Azidation of β-Keto Esters and Silyl Enol Ethers with a Benziodoxole Reagent
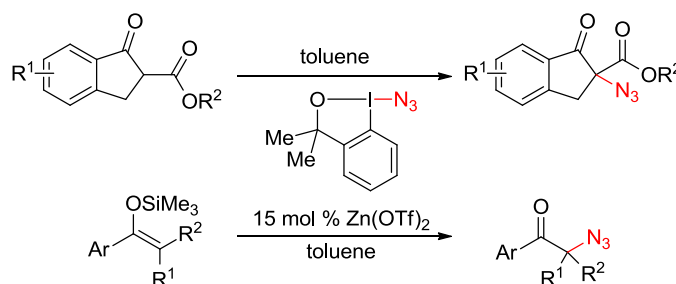
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ABSTRACT

The efficient azidation of β-keto esters and silyl enol ethers using a benziodoxole-derived azide transfer reagent is reported. The azidation of cyclic β-keto esters could be achieved in up to quantitative yields in the absence of any catalyst. In the case of less reactive linear β-keto esters and silyl enol ethers, complete conversion and good yields could be obtained by using a zinc catalyst.

Azides are extremely useful functional groups in synthetic chemistry.[1] They are easily reduced to amines, but are themselves non-basic. They consequently constitute ideal amine precursors in multi-step synthesis. Furthermore, cycloaddition of azides with alkynes, especially catalyzed by copper, has become the most impressive example of "Click" chemistry, as it is completely orthogonal to other functionalities and can run under mild conditions without the need to exclude oxygen or moisture. This reaction is now one of the most often used functionalization methods for biomolecules and polymers.[2] In this context, new methods to introduce azides, especially in complex molecules, are urgently needed.

Most approaches to access azides are based on the use of nucleophilic sodium azide. In contrast, the introduction of azides onto nucleophiles is much less developed. Such reactions would be especially useful to access α-azido carbonyl compounds, which are important building

(1) (a) Bräse, S.; Gil, C.; Knepper, K.; Zimmermann, V *Angew. Chem., Int. Ed.* **2005**, *44*, 5188. (b) *Organic Azides: Syntheses and Applications*. Bräse, S.; Banert, K. ed.; Wiley: 2009.

(2) (a) Rostovtsev, V. V.; Green, L. G.; Fokin, V. V.; Sharpless, K. B. *Angew. Chem., Int. Ed.* **2002**, *41*, 2596. (b) Tornoe, C. W.; Christensen, C.; Meldal, M. *J. Org. Chem.* **2002**, *67*, 3057. Reviews: (c) Kolb, H. C.; Sharpless, K. B. *Drug Discovery Today* **2003**, *8*, 1128. (d) Lutz, J.-F. *Angew. Chem., Int. Ed.* **2007**, *46*, 1018. (e) Moses, J. E.; Moorhouse, A. D. *Chem. Soc. Rev.* **2007**, *36*, 1249. (f) Meldal, M.; Tornoe, C. W. *Chem. Rev.* **2008**, *108*, 2952. (g) Amblard, F.; Cho, J. H.; Schinazi, R. F. *Chem. Rev.* **2009**, *109*, 4207. (h) Iha, R. K.; Wooley, K. L.; Nystrom, A. M.; Burke, D. J.; Kade, M. J.; Hawker, C. J. *Chem. Rev.* **2009**, *109*, 5620.

