8, 150.0, 140.6, 123.4, 123.1, 118.4, 109.2, 13.5. GC-MS (EI) *m/z*: 133.

4. NMR spectra



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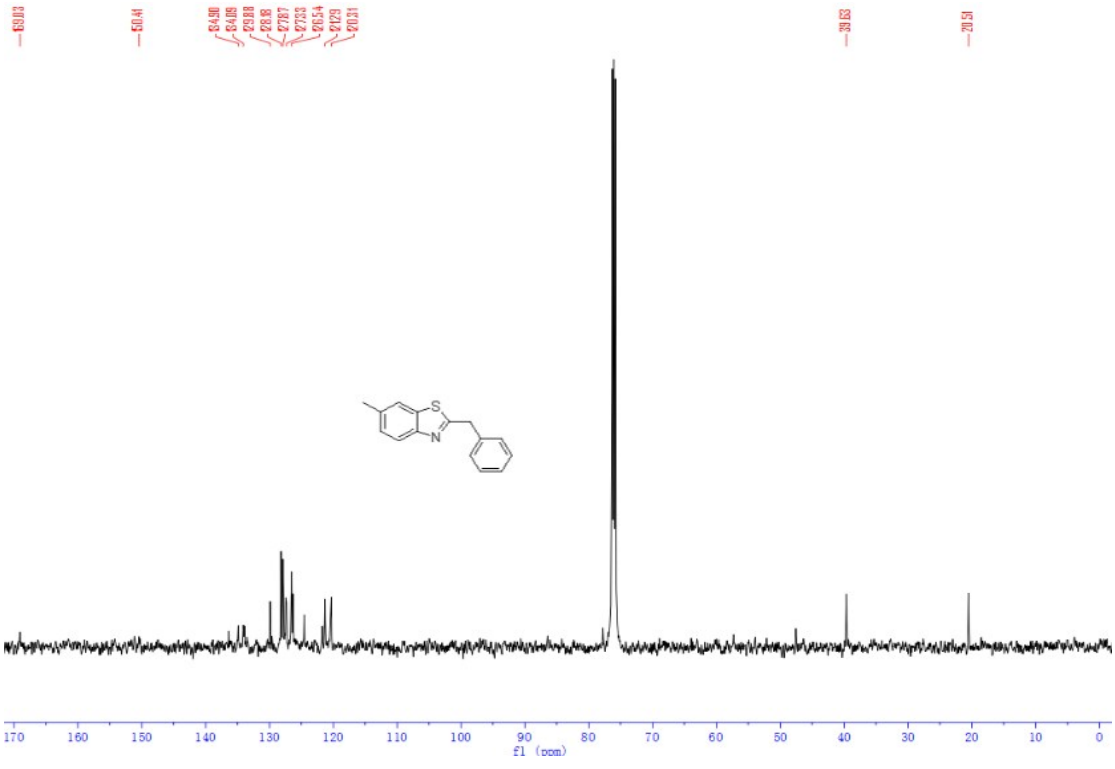
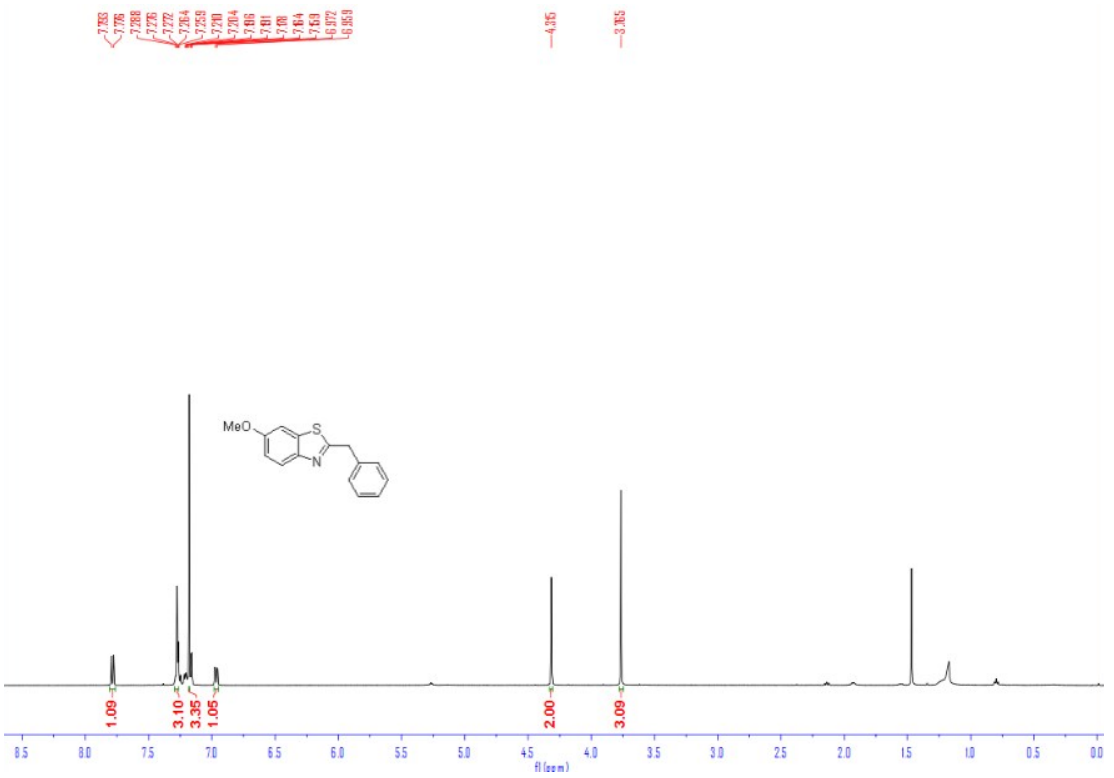
1.23
0.97
2.00
3.14
f1(ppm)


f1 (ppm)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N
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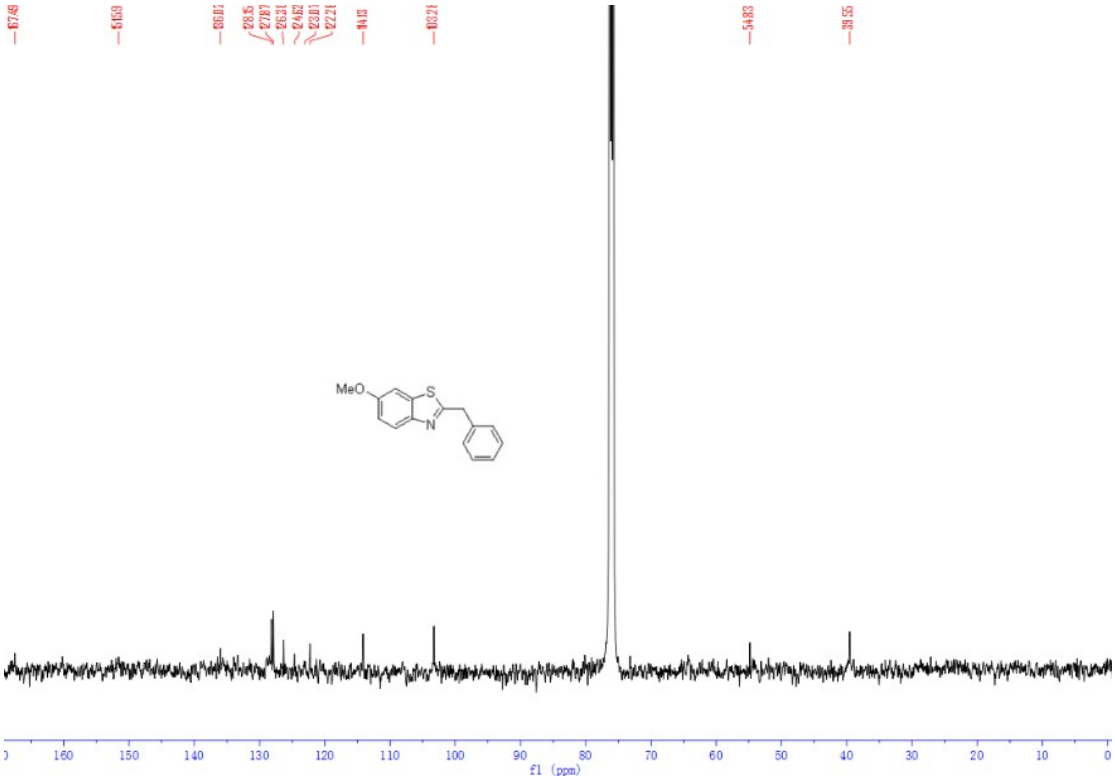
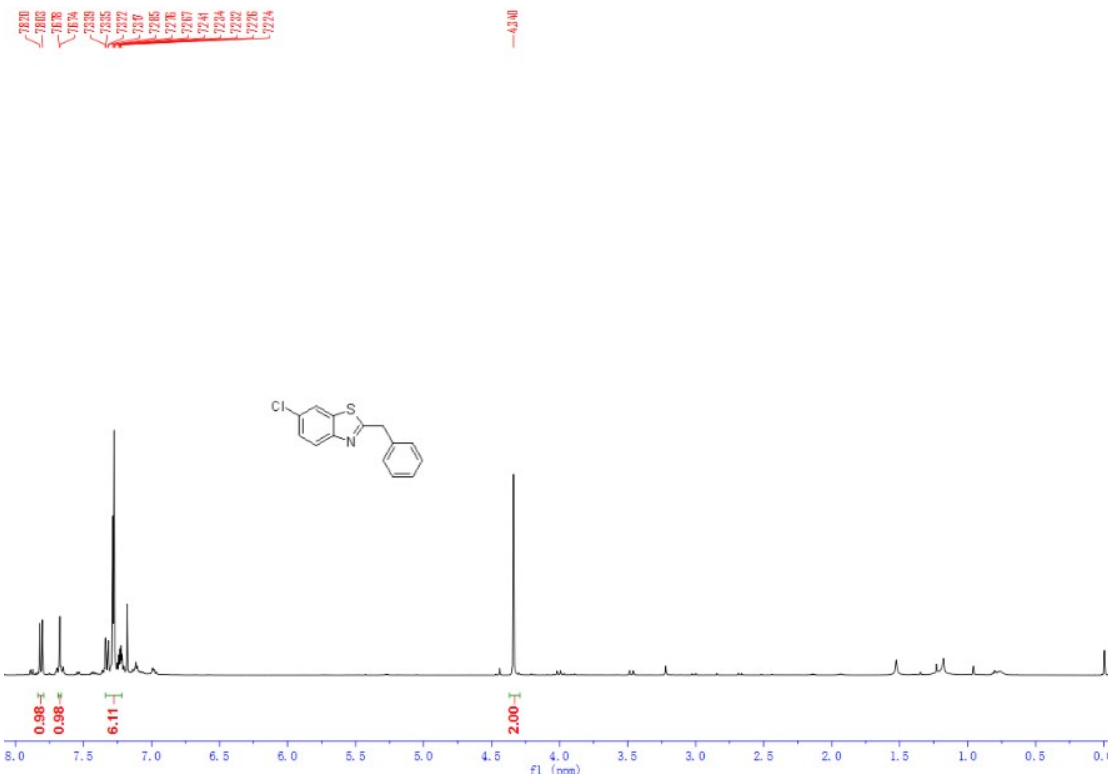
1.05
2.00
3.09
f1 (ppm)


MeO
S
N
f1 (ppm)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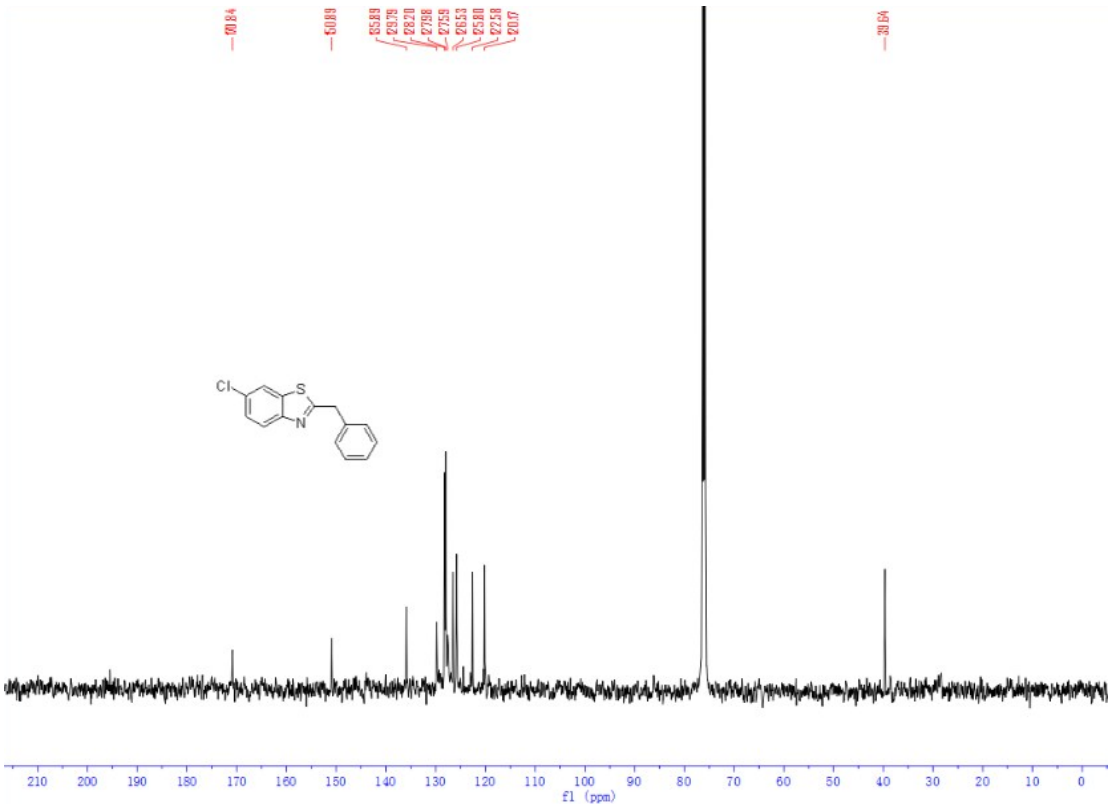
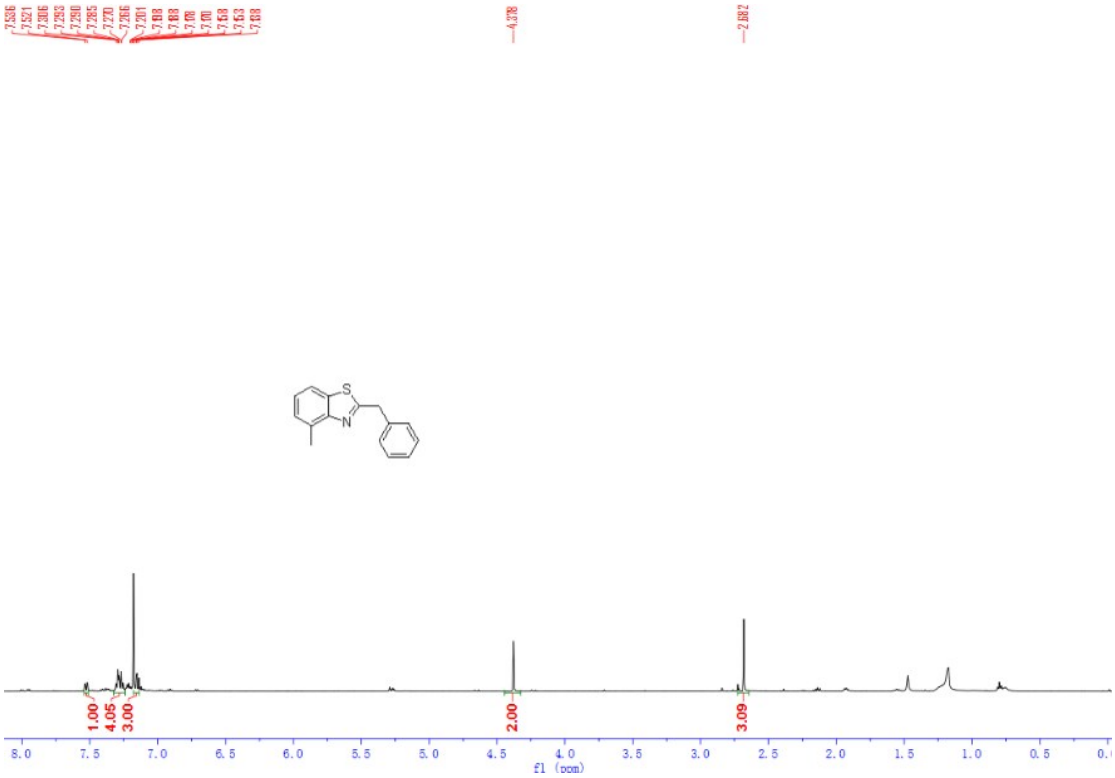
2.00
f1 (ppm)