blocks in synthetic chemistry as precursors of amino acid derivatives.[3] Sulfonyl azides have been most often used as electrophilic azide sources, but they work best for strongly nucleophilic lithium enolates.[4] For the stabilized enolates derived from dicarbonyl compounds, a mixture of products resulting from competing diazo transfer and subsequent rearrangements has been observed.[5] Another successful approach is based on the in situ *Umpolung* of either the azide or the enolate using a strong oxidant. These reactions often involve the formation of iodoazide or hypervalent iodine reagents, and have been usually proposed to proceed via a radical pathway.[6] In the case of the azidation of dicarbonyl compounds, the most general protocol has been reported in 2012 by Kirsch and co-workers based on the combination of sodium azide and IBX.[6n] In most oxidative methods, the actual azidation reagent is either unknown, or so unstable that it cannot be isolated. This makes the development of catalytic or asymmetric methods very difficult. In fact, until 2013, no catalytic asymmetric α-azidation of carbonyl compounds had been reported, and the only method to access enantiopure products was based on a chiral auxiliary approach.[4]

To solve this challenge, we decided to make use of the exceptional stability of benziodoxol(on)e-based hypervalent iodine reagents.[7] Our group has recently demonstrated the exceptional properties of this class of reagents for acetylene transfer onto dicarbonyl compounds,[8] and we wondered if similar azido reagents would be equally successful. In fact, Zhdankin and co-workers have described the synthesis of azido benziodoxol(on)e compounds, which were surprisingly stable.[9] The reactivity of these reagents was studied for the radical-based azidation of aliphatic C-H bonds.[9,10] During completion of our work, Gade and co-workers reported the first catalytic asymmetric method for the azidation of β-keto esters and oxindoles using a chiral iron catalyst together with an azidobenziodoxole reagent.[11] This major breakthrough motivate us to report our own preliminary results in the area, including the very efficient azidation of cyclic β-keto esters with azidobenziodoxole **2** in the absence of any catalyst and the zinc-catalyzed azidation of less reactive linear keto esters and silyl enol ethers using the same reagent (Scheme 1). Our results demonstrated that the potential of azidobenziodoxole reagents as electrophilic azidation reagents is not limited to cyclic β-keto esters.

Scheme 1. Azidation of Keto Esters and Silyl Enol Ethers
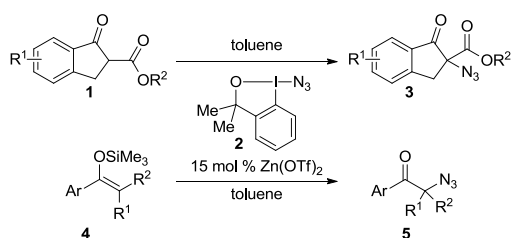
We started our studies with the investigation of the azidation of keto ester **1a** with benzidoxol(on)e reagents **2** and **6**. Whereas no reaction was observed with benziodoxolone **6**, a complete conversion to azide **3a** was observed with benziodoxole **2** in different solvents, with the best yield (82% by ^{1}H NMR) obtained in toluene.[12] The better result obtained with benziodoxole **2** is probably due to the higher basicity of the alcoholate generated after azide transfer.

Scheme 2. Azidation of Keto Ester **1a**.
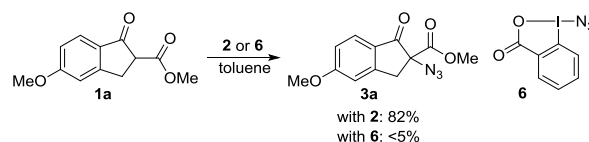
With this extremely simple protocol for the azidation of keto esters in hand, we shortly investigated the scope of the reaction (Table 1). On a 0.40 mmol scale, azide **3a** could be isolated in 94% yield (entry 1). The azidation

(3) Patonay, T.; Konya, K.; Juhasz-Toth, E. *Chem. Soc. Rev.* **2011**, *40*, 2797.

(4) Evans, D. A.; Britton, T. C. *J. Am. Chem. Soc.* **1987**, *109*, 6881.

(5) (a) Benati, L.; Calestani, G.; Nanni, D.; Spagnolo, P. *J. Org. Chem.* **1998**, *63*, 4679. (b) Benati, L.; Nanni, D.; Spagnolo, P. *J. Org. Chem.* **1999**, *64*, 5132.