Cl
S
N
f1 (ppm)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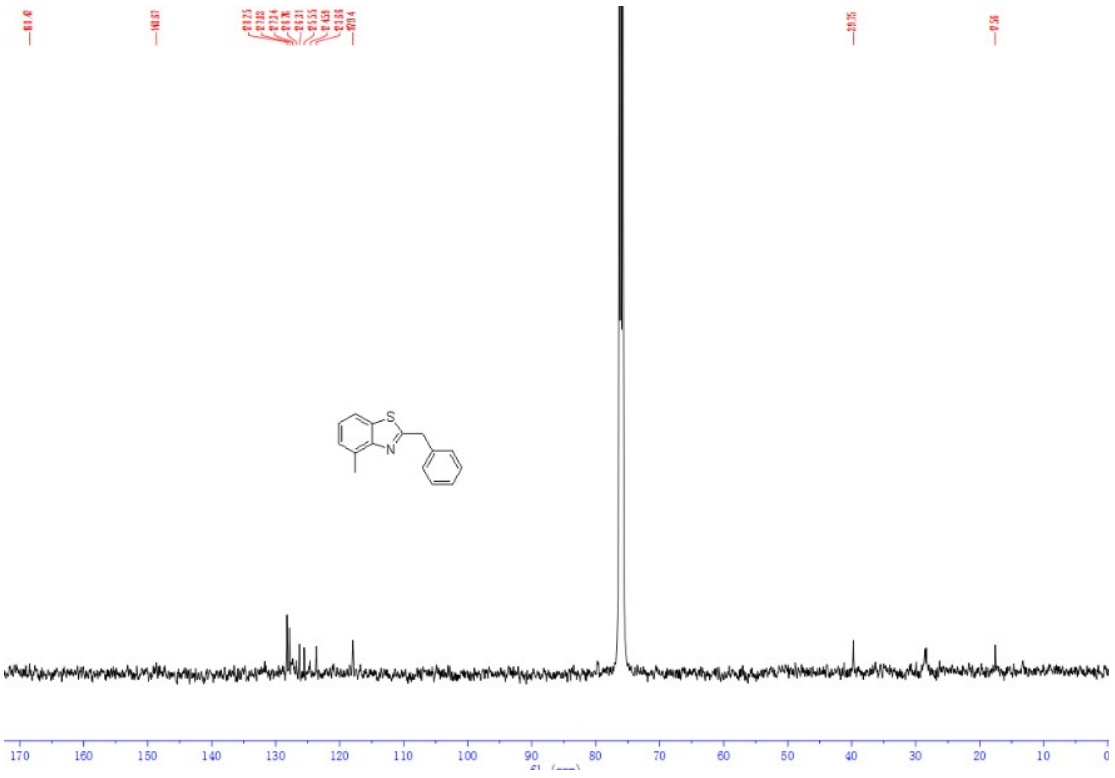
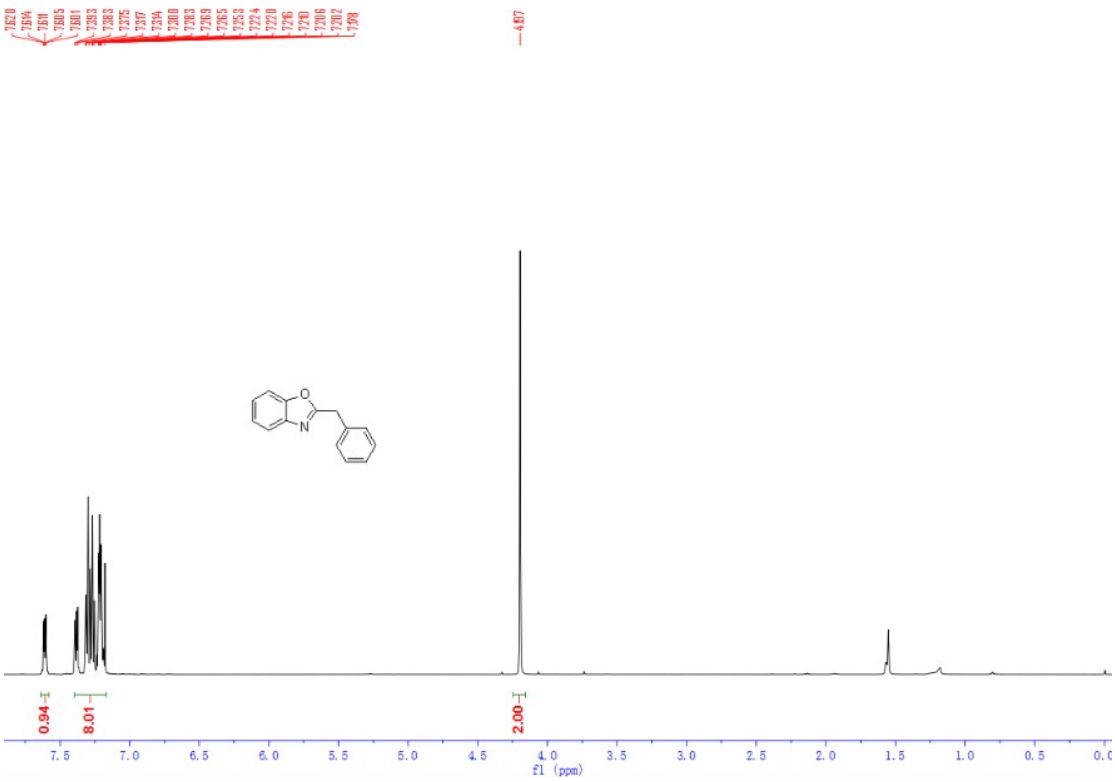
2.00
3.09
f1 (ppm)


f1 (ppm)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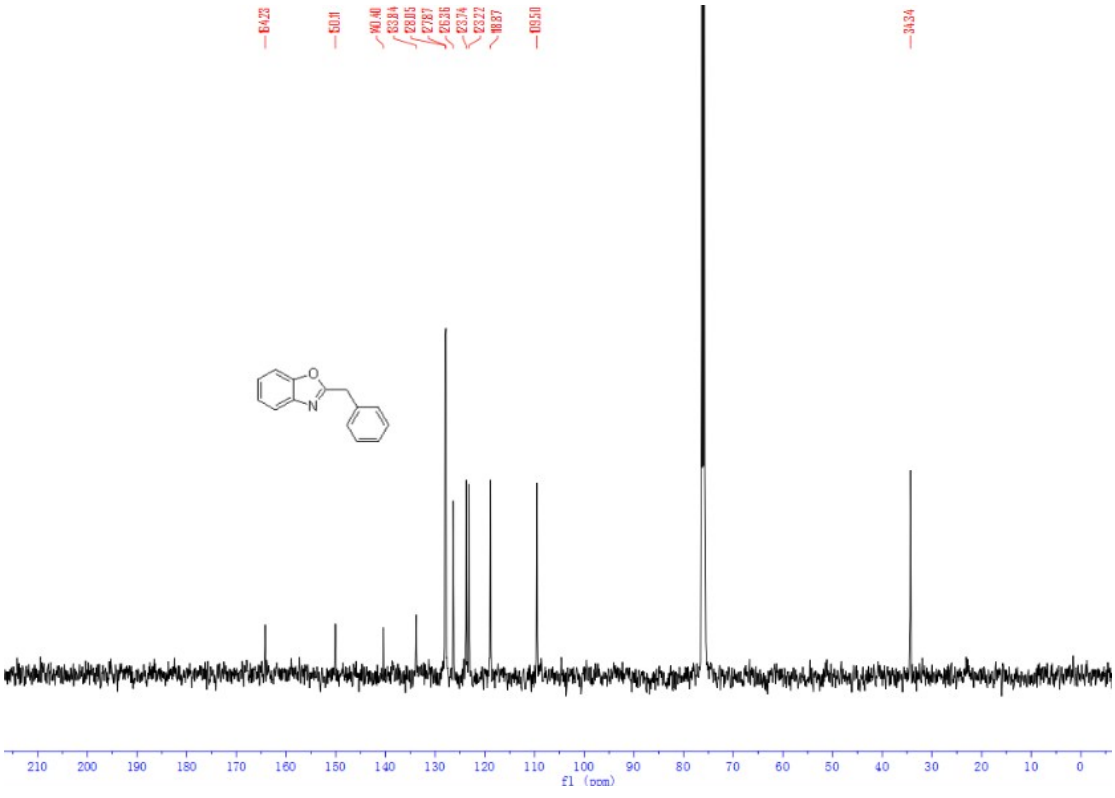
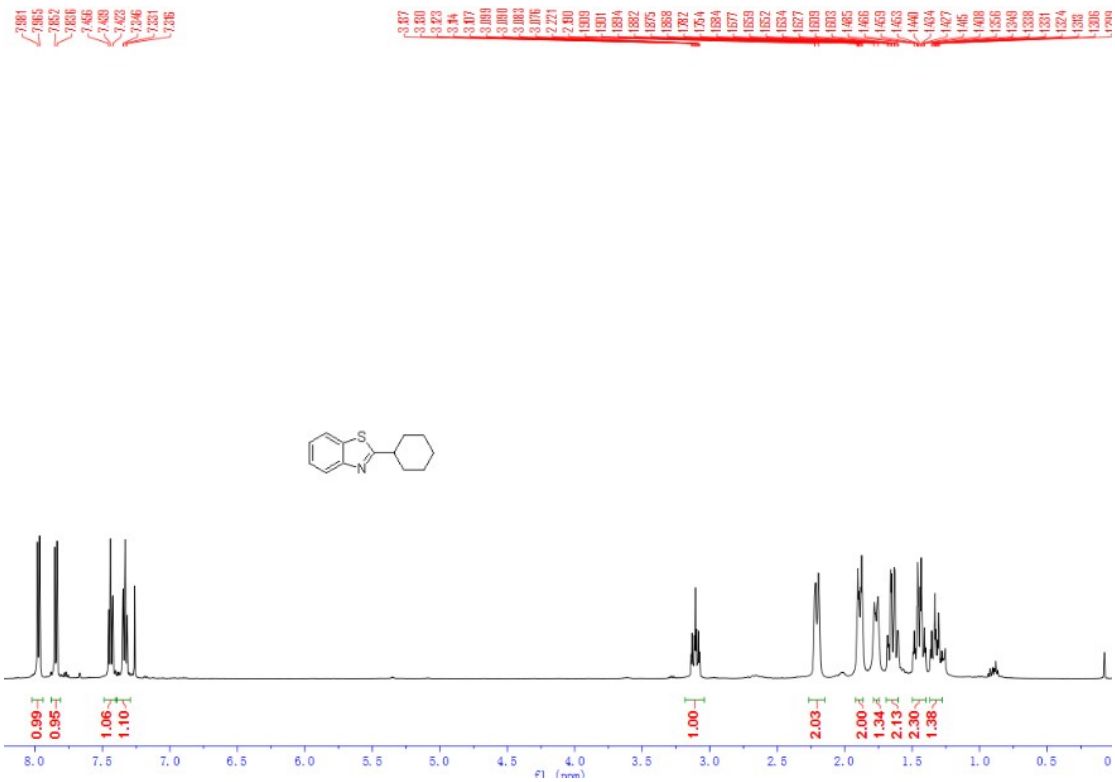
f1 (ppm)


f1 (ppm)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1.06
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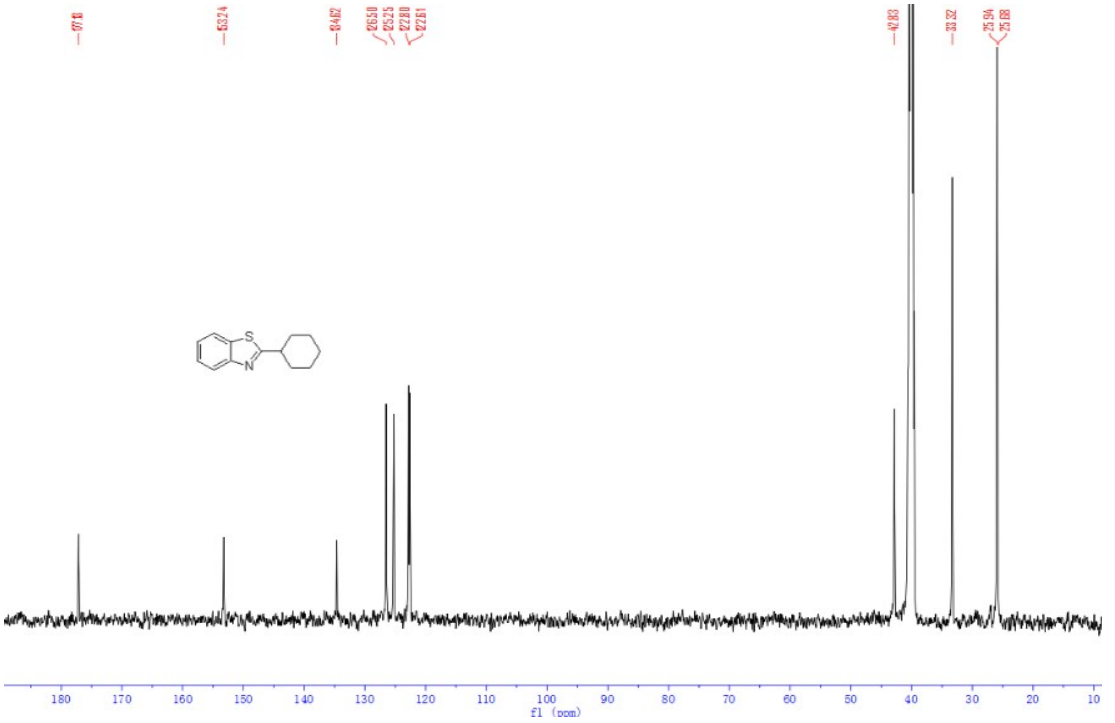
1.00
2.03
2.00
1.34
2.13
2.30
1.38
f1 (ppm)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40.83
33.22
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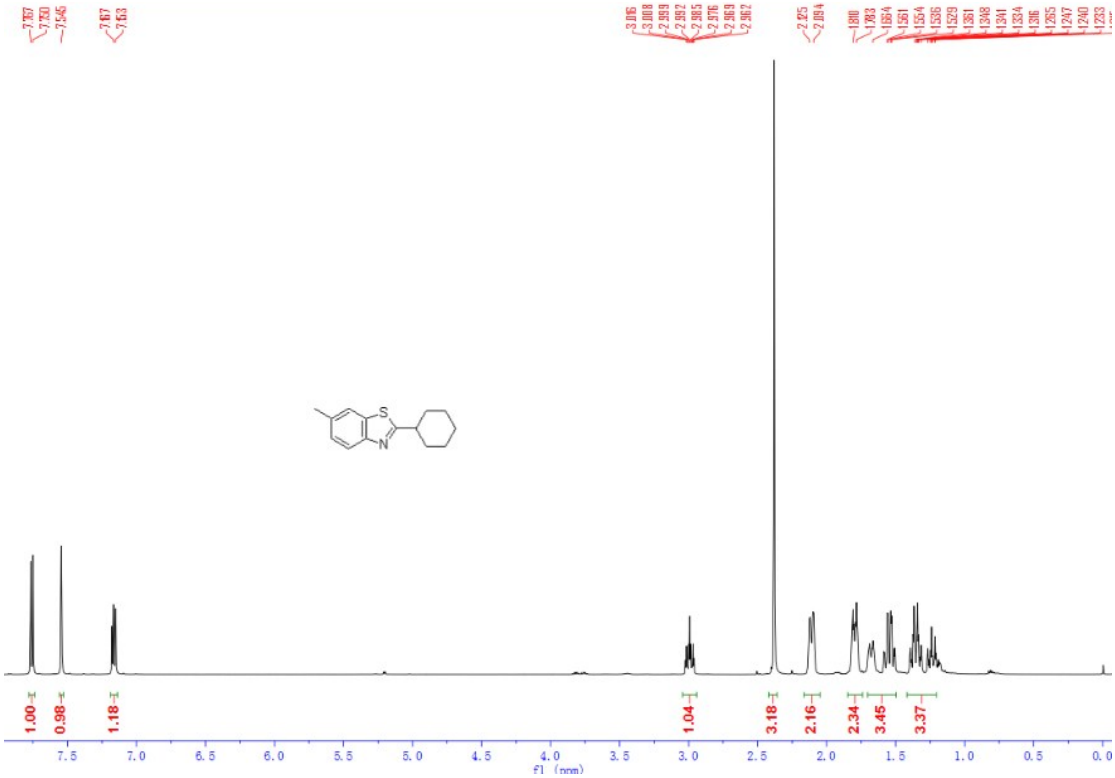
25.88
f1 (ppm)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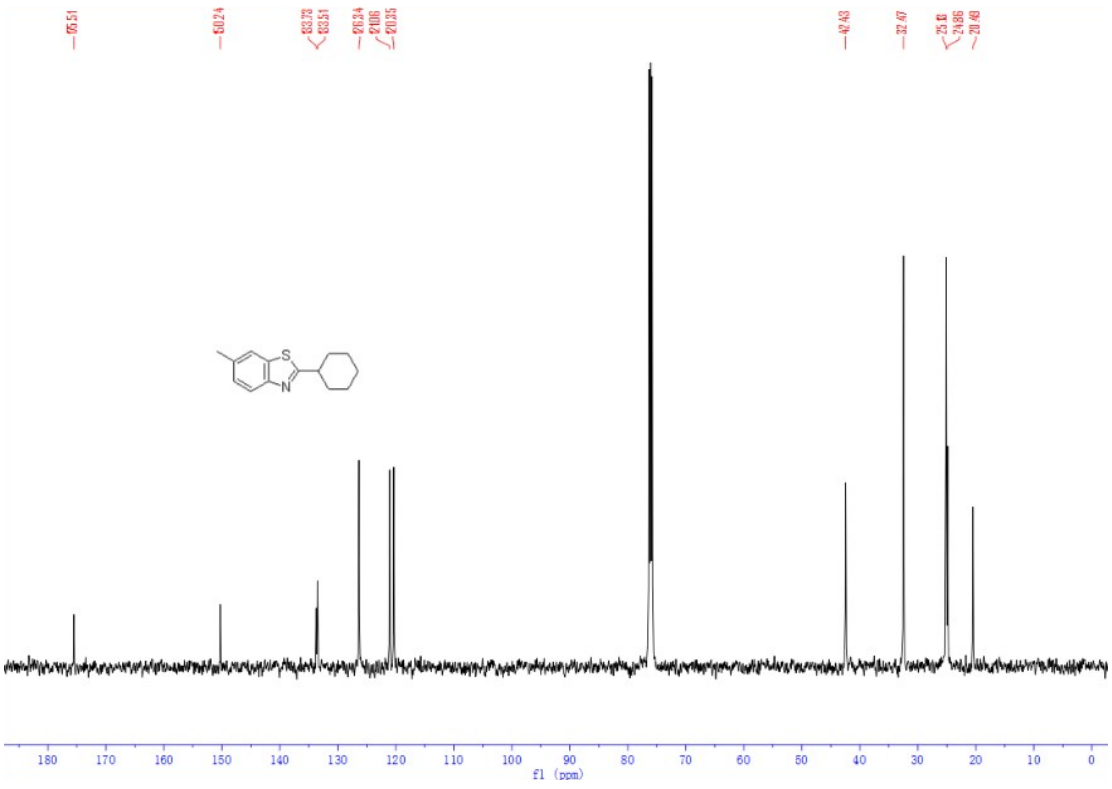
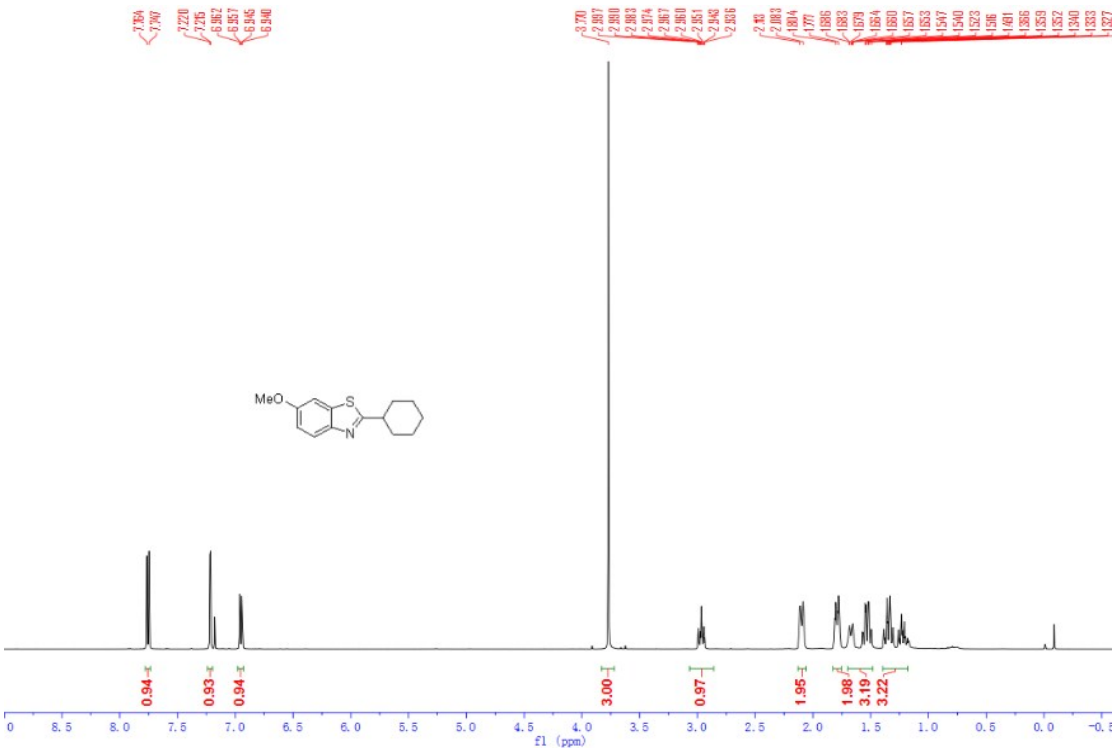
1.04
3.18
2.16
2.34
3.45
3.37
f1 (ppm)


f1 (ppm)


MeO
S
N
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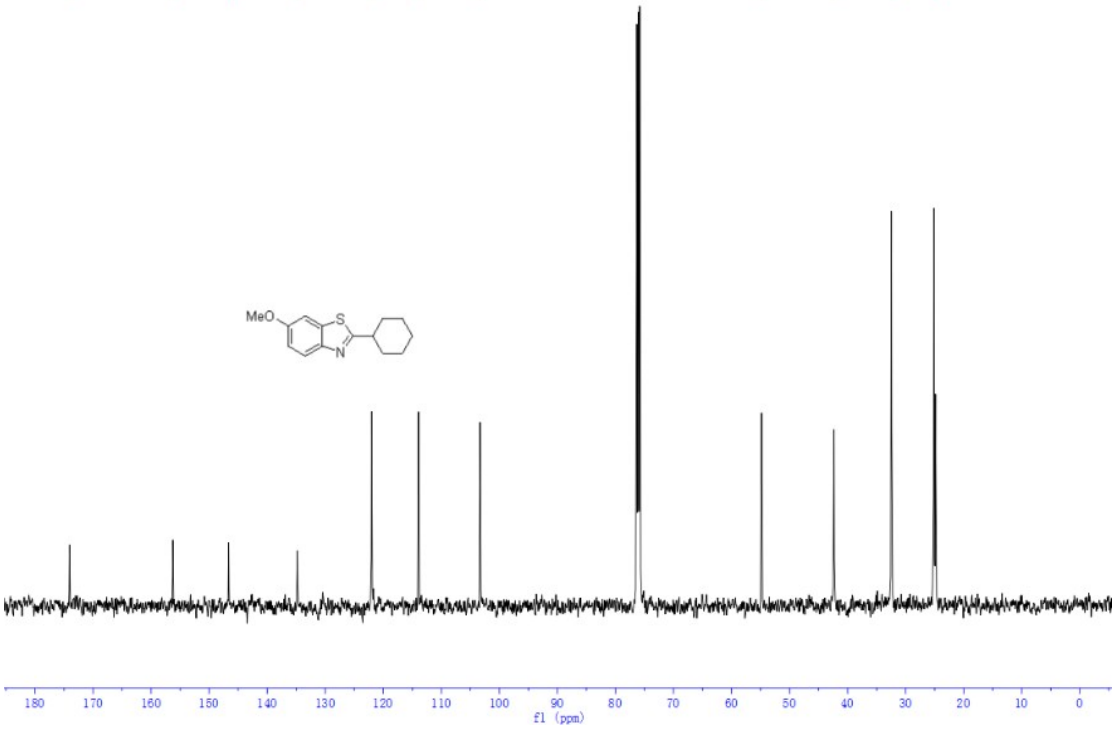
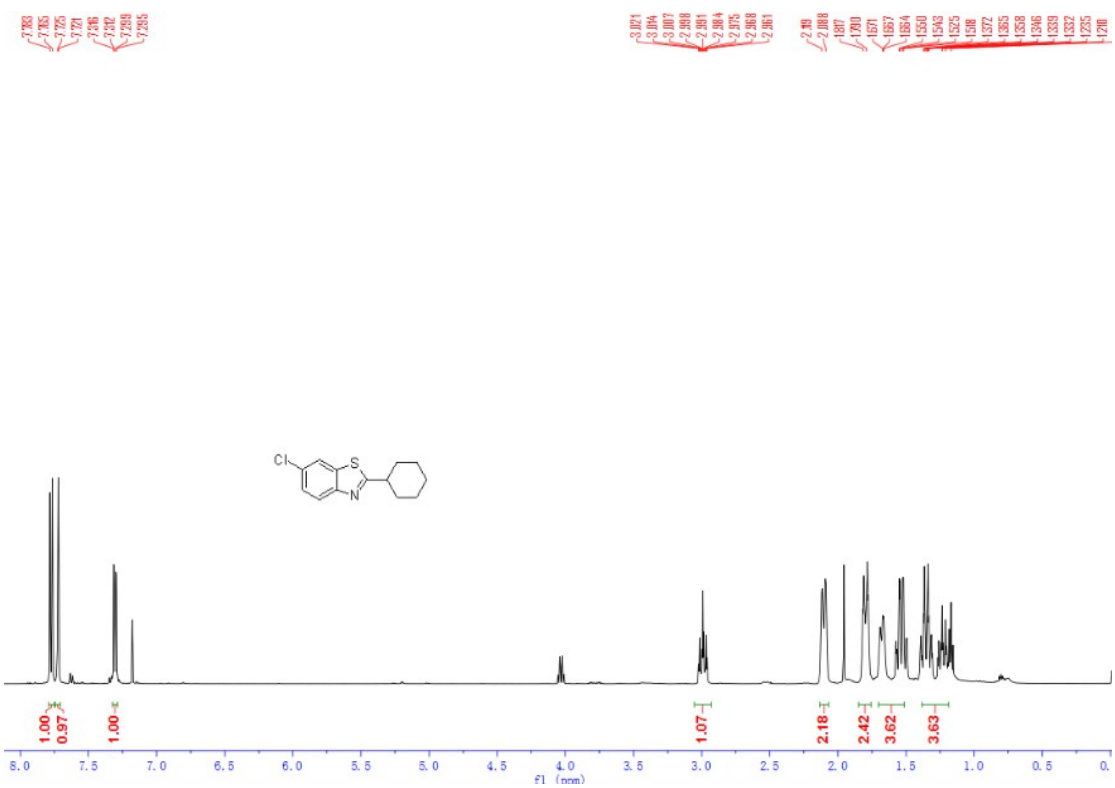
0.93
0.94
3.00
0.97
1.95
1.98
3.19
3.22
f1 (ppm)


MeO
S
N
f1 (ppm)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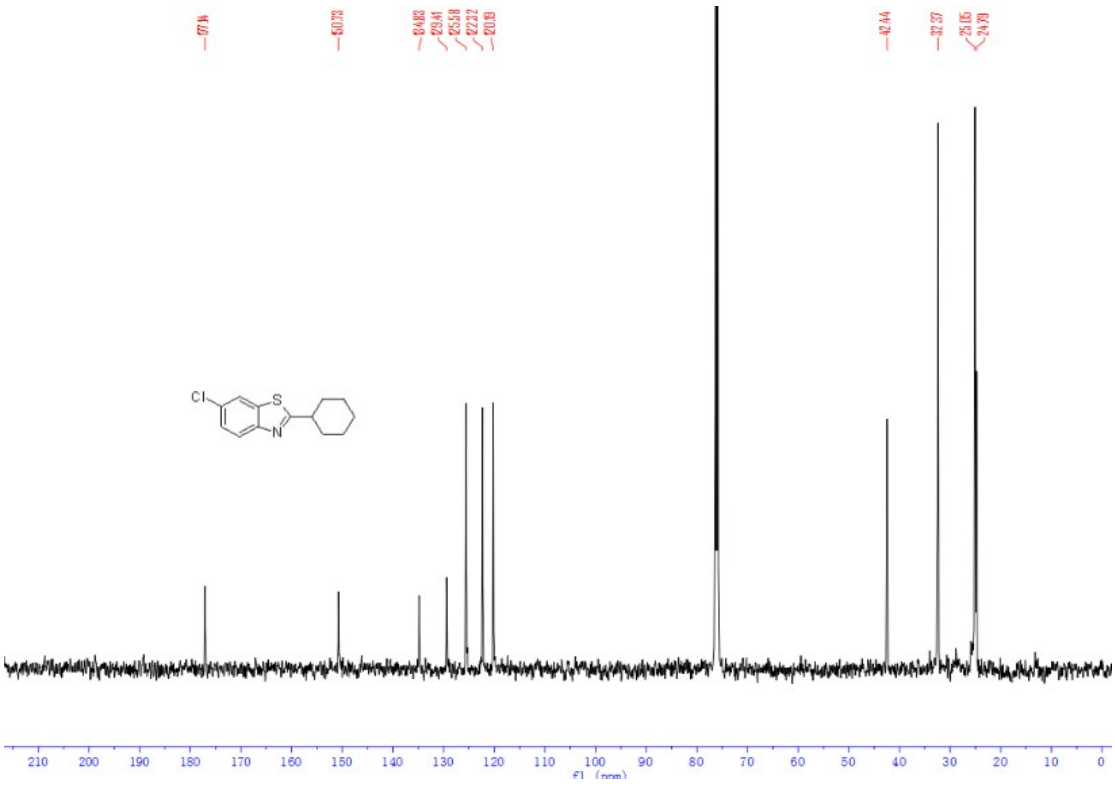
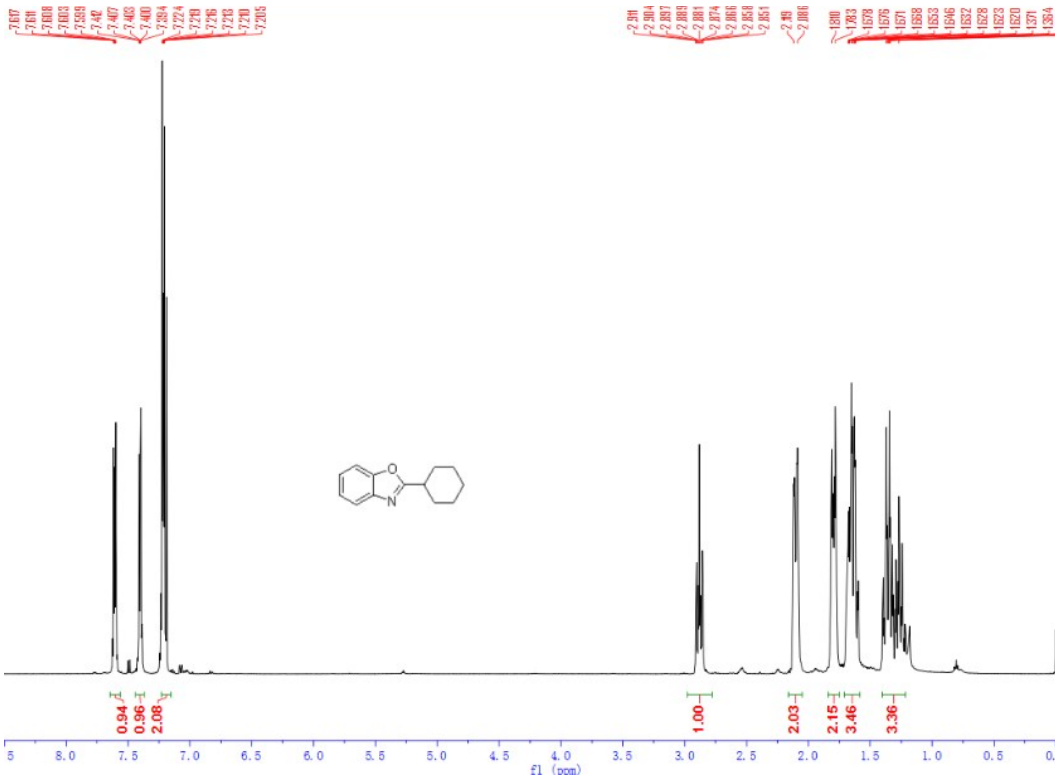
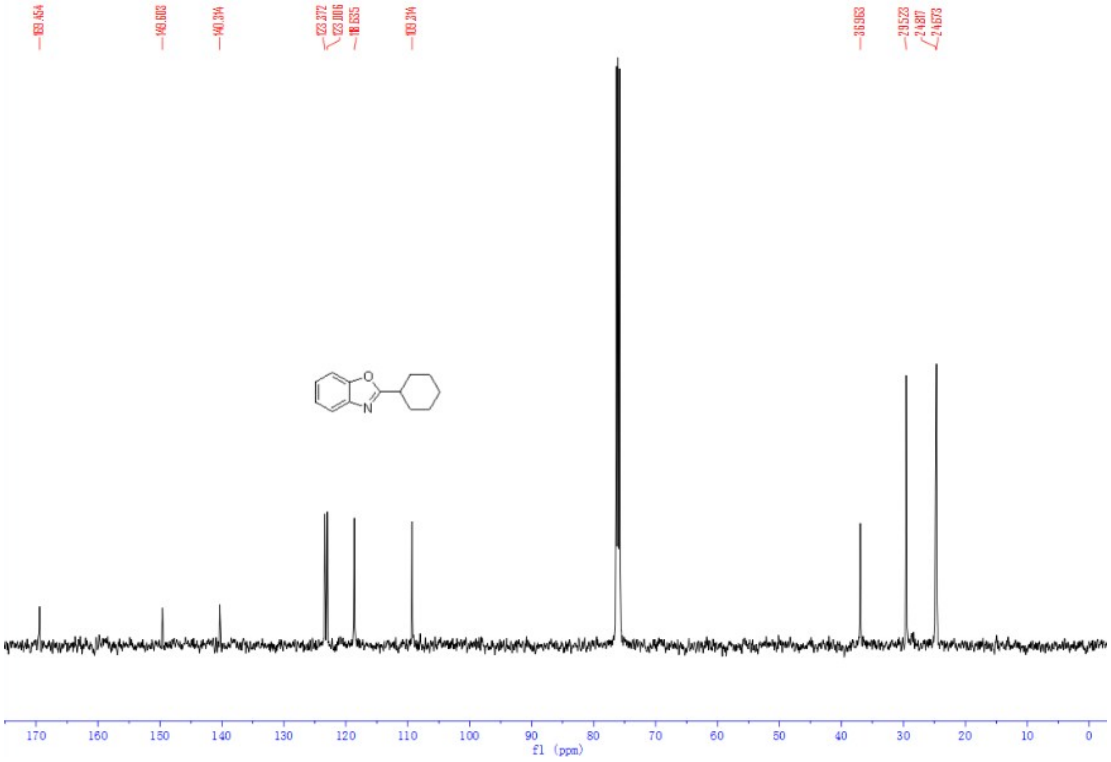
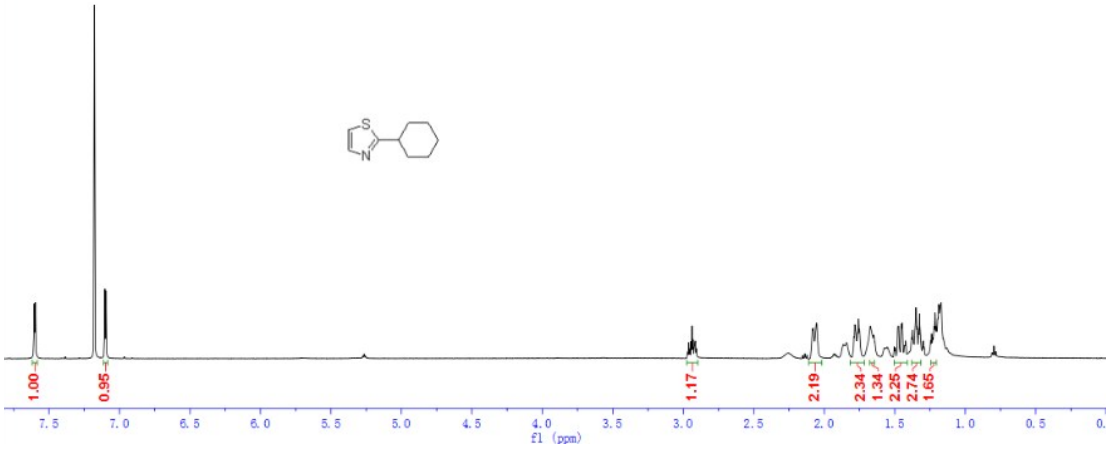
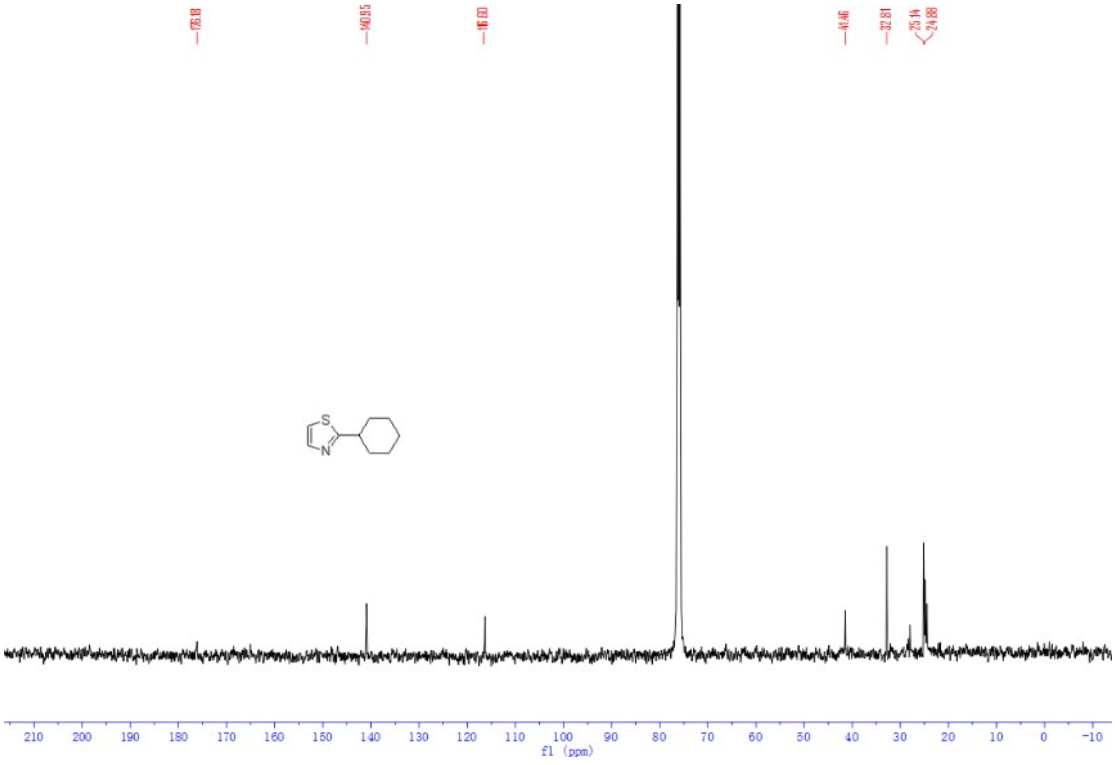
3.63
f1 (ppm)