(6) (a) Fowler, F. W.; Hassner, A.; Levy, L. A. *J. Am. Chem. Soc.* **1967**, *89*, 2077. (b) Moriarty, R. M.; Vaid, R. K.; Ravikumar, V. T.; Vaid, B. K.; Hopkins, T. E. *Tetrahedron* **1988**, *44*, 1603. (c) Magnus, P.; Barth, L. *Tetrahedron Lett.* **1992**, *33*, 2777. (d) Magnus, P.; Lacour, J *J. Am. Chem. Soc.* **1992**, *114*, 767. (e) Magnus, P.; Hulme, C.; Weber, W. *J. Am. Chem. Soc.* **1994**, *116*, 4501. (f) Magnus, P.; Barth, L. *Tetrahedron* **1995**, *51*, 11075. (g) Magnus, P.; Lacour, J.; Evans, P. A.; Roe, M. B.; Hulme, C. *J. Am. Chem. Soc.* **1996**, *118*, 3406. (h) Magnus, P.; Lacour, J.; Evans, P. A.; Rigollier, P.; Tobler, H. *J. Am. Chem. Soc.* **1998**, *120*, 12486. (i) Tohma, H.; Egi, M.; Ohtsubo, M.; Watanabe, H.; Takizawa, S.; Kita, Y. *Chem. Commun.* **1998**, 173. (j) Lee, J. C.; Kim, S.; Shin, W. C. *Synth. Commun.* **2000**, *30*, 4271. (k) Pedersen, C. M.; Marinescu, L. G.; Bols, M. *Org. Biomol. Chem.* **2005**, *3*, 816. (l) Kumar, D.; Sundaree, S.; Rao, V. S. *Synth. Commun.* **2006**, *36*, 1893. (m) Telvekar, V. N.; Patile, H. V. *Synth. Commun.* **2011**, *41*, 131. (n) Harschneck, T.; Hummel, S.; Kirsch, S. F.; Klahn, P. *Chem. Eur. J.* **2012**, *18*, 1187.

(7) (a) Zhdankin, V. V. *Curr. Org. Synth.* **2005**, *2*, 121. (b) Brand, J. P.; Fernandez Gonzalez, D.; Nicolai, S.; Waser, J. *Chem. Commun.* **2011**, *47*, 102.

(8) Fernandez Gonzalez, D.; Brand, J. P.; Waser, J. *Chem. Eur. J.* **2010**, *16*, 9457.

(9) (a) Zhdankin, V. V.; Kuehl, C. J.; Krasutsky, A. P.; Formaneck, M. S.; Bolz, J. T. *Tetrahedron Lett.* **1994**, *35*, 9677. (b) Krasutsky, A. P.; Kuehl, C. J.; Zhdankin, V. V. *Synlett* **1995**, 1081. (c) Zhdankin, V. V.; Krasutsky, A. P.; Kuehl, C. J.; Simonsen, A. J.; Woodward, J. K.; Mismash, B.; Bolz, J. T. *J. Am. Chem. Soc.* **1996**, *118*, 5192.

(10) In their first communication,[9a] Zhdankin and co-workers indicated that these reagents may also react with nucleophiles derived from carbonyls, but the result of such reactions was never reported.

(11) Deng, Q. H.; Bleith, T.; Wadepohl, H.; Gade, L. H. *J. Am. Chem. Soc.* **2013**, *135*, 5356.

(12) Yield obtained in other solvents: CH₂Cl₂: 79%, CH₃CN: 75%, Et₂O: 69%, THF: 63%, ⁱPrOH: 49%. See Supporting Information for further detail.

proceeded in good yields independent of the electronic properties of the substituent on the benzene ring of indanone (entries 2-4). More sterically hindered esters gave quantitative yields of azide (entries 5 and 6). Azidation of keto amide **1g** was also possible in 67% yield (entry 7).[13] Nevertheless, the reaction did not work for less reactive substrates, and no conversion was observed for both acyclic keto ester **1h** (entry 8) or silyl enol ether **4a** (entry 9).