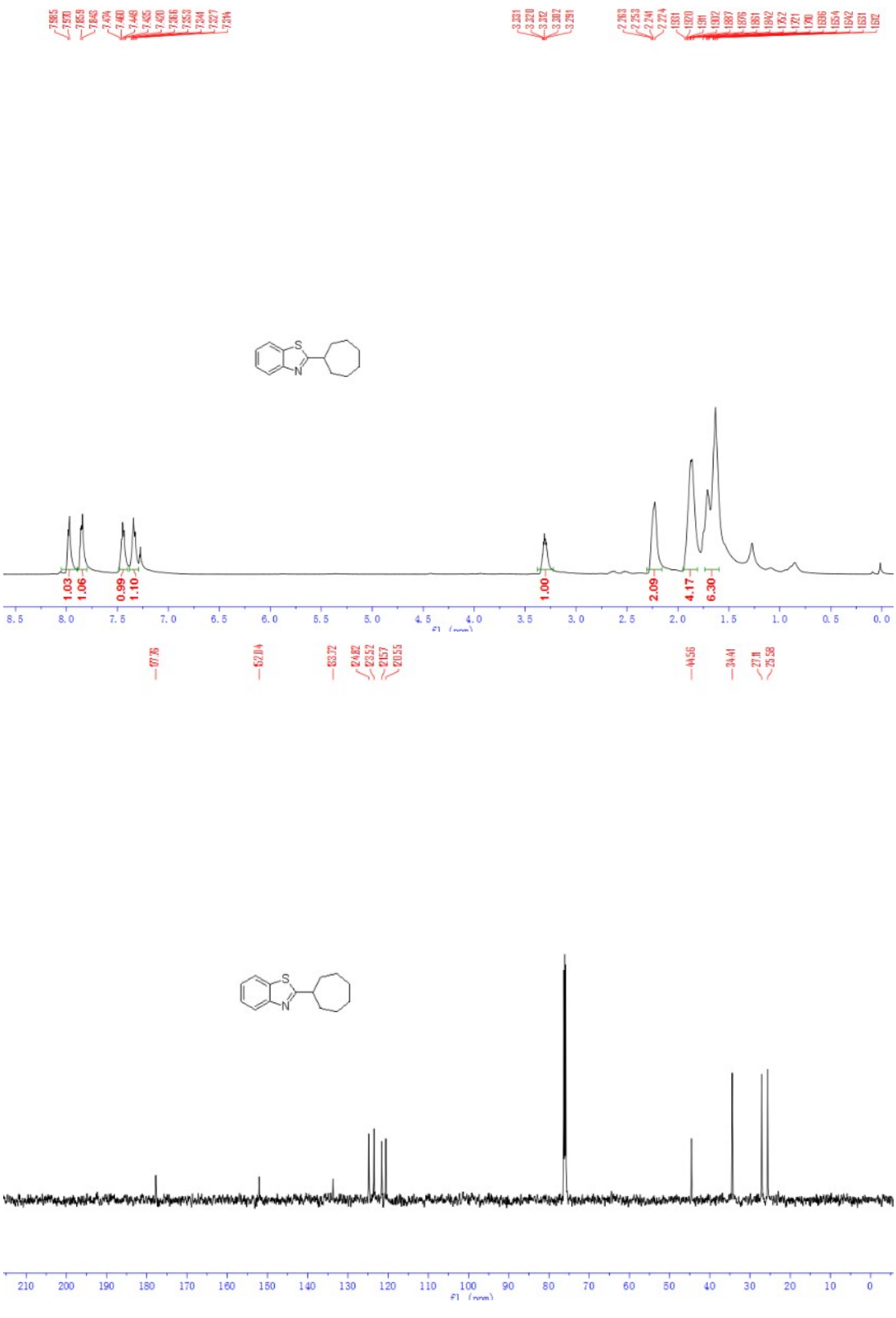

Cl
S
N
f1 (ppm)


0.94
0.96
2.08
1.00
2.03
2.15
3.46
3.36
f1 (ppm)


f1 (ppm)


1.00
0.95
1.17
2.19
2.34
1.34
2.25
2.74
1.65
fl (ppm)


fl (ppm)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7.440
7.435
7.420
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7.353
7.344
7.327
7.314
3.331
3.320
3.312
3.302
3.291
2.263
2.253
2.234
2.224
1.931
1.920
1.911
1.902
1.887
1.876
1.851
1.842
1.552
1.721
1.701
1.636
1.554
1.542
1.531
1.512
1.03
1.06
0.99
1.10
1.00
2.09
4.17
6.30
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)
167.76
152.04
133.72
124.82
123.52
121.57
120.55
44.56
34.41
27.11
25.58
210
200
190
180
170
160
150
140
130
120
110
100
90
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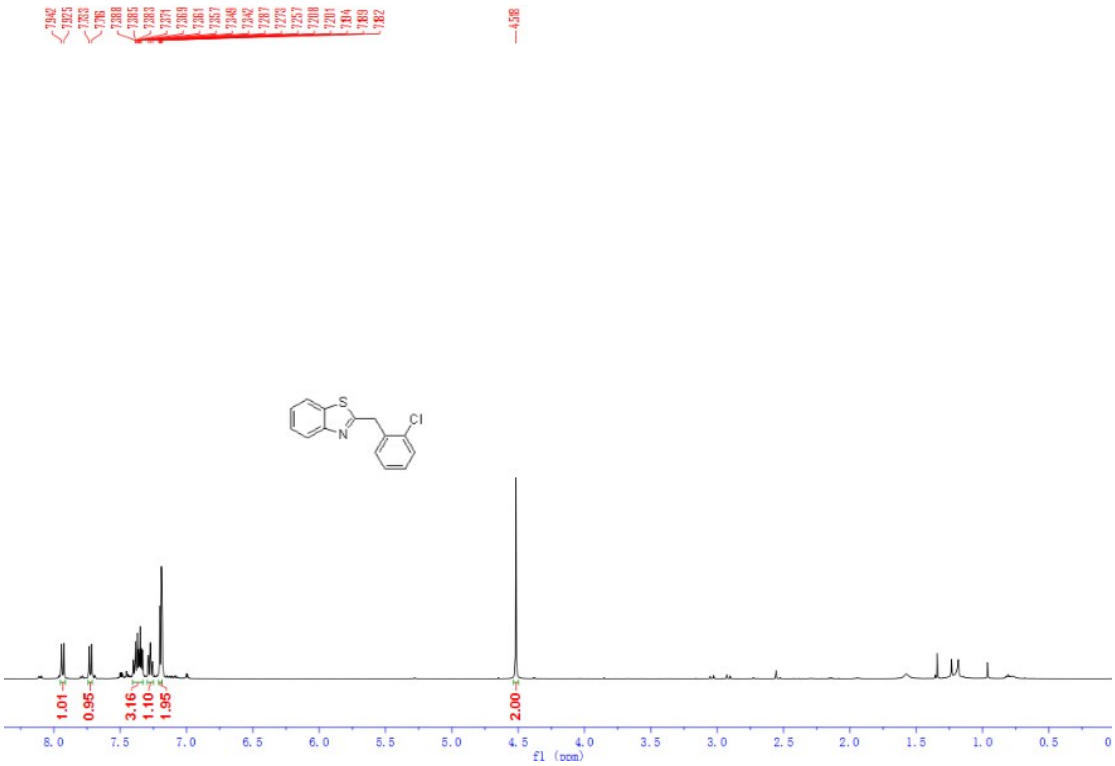
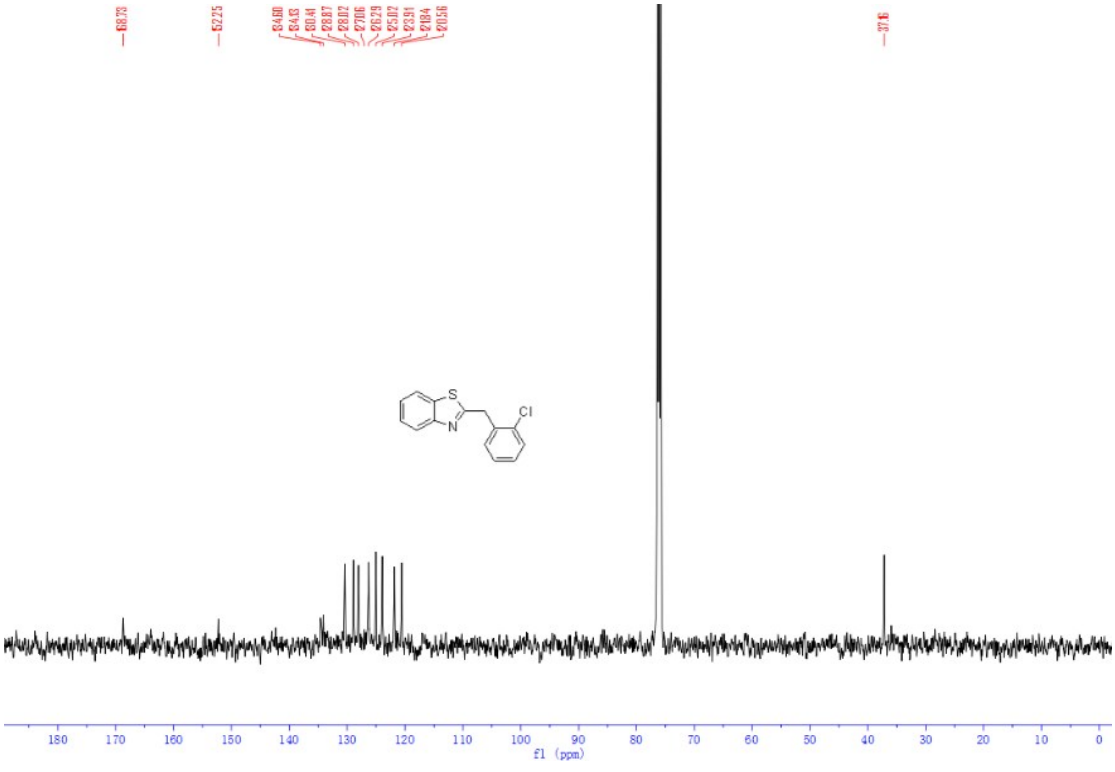
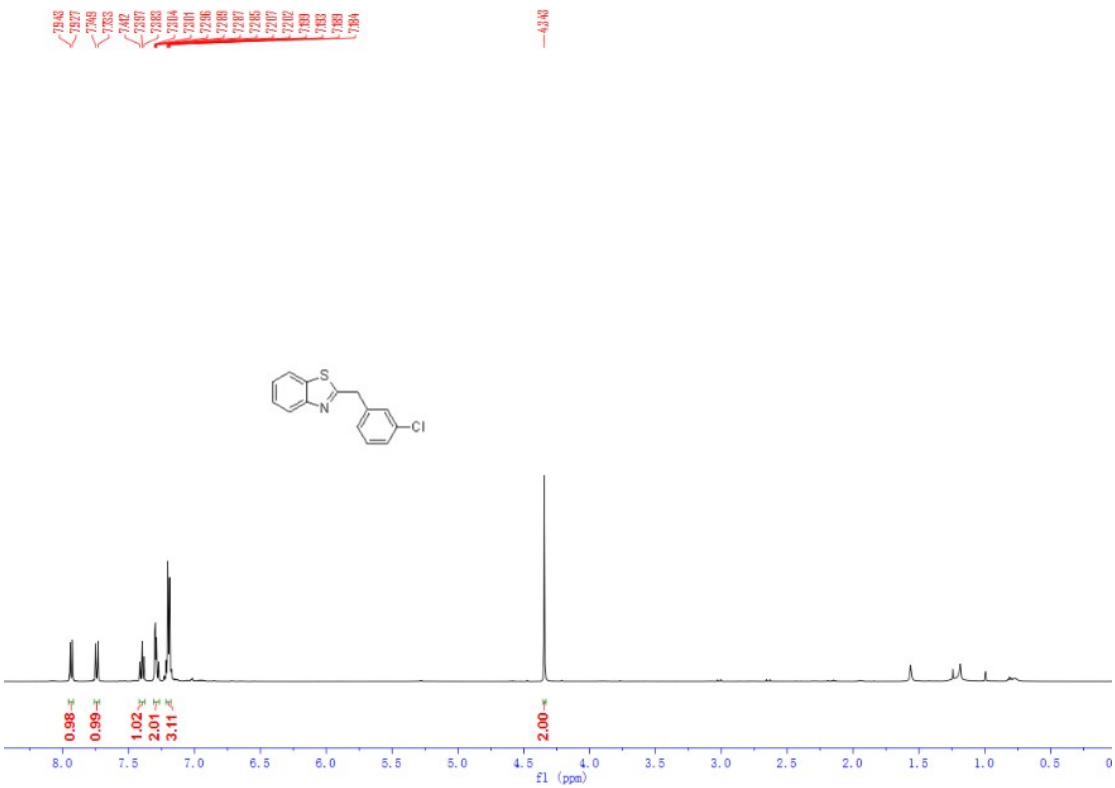
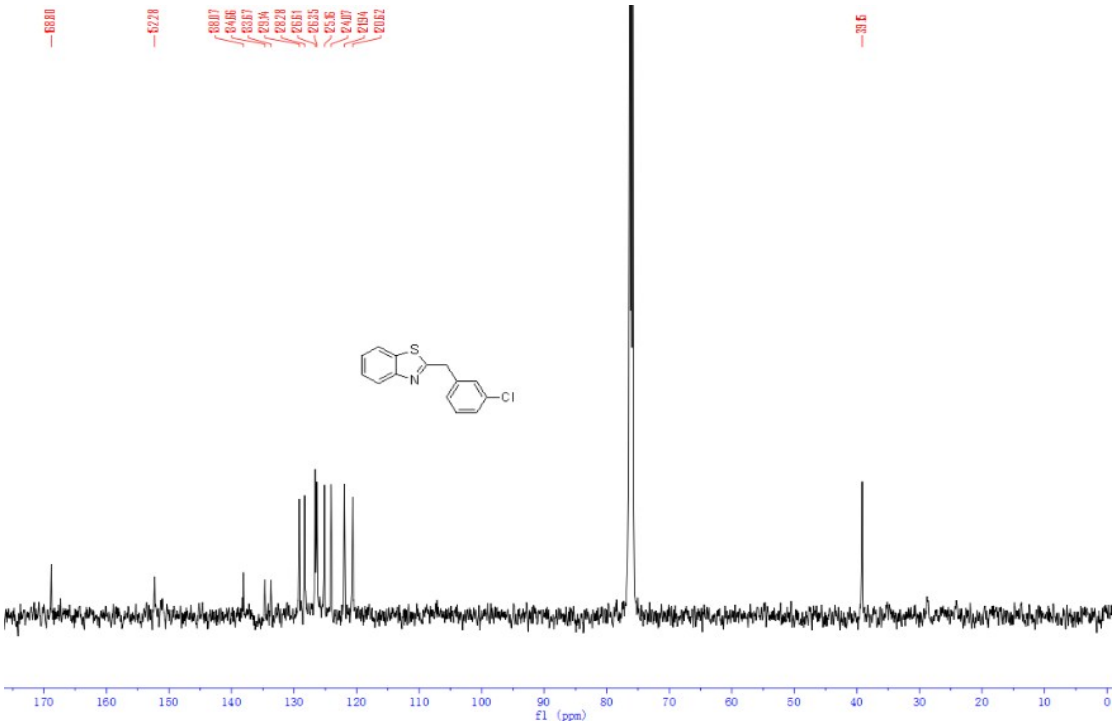
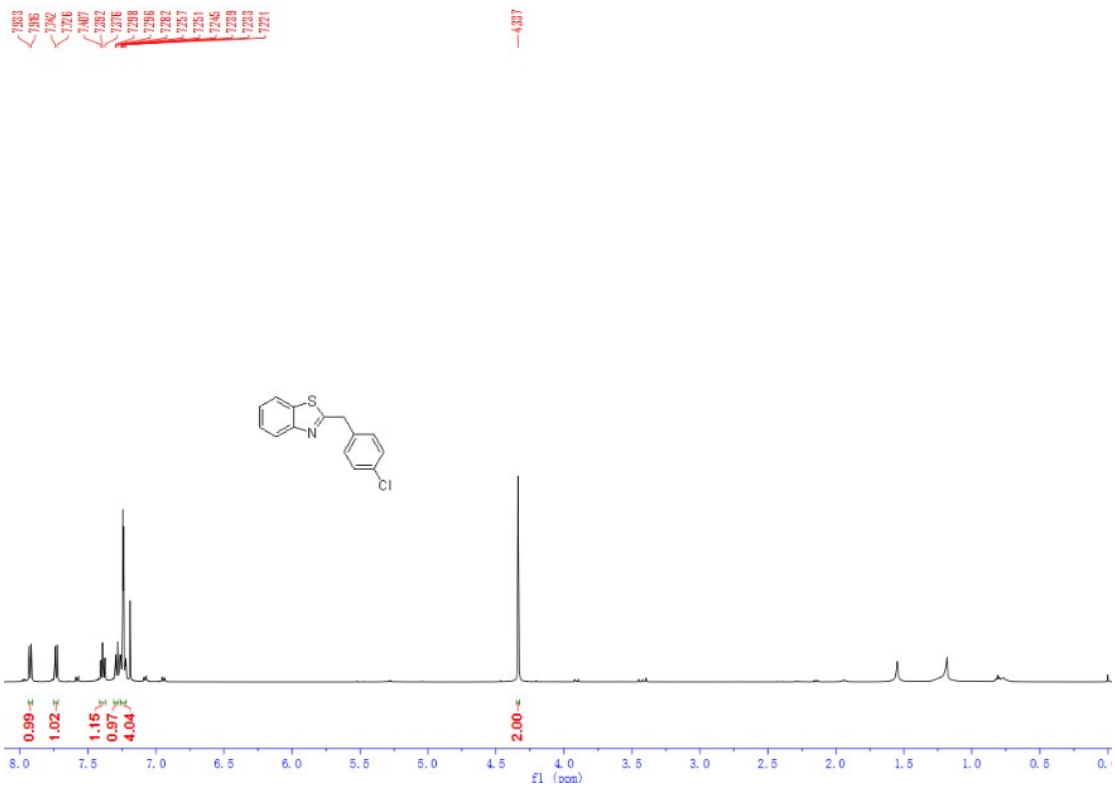
70
60
50
40
30
20
10
0
f1 (ppm)

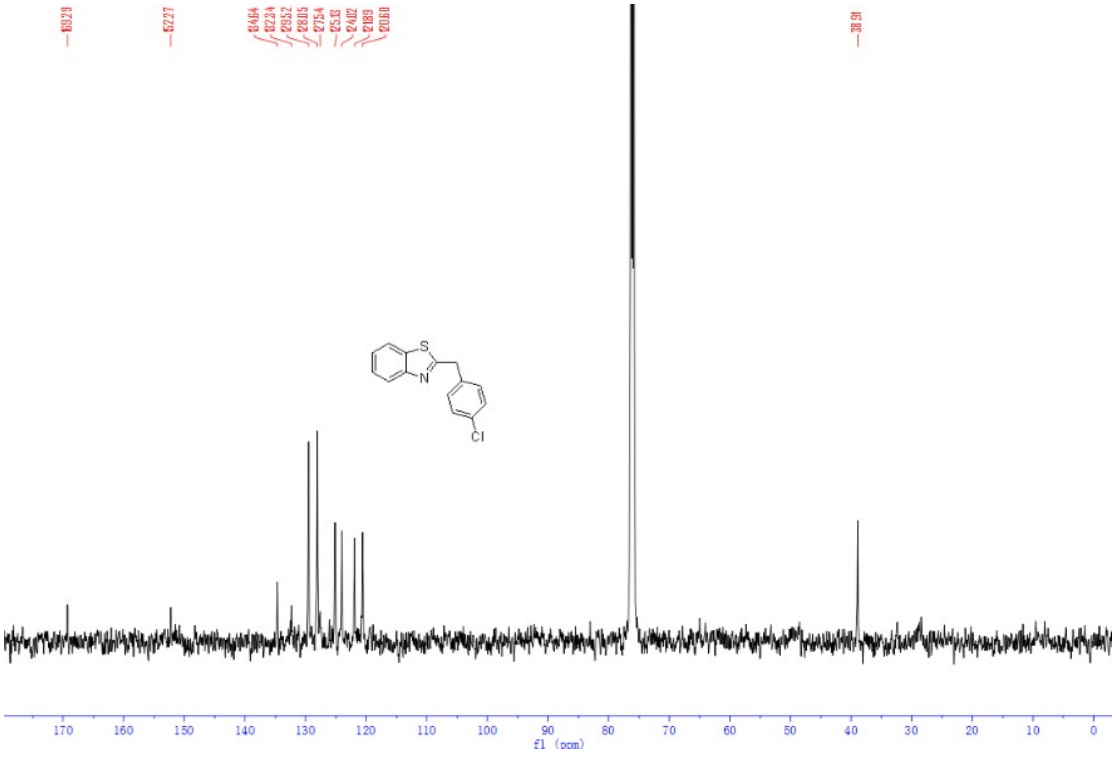

1.01
0.95
3.16
1.10
1.95
2.00
f1 (ppm)