Table 1. Azidation of cyclic β–keto esters with benziodoxole **2**.

entry	β-keto ester	product	yield(%)[a]
1	**1a**	**3a**	94
2	**1b**	**3b** 3b	79
3	**1c**	**3c**	quant.
4	**1d**	**3d**	92
5	**1e**	**3e**	quant.
6	**1f**	**3f**	98
7	**1g**	**3g**	67
8	**1h**	**3h**	<5
9	**4a**	**5a**	<5

[a]Isolated yields with keto ester **1** or enol ether **4a** (0.40 mmol), benziodoxole **2** (0.52 mmol), toluene (0.4 mL), 1-3 h at rt.

The low reactivity of **2** with silyl enol ethers is contrasting with the fast reaction reported for in situ generated non cyclic reagents.[6c-h] We wondered if the reactivity of the reagent could be further enhanced in the presence of a Lewis acid. In fact, several Lewis acids were able to catalyze the reaction of silyl enol ether **4a**

(13) In the case of a tetralone-derived keto-ester, only a low yield (10%) of azidation was obtained, due to the formation of an aromatic product. A simple cyclopentanone could also be azidated in moderate yield (54%). See Supporting Information for further details.

with benziodoxole **2** in toluene (Table 2). Moderate yields were obtained with Sc(OTf)$_3$, Cu(OTf)$_2$ and In(OTf)$_3$ as catalysts (entries 1-3). The best results were obtained when using Sn(OTf)$_2$, Hf(OTf)$_4$•4H$_2$O or Zn(OTf)$_2$, which gave nearly identical yields (67-71%, entries 4-6).When considering that zinc is cheap and non-toxic, we decided to continue with this metal as catalyst. Other zinc salts gave inferior results (entries 7-9). Triflic acid was also able to catalyze the reaction, but in only 28% yield (entry 10). Lower yields were also obtained in solvent different from toluene (entries 11-15). Finally, more sterically hindered silyl enol ethers **4b** and **4c** led to inferior results when compared to trimethylsilyl enol ether **4a** (entries 16 and 17). We consequently decided to examine the scope of the reaction with trimethysilyl enol ethers and zinc triflate as catalyst (Table 3, entries 1-9).

Table 2. Optimization of the azidation of silyl enol ethers.

entry	R	catalyst	solvent	yield(%)[a]
1	Me (**4a**)	Sc(OTf)$_3$	toluene	23
2	Me (**4a**)	Cu(OTf)$_2$	toluene	36
3	Me (**4a**)	In(OTf)$_3$	toluene	58
4	Me (**4a**)	Sn(OTf)$_2$	toluene	68
5	Me (**4a**))	Hf(OTf)$_4$•4H$_2$O	toluene	71
6	Me (**4a**)	Zn(OTf)$_2$	toluene	67
7	Me (**4a**)	Zn(NTf$_2$)$_2$	toluene	41
8	Me (**4a**)	Zn(OAc)$_2$	toluene	22
9	Me (**4a**)	Zn(BF$_4$)$_2$	toluene	47
10	Me (**4a**)	HOTf	toluene	28
11	Me (**4a**))	Zn(OTf)$_2$	CH$_3$CN	53
12	Me (**4a**)	Zn(OTf)$_2$	Et$_2$O	52
13	Me (**4a**)	Zn(OTf)$_2$	CH$_2$Cl$_2$	30
14	Me (**4a**))	Zn(OTf)$_2$	THF	26
15	Me (**4a**))	Zn(OTf)$_2$	^{i}PrOH	0
16	Et (**4b**)	Zn(OTf)$_2$	toluene	44
17	^{i}Pr (**4c**))	Zn(OTf)$_2$	toluene	23

[a] **4** (0.1 mmol), **2** (0.13 mmol), catalyst (15 mol %), solvent (2 mL); Yield obtained by ^{1}H NMR using 1,3,5-trimethoxybenzene as standard.
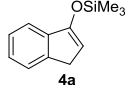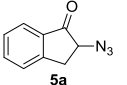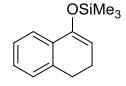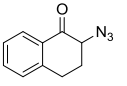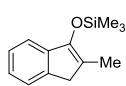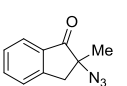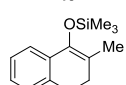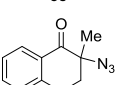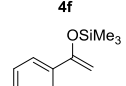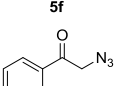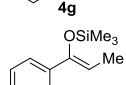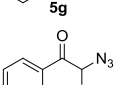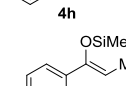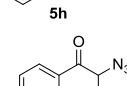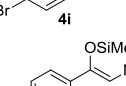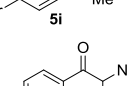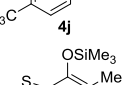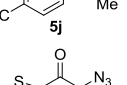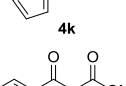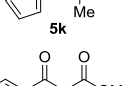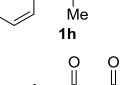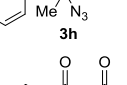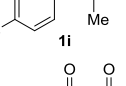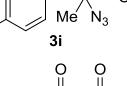
On a 0.40 mmol scale, the azidation worked for silyl enol ethers derived from indanone and tetralone (Table 3, entries 1 and 2). Complete conversion was achieved in a few hours. The reaction could also be applied to the synthesis of tertiary azides (entries 3 and 4). The silyl enol ethers of acetophenone derivatives also worked in the reaction (entries 5-8), giving access to both primary and secondary azides. The azidation also proceeded well in presence of a thiophene heterocycle (entry 9).
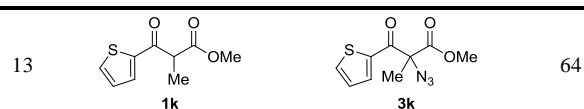
At this point, we wondered if the zinc-catalyzed conditions could also be used to extend the scope of azidation for keto ester substrates. Indeed, acyclic keto ester **1h**, which did not react in the presence of azidobenziodoxole **2** only, could be now azidated in 73% yield (Table 3, entry 10). The reaction was also successful for keto esters bearing a more functionalized benzene ring (entries 11 and 12) or a thiophene heterocycle (entry 13).

Cyclic keto esters are a privileged class of substrates for the development of asymmetric reactions, as two-points binding of a chiral catalyst can lead to good enantioselectivity. However, the high background rate observed with reagent **2** for cyclic keto esters constituted an important challenge for asymmetric induction. Nevertheless, an interesting preliminary result was obtained using a copper catalyst and bisoxazoline **7** as chiral ligand for the azidation of keto ester **1e** with 49% *ee* (Scheme 3). The results of Gade and co-workers obtained simultaneously to our own investigations demonstrated the higher efficiency of a tridentate bisoxazoline ligand with iron as catalyst.[11]

Table 3. Scope of the zinc-catalyzed azidation.

entry	indole	product	yield(%)[a]
1	**4a**	**5a**	58
2	**4d**	**5d**	58
3	**4e**	**5e**	62
4	**4f**	**5f**	55
5	**4g**	**5g**	73
6	**4h**	**5h**	72
7	**4i**	**5i**	82
8	**4j**	**5j**	75
9	**4k**	**5k**	81
10	**1h**	**3h**	73
11	**1i**	**3i**	58
12	**1j**	**3j**	55
13	**1k**	**3k**	64

[a]Isolated yields with keto ester **1** or enol ether **4** (0.40 mmol), benziodoxole **2** (0.52 mmol), Zn(OTf)$_2$ (0.060-0.12 mmol), toluene (0.8 mL), 12 h at rt.