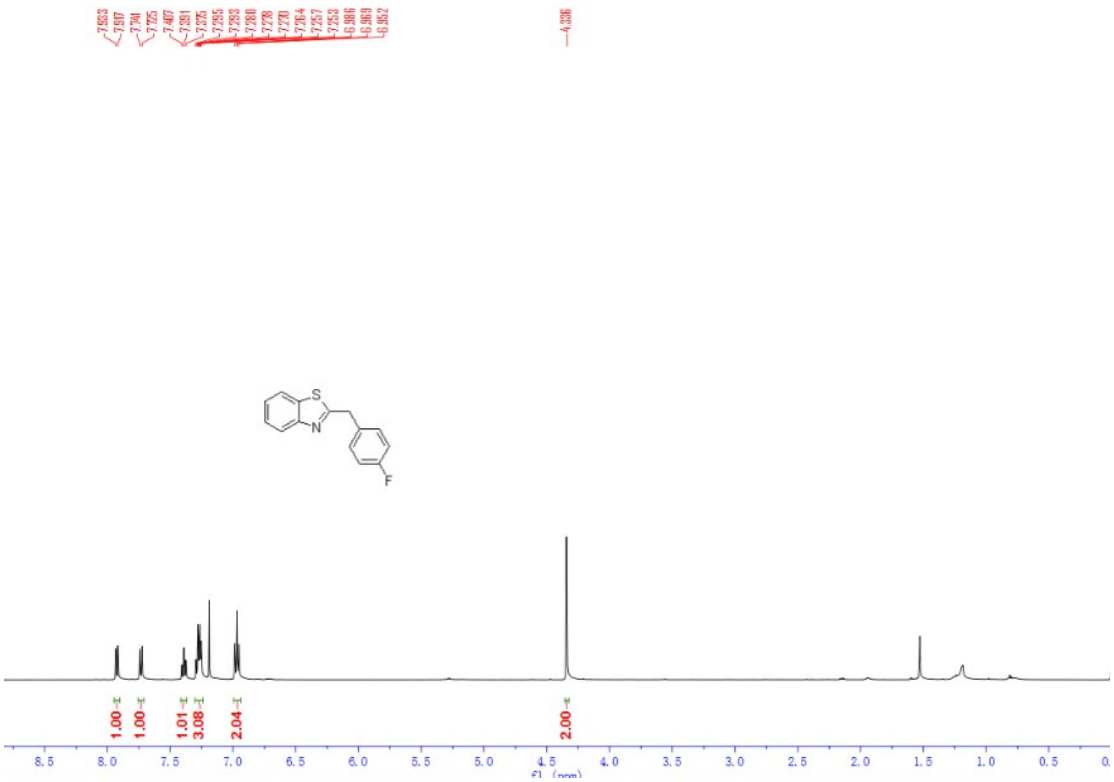

f1 (ppm)


S
N
Cl
0.98
0.99
1.02
2.01
3.11
2.00
f1 (ppm)


S
N
Cl
f1 (ppm)


0.99
1.02
1.15
0.97
4.04
2.00
f1 (ppm)


f1 (ppm)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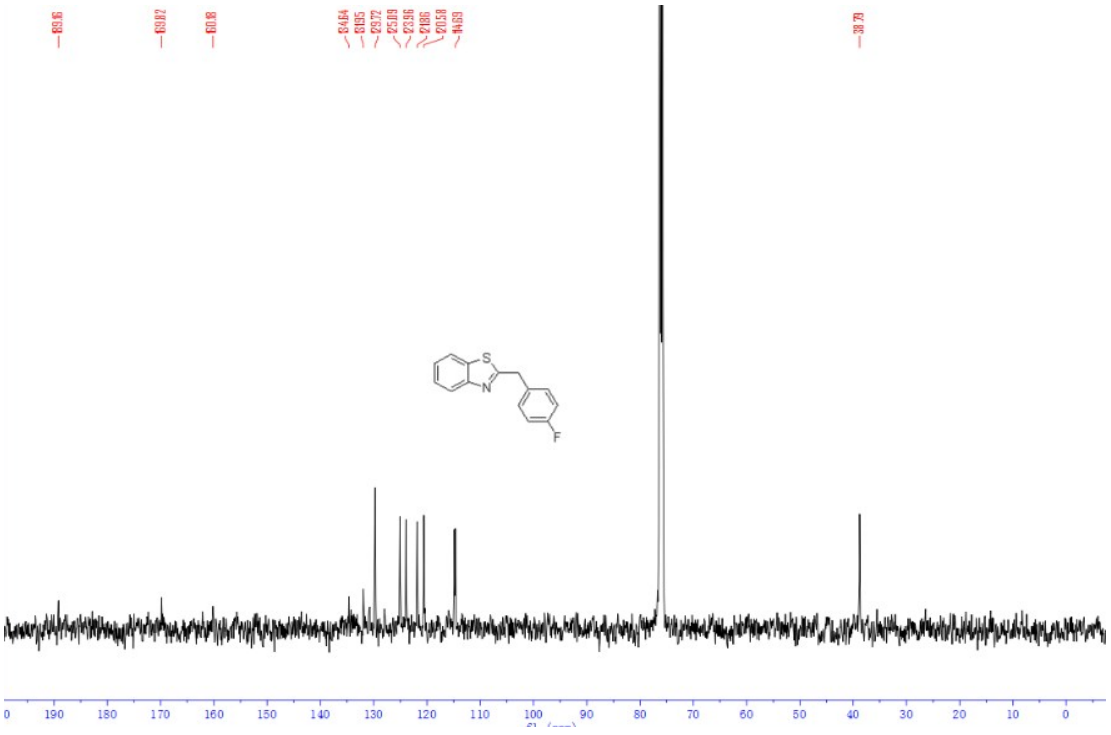
7.7517
7.7341
7.7325
7.7307
7.7281
7.7275
7.7255
7.7253
7.7230
7.7228
7.7220
7.7064
7.7057
7.7053
6.9886
6.9869
6.9852
4.3306
S
N
F
1.00
1.00
1.01
3.08
2.04
2.00
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5


169.16
159.02
150.18
134.64
129.35
129.32
125.09
123.36
121.06
120.58
114.59
38.78
S
N
F
190
180
170
160
150
140
130
120
110
100
90
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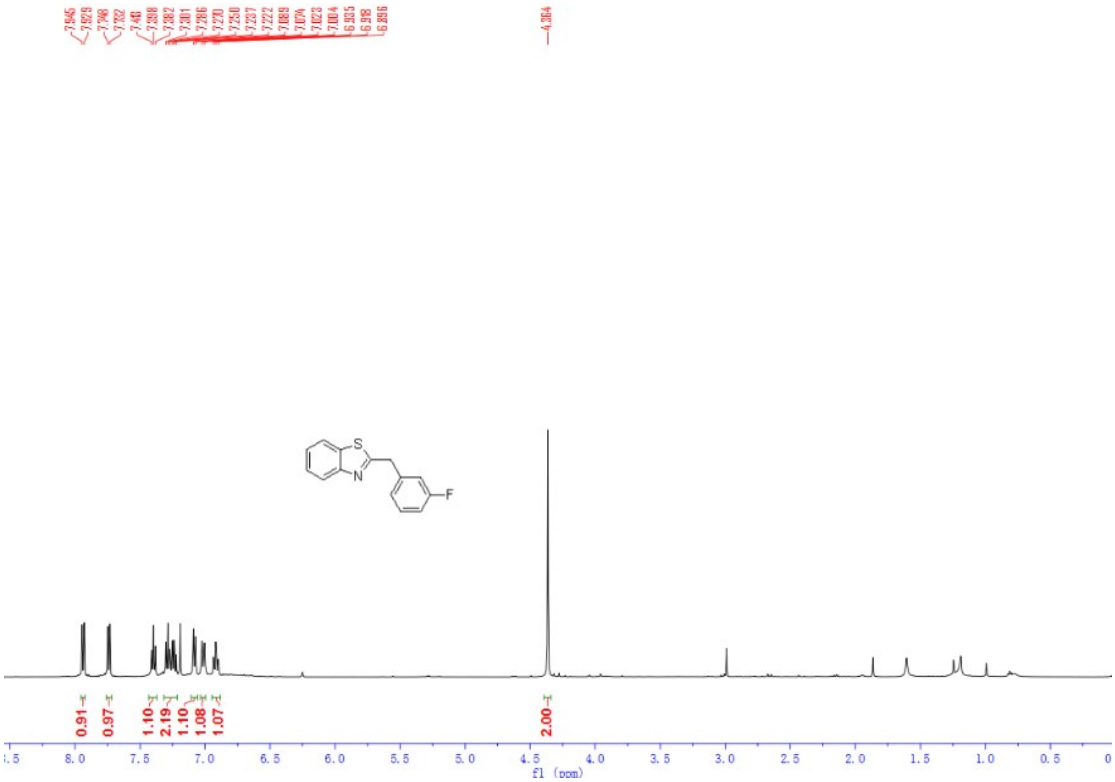
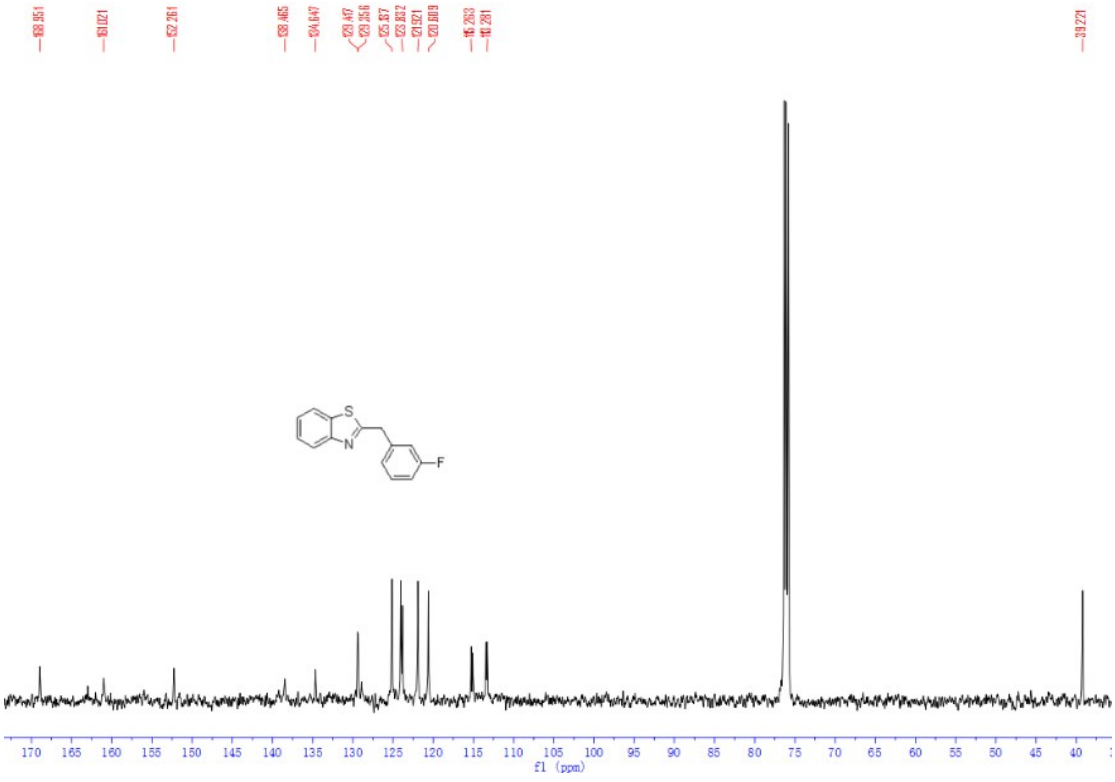
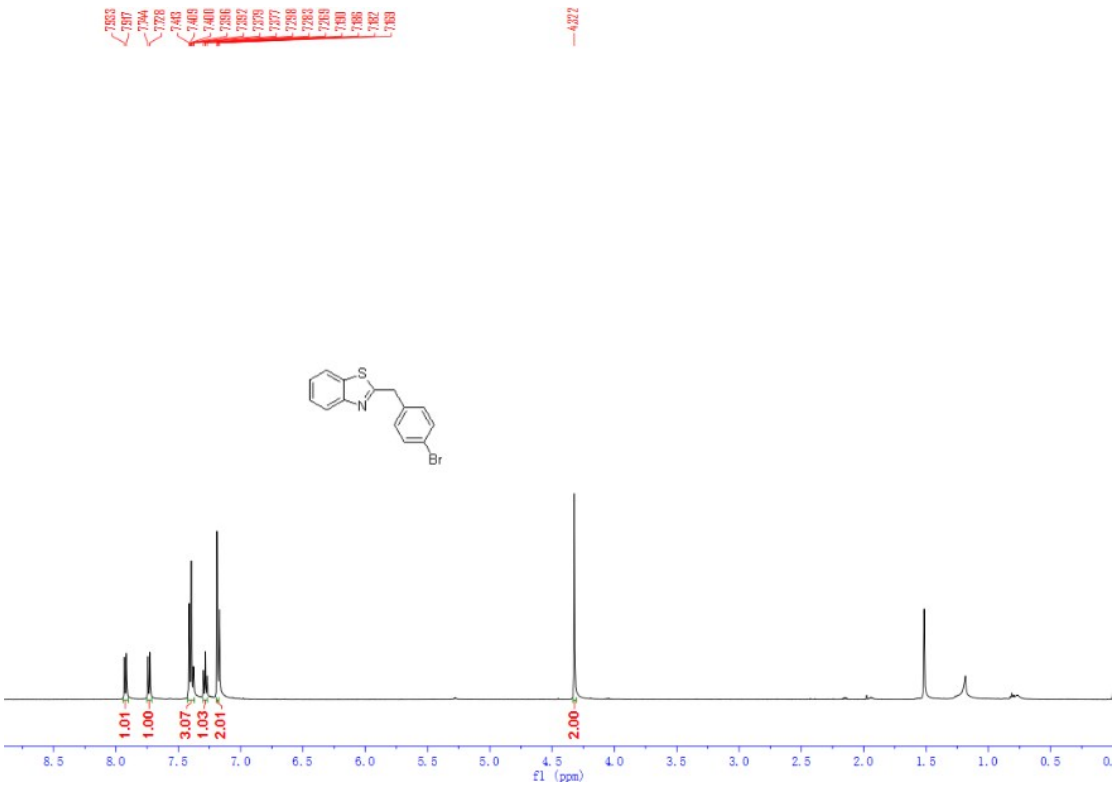
70
60
50
40
30
20
10
0


S
N
F
0.91
0.97
1.10
2.19
1.10
1.08
1.07
2.00
f1 (ppm)


S
N
F
f1 (ppm)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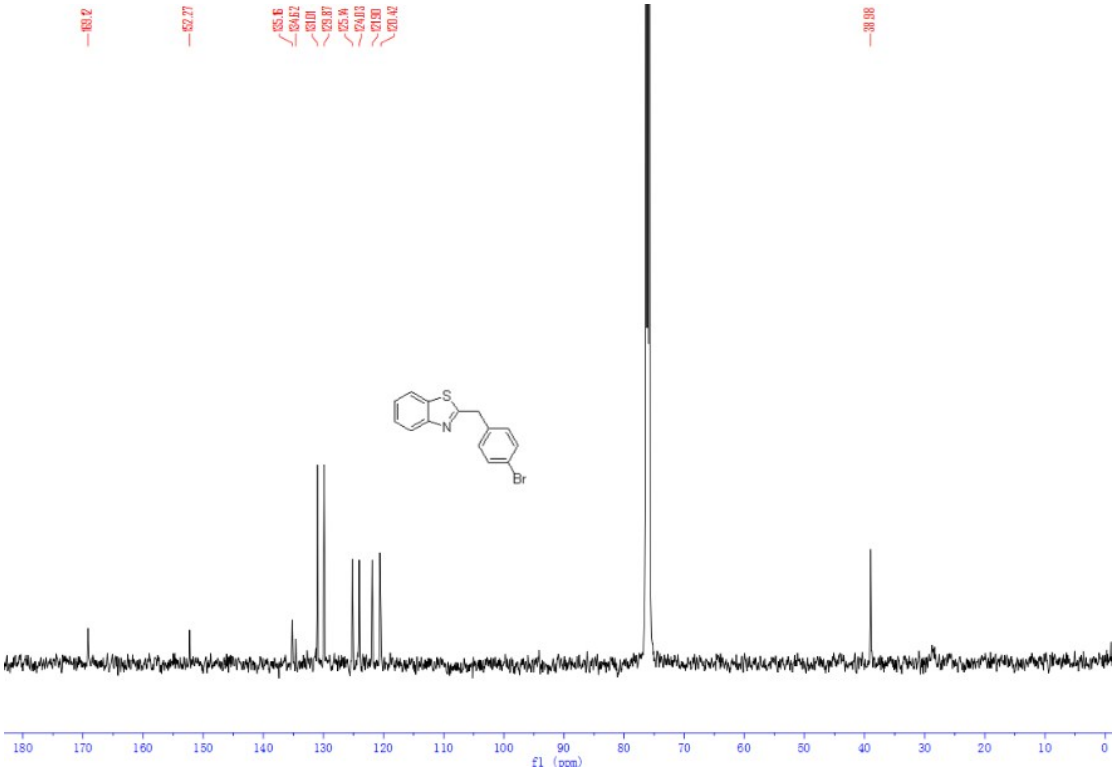
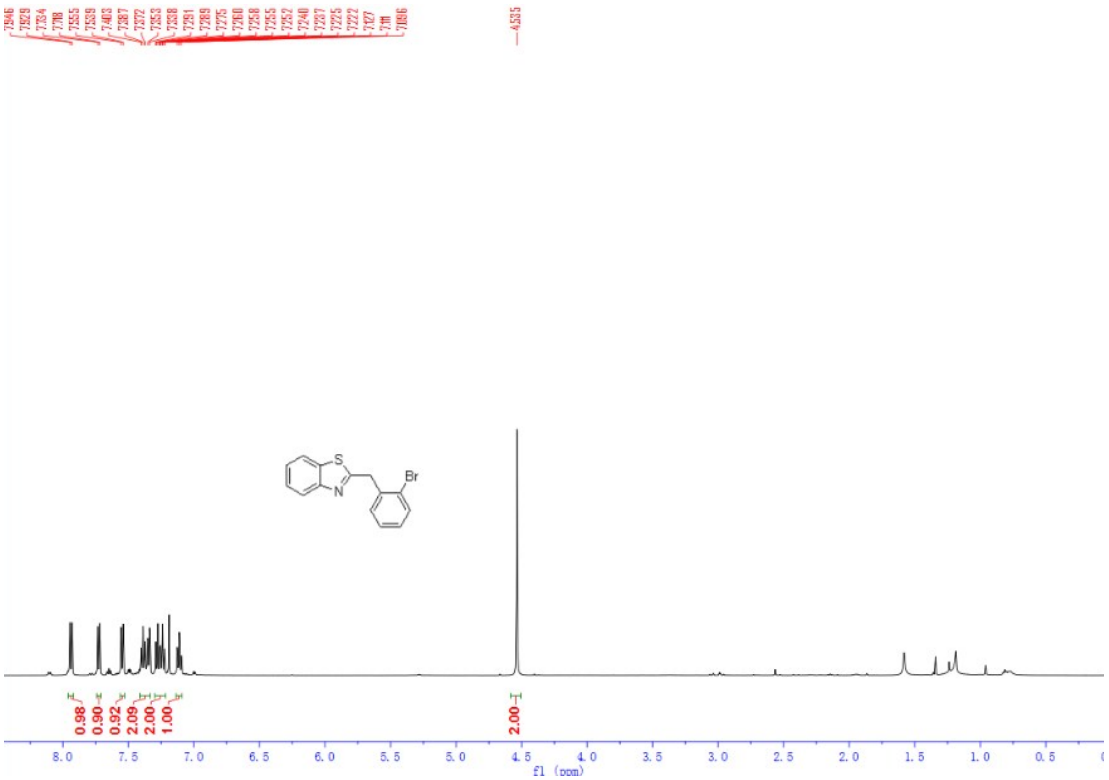
7328
7443
7409
7400
7286
7282
7279
7277
7268
7263
7249
7180
7166
7162
7159
4322
S
N
Br
1.01
1.00
3.07
1.03
2.01
2.00
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.
f1 (ppm)