Scheme 3. Enantioselective Azidation of Keto-Ester **1e**.
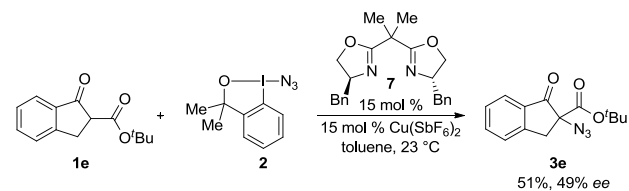
Several mechanisms can be envisaged for the azidation reaction. A first possibility is nucleophilic attack of either the oxygen or the carbon atom of the enolate on the iodine atom of benziodoxole **2**, followed by C-N bond formation. A second alternative would involve a radical chain reaction, as has been proposed by Magnus and co-workers.[6c-h] However, several observations make the latter less probable: in contrast to what was reported by Magnus and co-workers, no reaction was observed in the absence of catalyst. Furthermore, diazidation products resulting from radical pathways were not obtained, and the reaction did not require the presence of a bulky triisopropylsilyl group on the oxygen. Finally, the addition of TEMPO to the reaction mixture had no influence on the reaction outcome, neither with keto esters nor with silyl enol ethers. These results are consequently more in accordance with an electrophilic azidation, as has been proposed recently by Muniz and co-workers for the transfer of NTs group using an hypervalent iodine reagent.[14] The role of the zinc catalyst is also intriguing, as it may act either through nucleophilic activation by formation of a zinc enolate, or by electrophilic activation of benziodoxole **2**. Further investigations will be required to gain a better understanding of the reaction mechanism.

In conclusion, we have described that the azidation of cyclic keto esters with benziodoxole reagent **2** proceeded in excellent yield in the absence of any catalyst. For less reactive acyclic keto esters and silyl enol ethers, an efficient zinc-catalyzed method could be developed, which gave access to primary, secondary and tertiary azides. Further extension of the scope of the reaction and development of asymmetric protocols not limited to

(14) Souto, J. A.; Martinez, C.; Velilla, I.; Muniz, K. *Angew. Chem., Int. Ed.* **2013**, *52*, 1324.

cyclic keto esters are currently under investigation and the results will be reported in due course.

Supporting Information

111 pages

Azidation of β-Keto Esters and Silyl Enol Ethers with a Benziodoxole Reagent.

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1. General Methods

All reactions were carried out in oven dried glassware under an atmosphere of nitrogen, unless stated otherwise. For quantitative flash chromatography technical grade solvents were used. For flash chromatography for analysis, HPLC grade solvents from Sigma-Aldrich were used. THF, Et_2O, CH_3CN, toluene, hexane and CH_2Cl_2 were dried by passage over activated alumina under nitrogen atmosphere (H_2O content < 10 ppm, *Karl-Fischer* titration). All chemicals were purchased from Acros, Aldrich, Fluka, VWR, Fluorochem, Aplichem or Merck and used without further purification, unless stated otherwise. Chromatographic purification was performed as flash chromatography using Macherey-Nagel silica 40-63, 60 Å, using the solvents indicated as eluent with 0.1-0.5 bar pressure. TLC was performed on Merck silica gel 60 F_{254} TLC aluminium plates and visualized with UV light and anisaldehyde stain. Melting points were measured on a calibrated Büchi B-540 melting point apparatus using open glass capillaries. ^{1}H-NMR spectra were recorded on a Bruker DPX-400 400 MHz spectrometer in chloroform-d and/or DMSO-d$_6$. All signals are reported in ppm with the internal chloroform signal at 7.26 ppm or the internal DMSO signal at 2.50 ppm as standard. The data is being reported as (s = singlet, d = doublet, t = triplet, q = quadruplet, qi = quintet, m = multiplet or unresolved, br = broad signal, app = apparent, coupling constant(s) in Hz, integration, interpretation).^{13}C-NMR spectra were recorded with ^{1}H-decoupling on a Bruker DPX-400 100 MHz spectrometer in chloroform-d and/or DMSO-d$_6$. All signals are reported in ppm with the internal chloroform signal at 77.0 ppm or the internal DMSO signal at 39.5 ppm as standard. Infrared spectra were recorded on a JASCO FT-IR B4100 spectrophotometer with an ATR PRO410-S and a ZnSe prisma and are reported as cm^{-1} (w = weak, m = medium, s = strong, br = broad). Gas chromatographic and low resolution mass spectrometric measurements were performed on a Perkin-Elmer Clarus 600 gas chromatographer and mass spectrometer using a Perkin-Elmer Elite fused silica column (length: 30 m, diameter: 0.32 mm) and Helium as carrier gas. High resolution mass spectrometric measurements were performed by the mass spectrometry service of ISIC at the EPFL on a MICROMASS (ESI) Q-TOF Ultima API. Compound **7** was purchase from Aldritch.