169.92
152.77
135.16
134.62
131.01
129.87
125.94
124.03
121.90
120.42
39.88
S
N
Br
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)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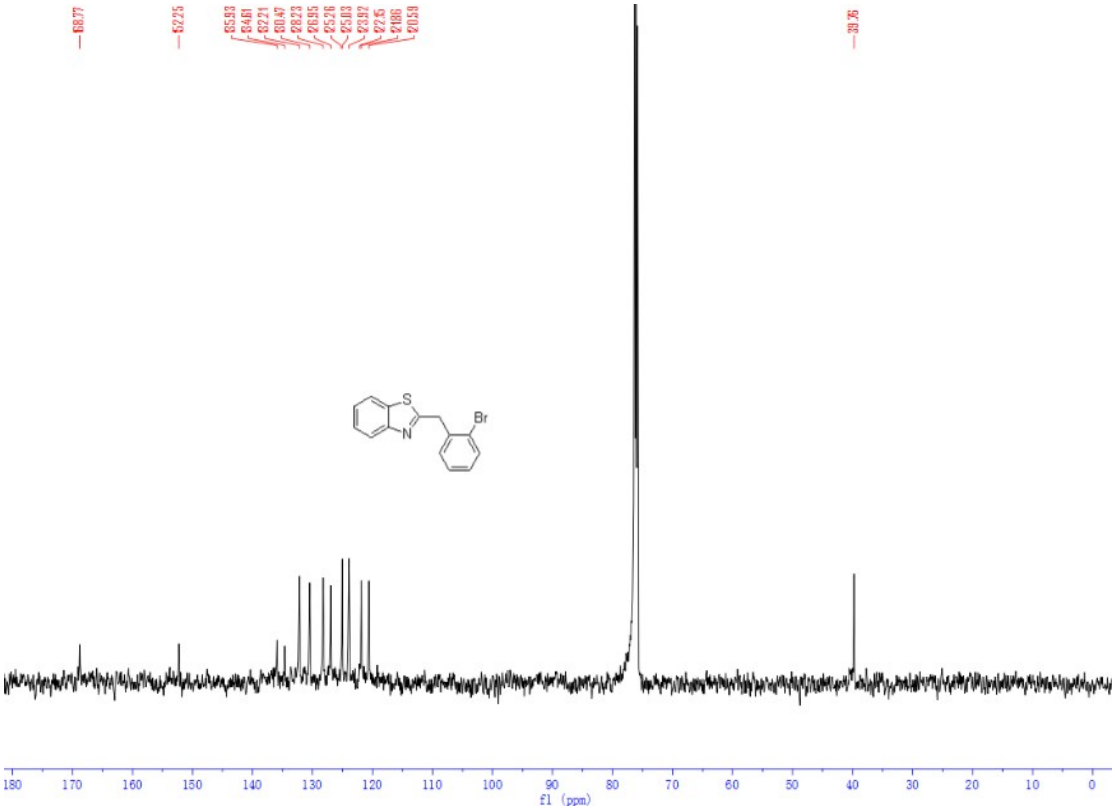
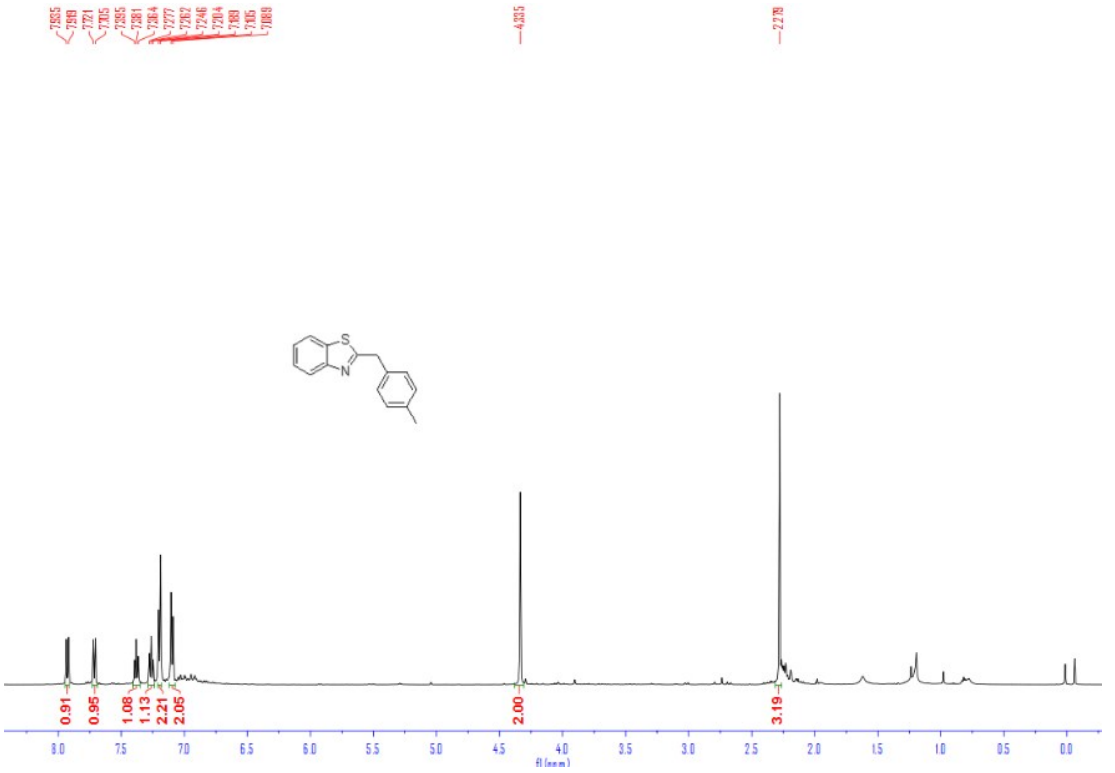
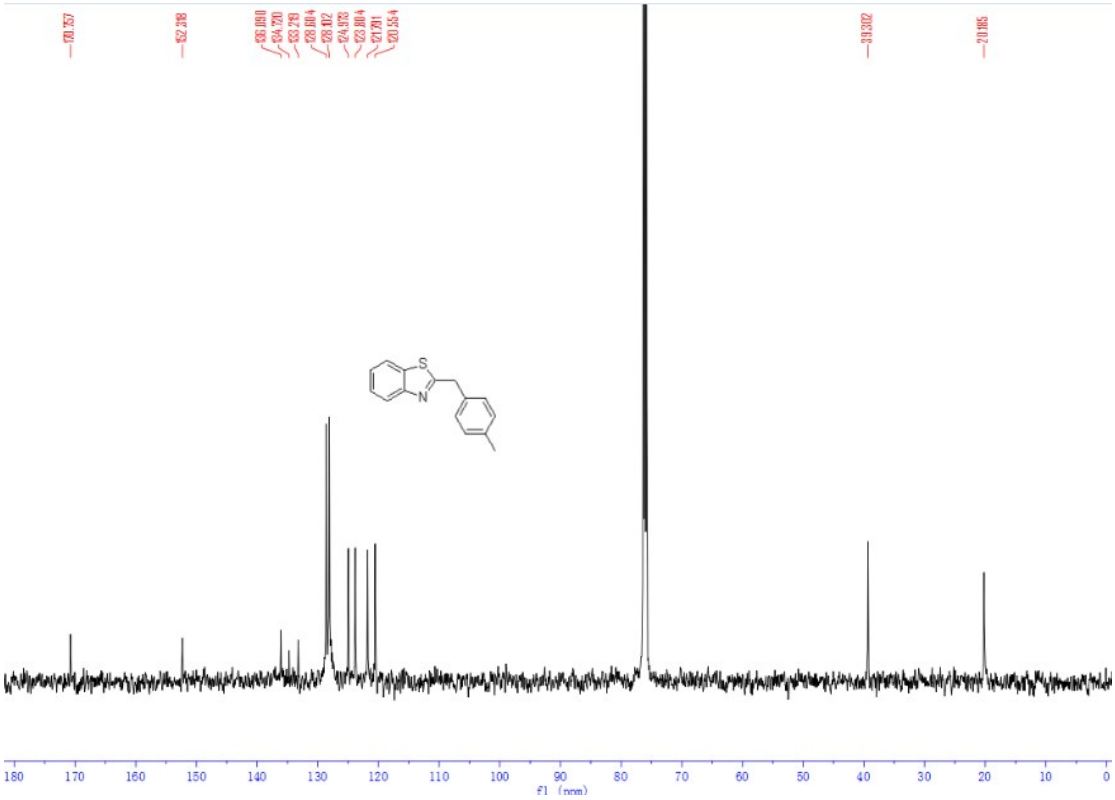
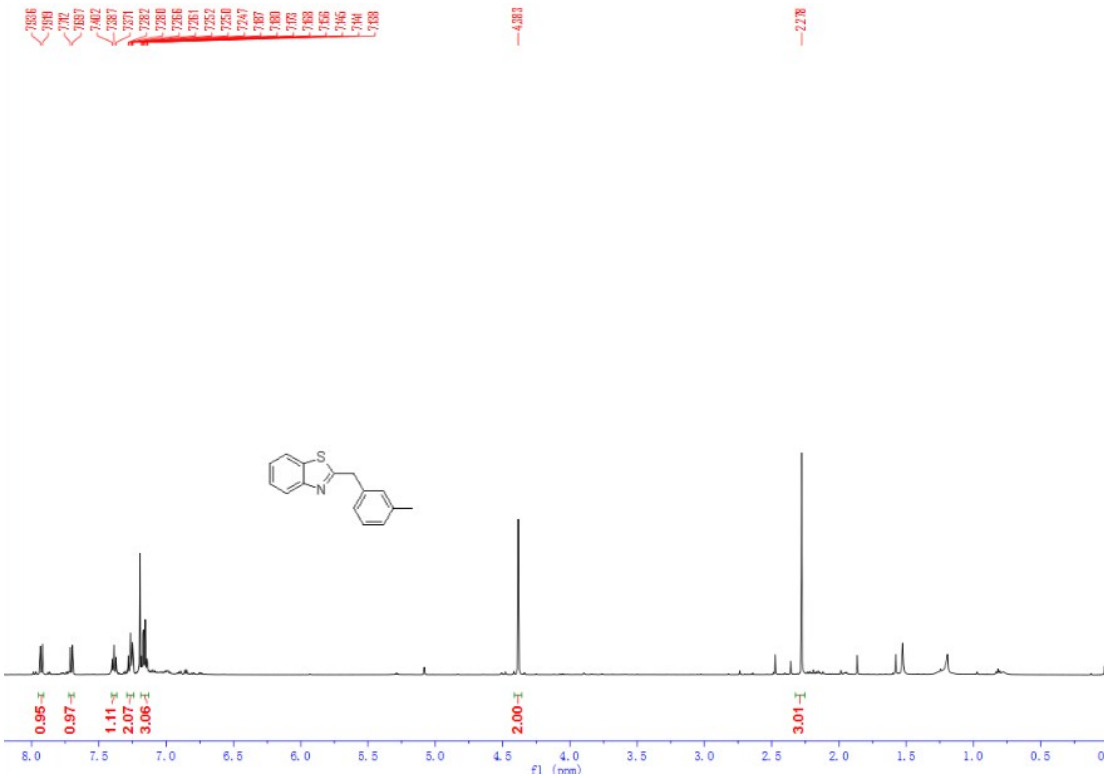
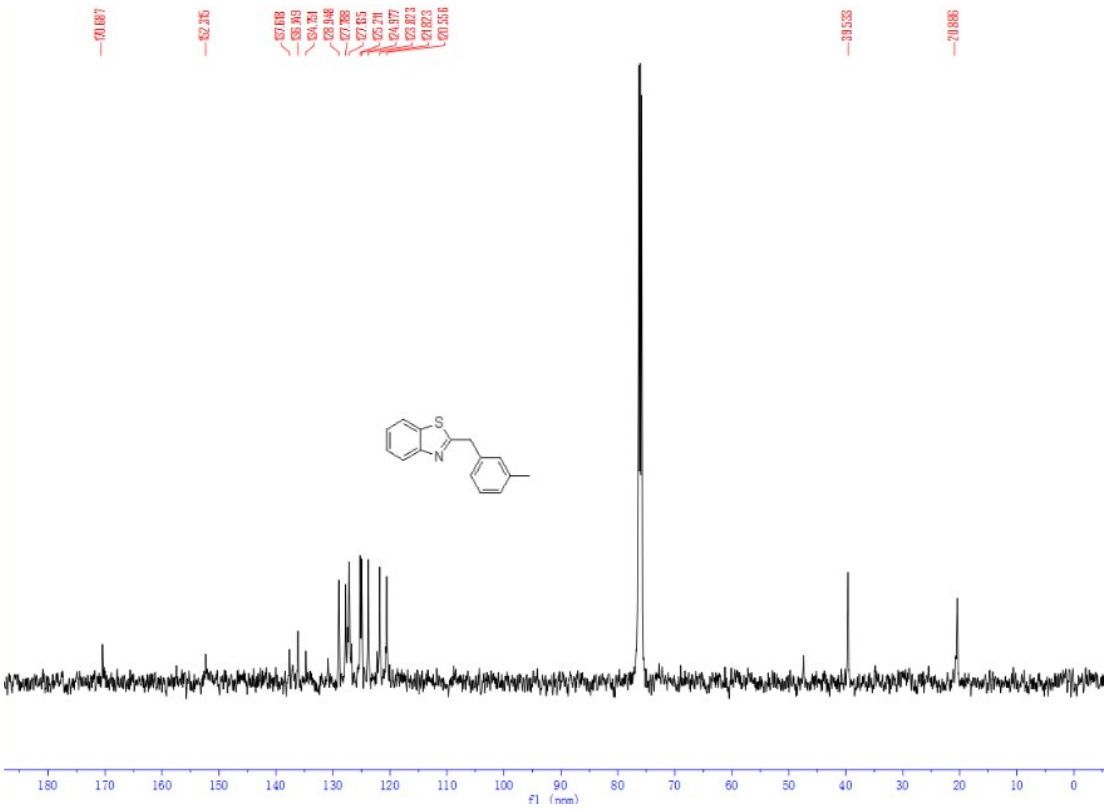
0.98
0.90
0.92
2.09
2.00
1.00
2.00
f1 (ppm)

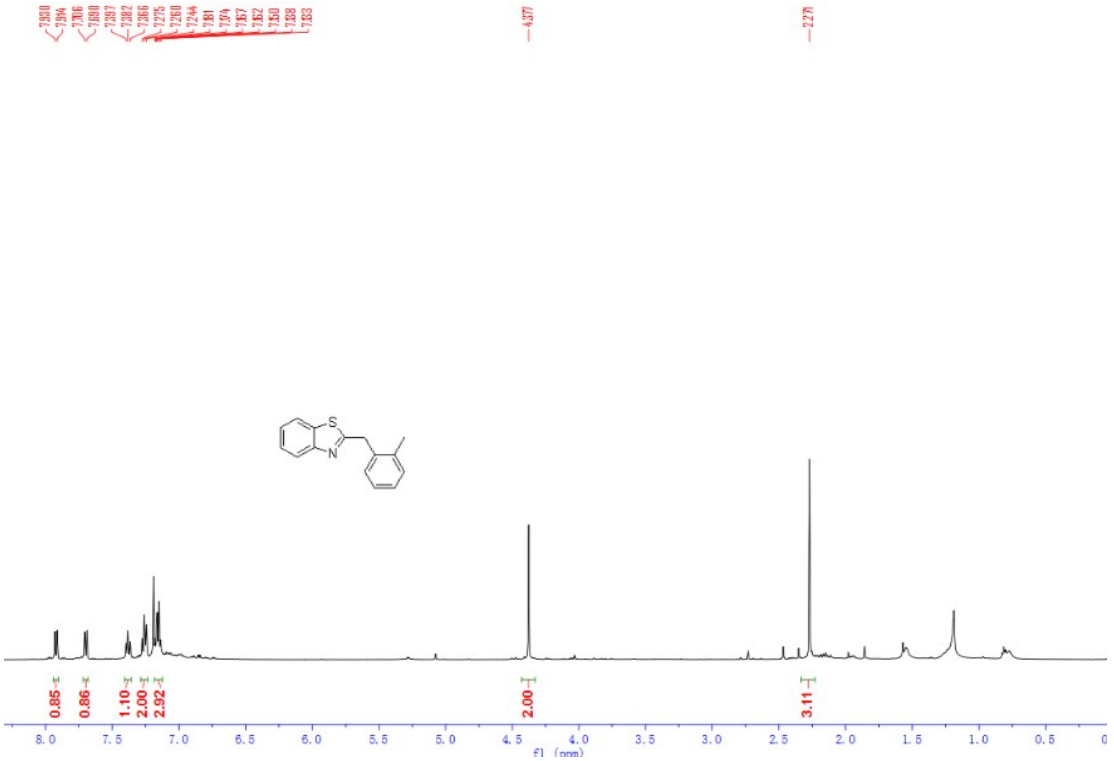

68.77
62.25
39.76
f1 (ppm)


0.91
0.95
1.08
1.13
2.21
2.05
2.00
3.19
f1 (ppm)


f1 (ppm)


7.8536
7.8510
7.7372
7.7037
7.6402
7.2387
7.2371
7.2362
7.2280
7.2266
7.2261
7.2252
7.2238
7.2247
7.2187
7.2180
7.2170
7.2158
7.2155
7.2145
7.2144
7.2138
4.5383
2.2278
0.95
0.97
1.11
2.07
3.06
2.00
3.01
f1 (ppm)


170.1867
152.2175
137.6118
136.1419
134.7251
128.9348
127.7288
127.1615
125.2711
124.1977
123.1873
121.6223
120.5516
39.5533
21.0886
f1 (ppm)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0.86
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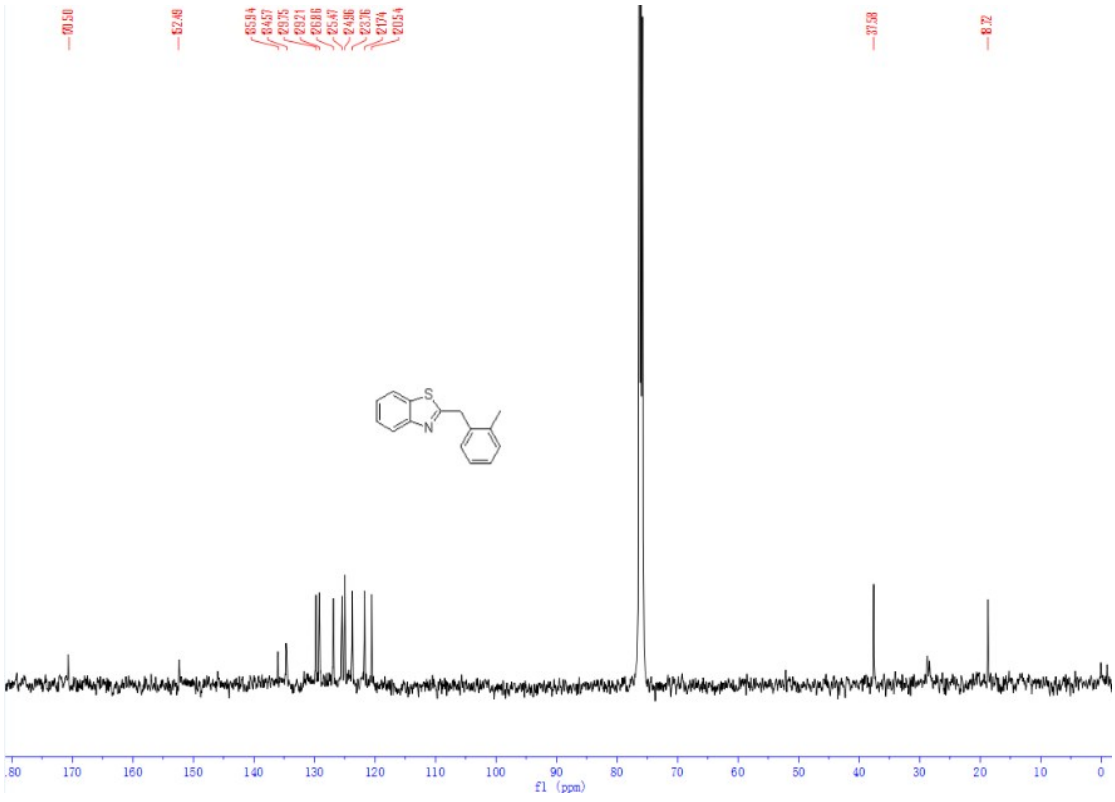
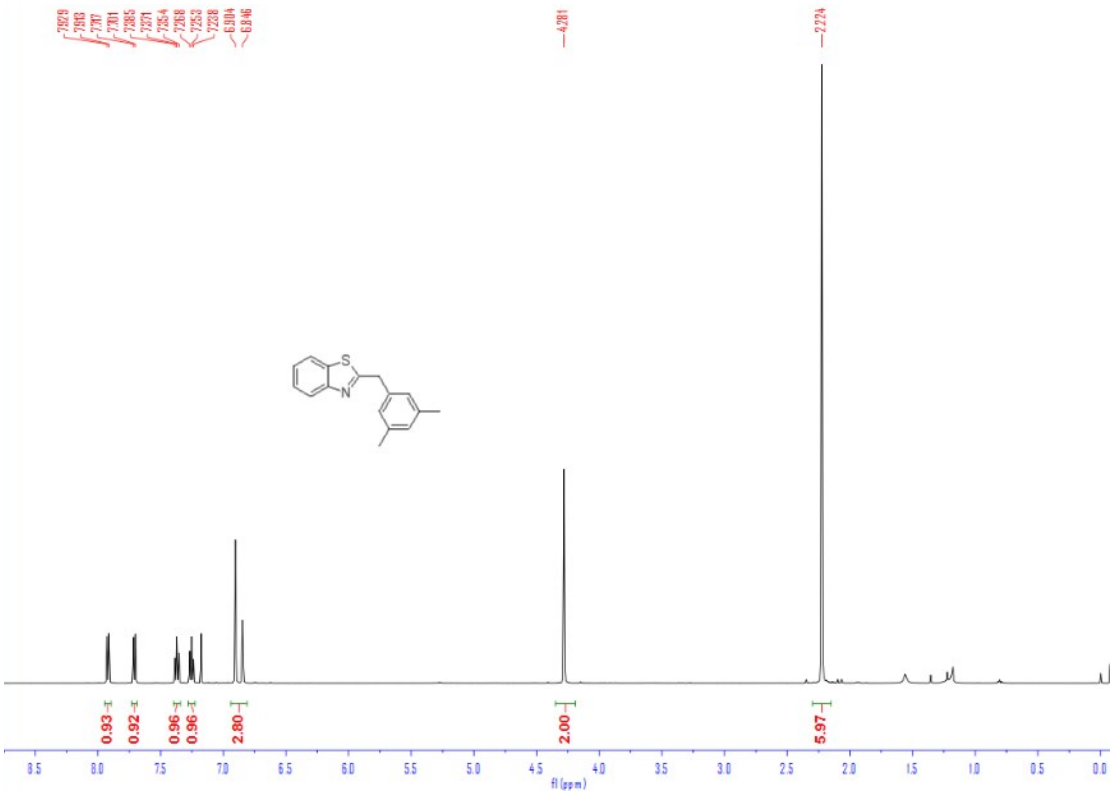
2.00
2.92
2.00
3.11
f1 (ppm)


f1 (ppm)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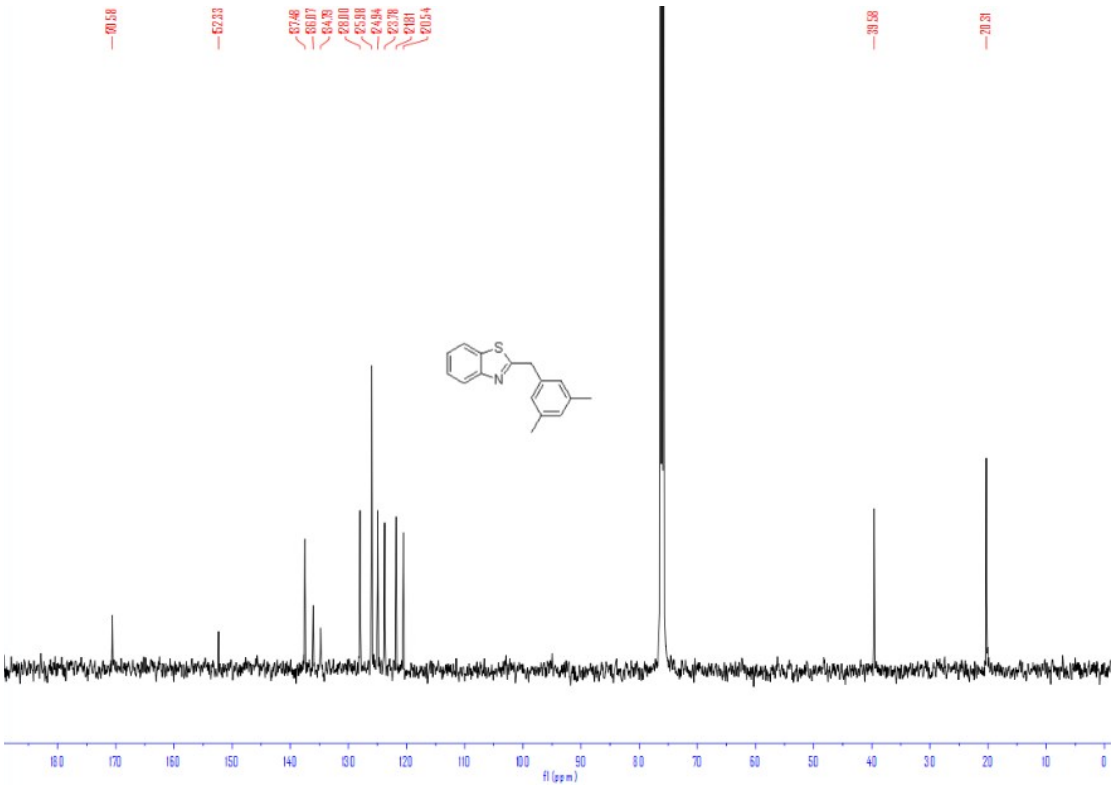
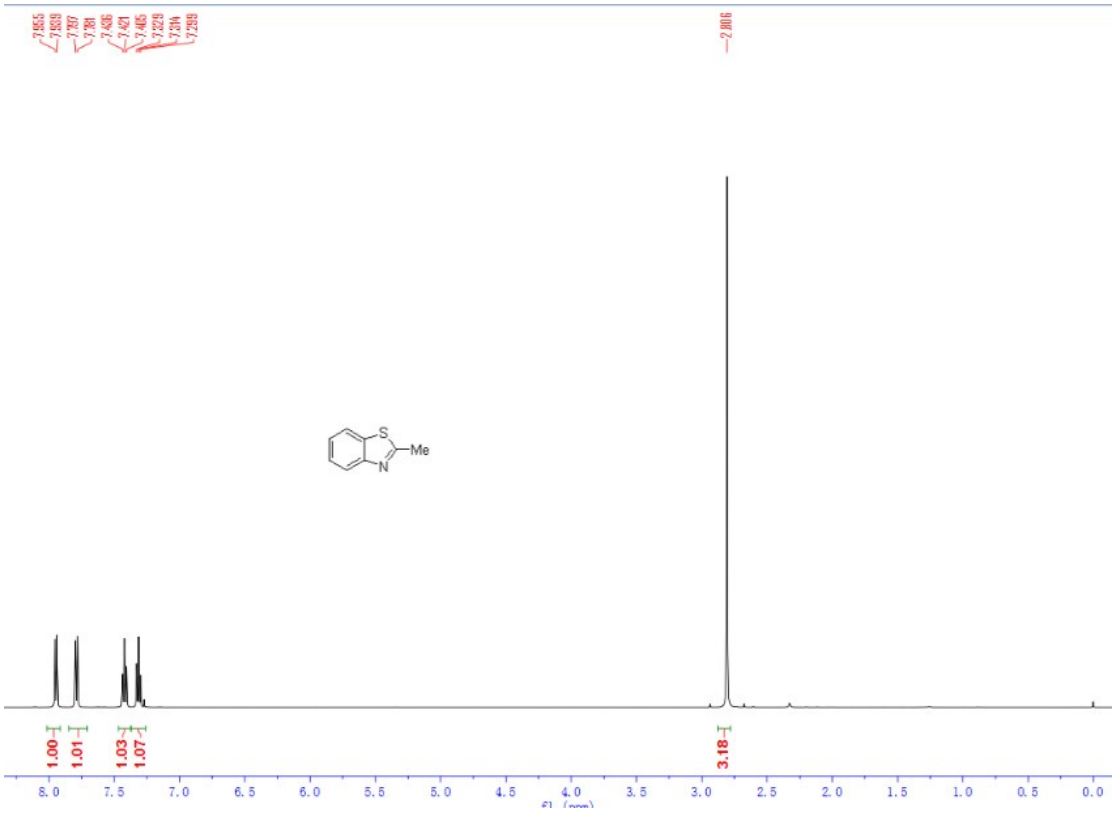
7.7797
7.7301
7.7265
7.7071
7.7054
7.7018
7.7003
7.6728
6.9304
6.8946
4.2261
2.2274
0.93
0.92
0.96
0.96
2.80
2.00
5.97
f1 (ppm)


170.58
152.33
137.48
136.87
134.38
129.80
125.98
124.94
123.78
121.81
120.54
39.58
20.31
f1 (ppm)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7.8659
7.7837
7.7681
7.7486
7.7421
7.7405
7.7329
7.7314
7.7259
2.8016
Me
1.00
1.01
1.03
1.07
3.18
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
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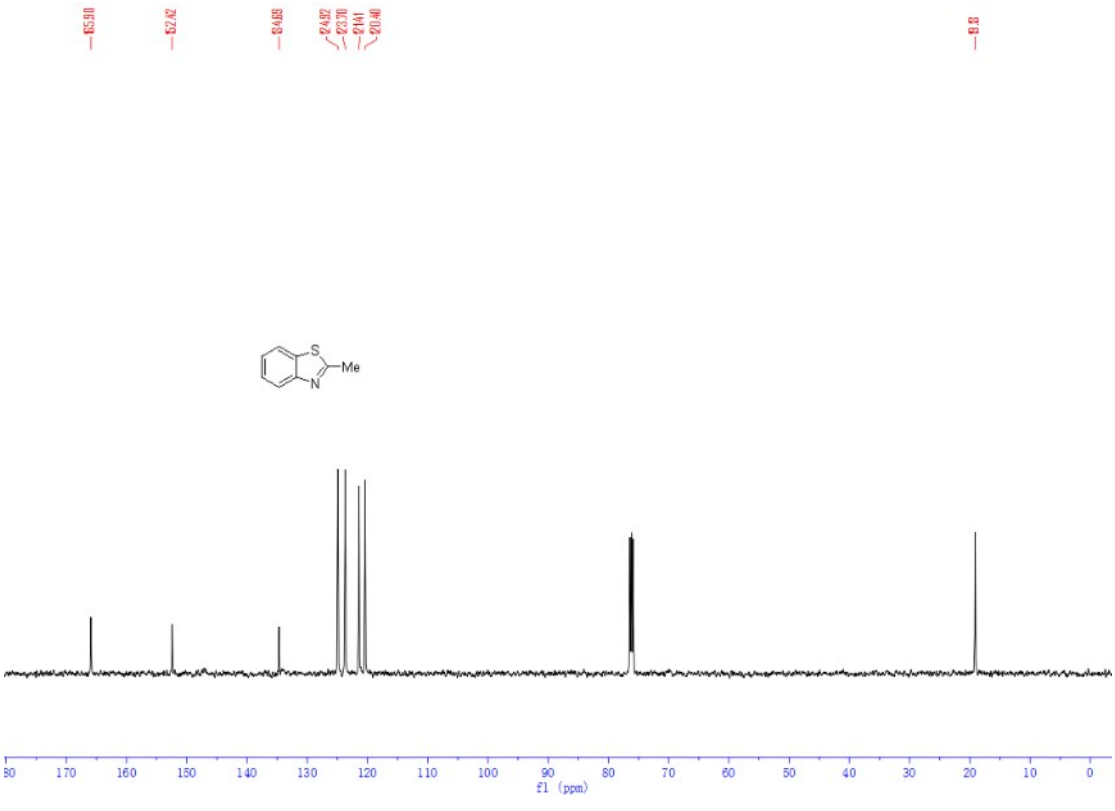
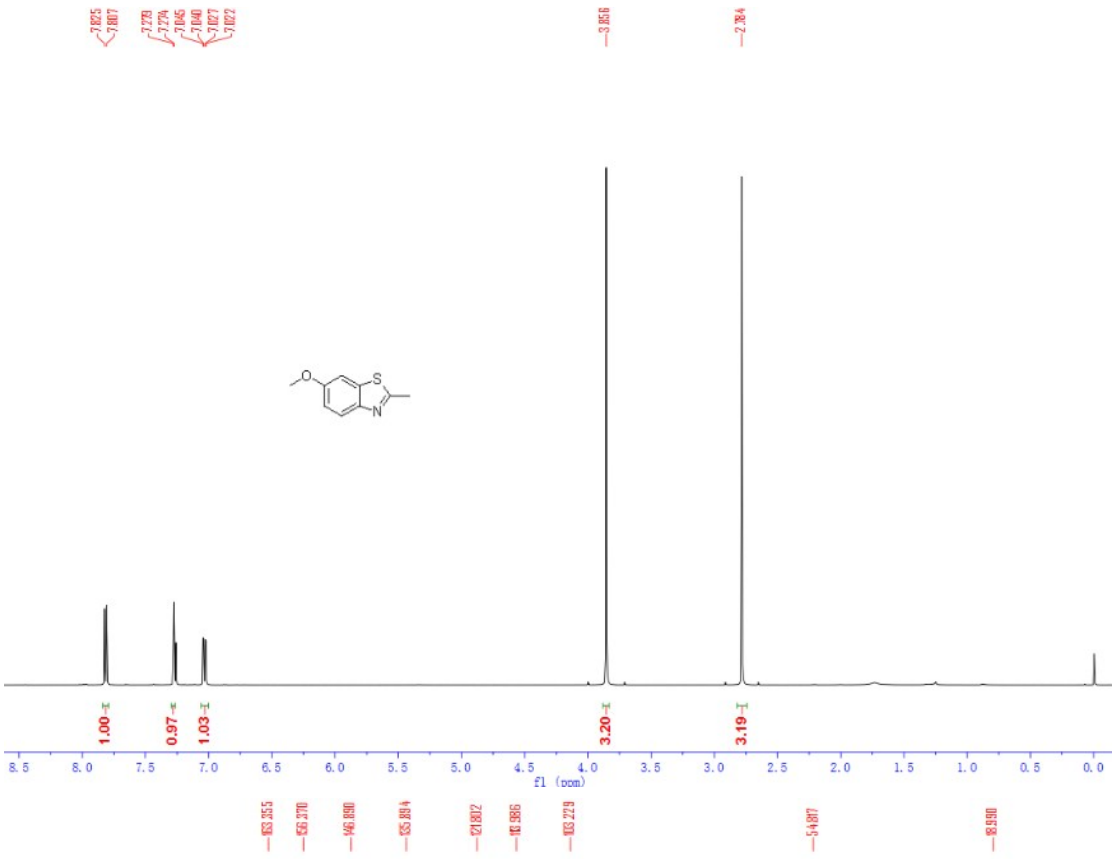
0.0


165.90
152.82
134.68
124.92
123.70
121.41
120.40
19.83
Me
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)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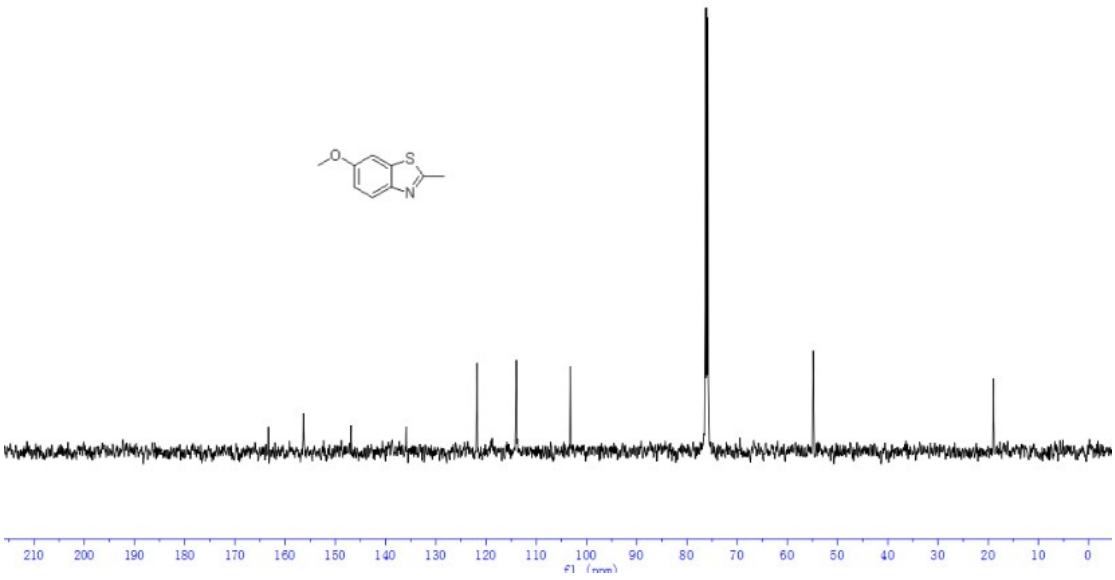
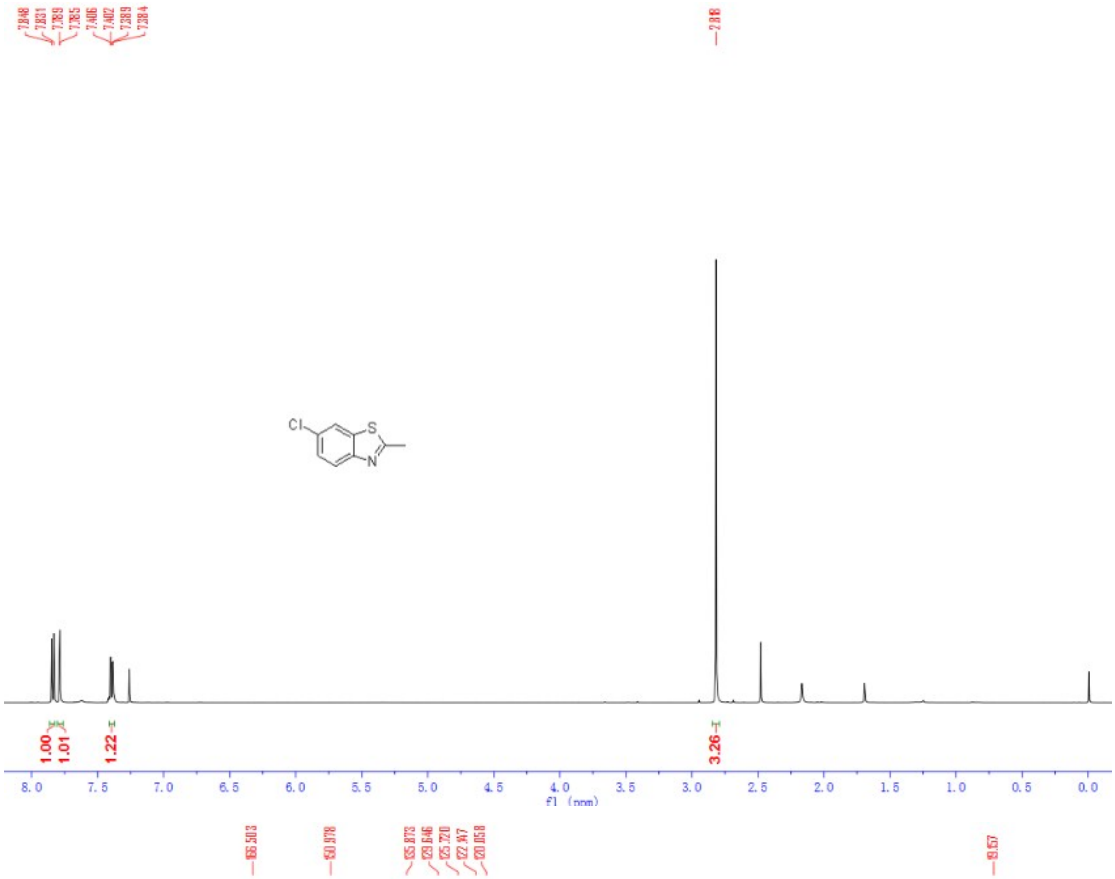
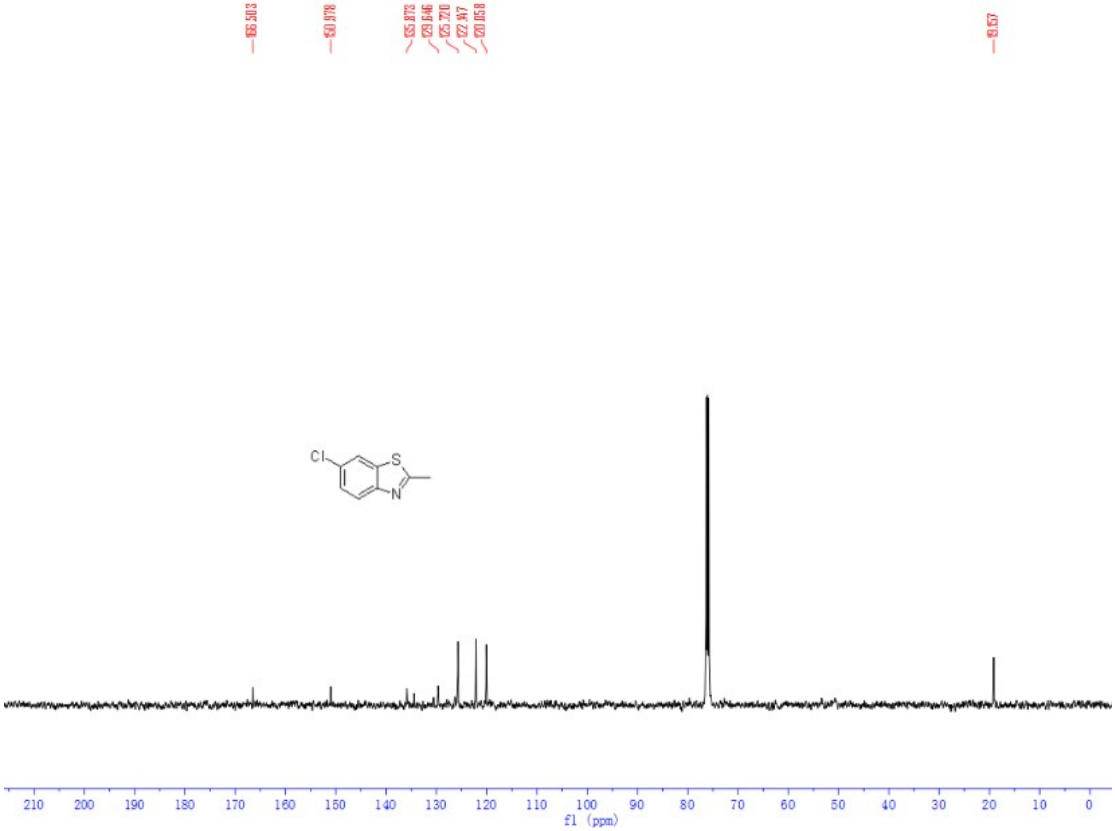
7.8007
7.2793
7.2774
7.1045
7.1040
7.1027
7.1022
3.8558
2.7864
1.00
0.97
1.03
3.20
3.19
f1 (ppm)


f1 (ppm)


7.8048
7.8031
7.3858
7.3855
7.3685
7.3682
7.3389
7.3384
2.916
Cl
S
N
1.00
1.01
1.22
3.26
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)


166.503
150.978
135.873
129.646
125.720
122.917
120.058
19.557
Cl
S
N
210
200
190
180
170
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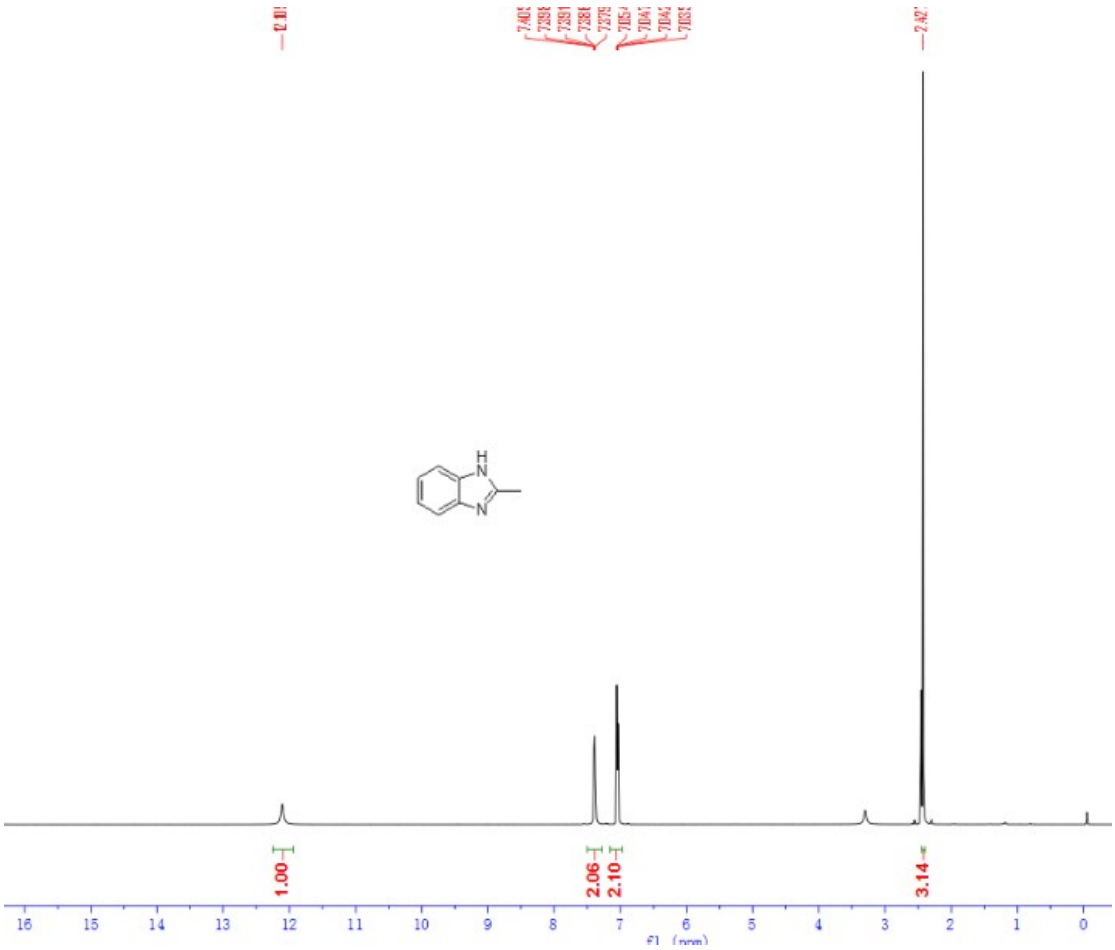
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)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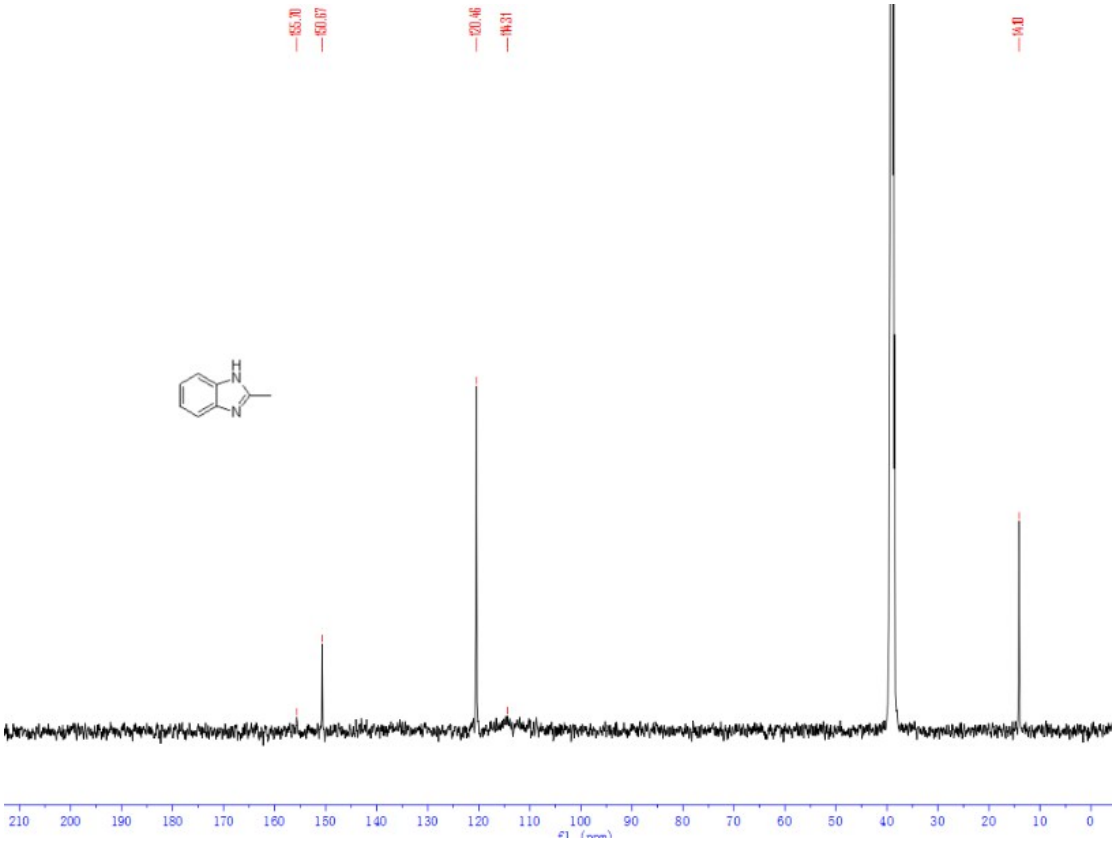
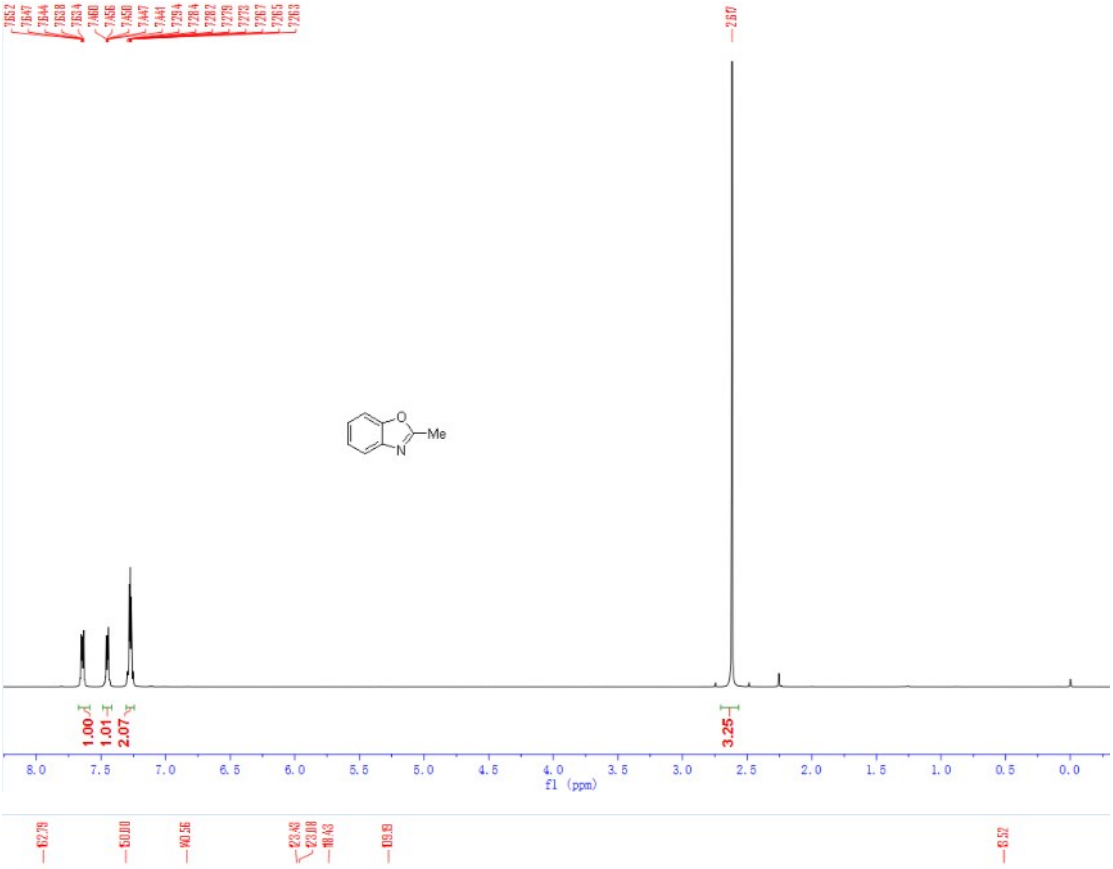
2.06
2.10
3.14

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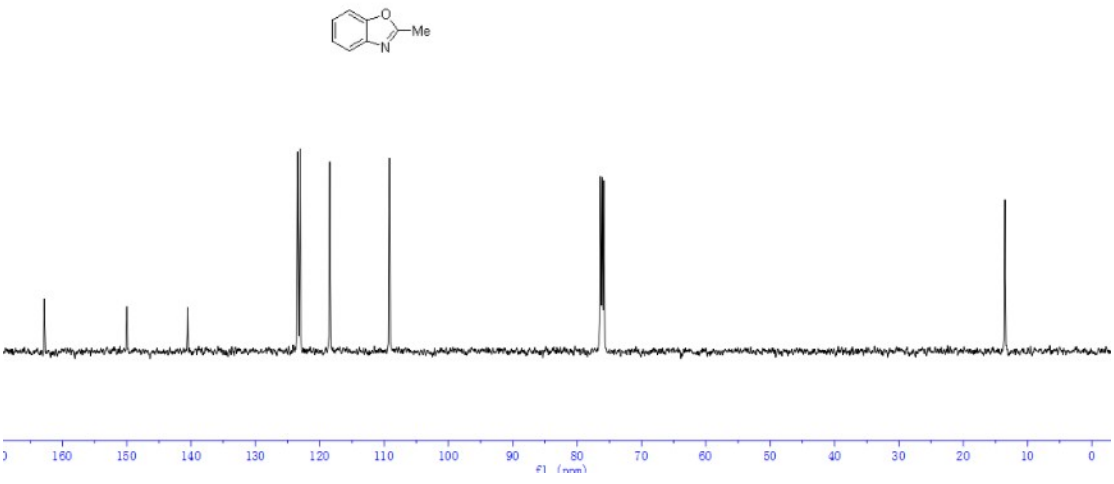
7265
7263
2.617
O
Me
N
1.00
1.01
2.07
3.25
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

162.79
150.00
140.56
128.48
123.08
118.43
109.83
13.52


O
Me
N
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0