2. Synthesis of Reagents

2.1 Synthesis of 1-azido-3,3-dimethyl-3-(1H)-1,2-benziodoxole (2)

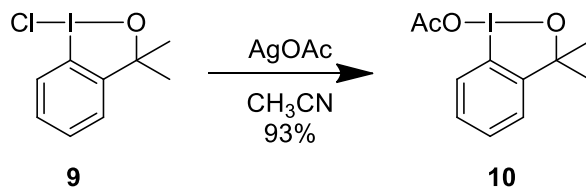**1-Chloro-1,3-dihydro-3,3-dimethyl-1,2-benziodoxole (9)**
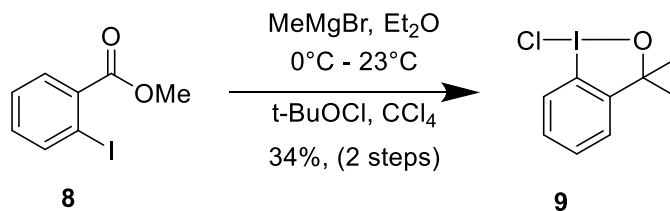
Following a reported procedure[1] methyl 2-iodobenzoate (**8**) (12 mL, 76 mmol) was dissolved under N_2 atmosphere in dry diethyl ether (400 mL) and then the solution was cooled down at 0 °C with an ice bath. Methylmagnesium bromide (56.0 mL, 168 mmol, 2.20 equiv) was added dropwise and the reaction was stirred for 30 min at 0 °C. The reaction mixture was then allowed to warm to room temperature and it was further stirred for 2 h. The reaction was quenched with NH_4Cl in an iced bath. The organic layer was separated and extracted with Et_2O (3 x 100 mL), water (2 x 200 mL), brine (1 x 100 mL) and the combined organic layers were dried over $MgSO_4$. The solvent was removed in vacuum.

With no further purification the crude mixture was dissolved in CCl_4 (7 mL) and *tert*-butyl hypochlorite (10 mL, 92 mmol, 1.2 equiv) and the reaction mixture was stirred at room temperature. After one hour a yellow precipitate was collected by filtration and washed with hexane (60 mL) to afford compound **9** (7.7 g, 26 mmol, 34% yield) as a yellow solid.

¹H NMR (400 MHz, $CDCl_3$) δ 8.03 (dd, 1 H, *J* = 8.1, 1.1 Hz, C*H*Ar), 7.55 (m, 2 H, C*H*Ar), 7.17 (dd, 1 H, *J* = 7.3, 1.7 Hz, C*H*Ar), 1.55 (s, 6 H, (C*H₃)₂*). **¹³C NMR** (101 MHz, $CDCl_3$) δ 149.5, 131.0, 130.5, 128.4, 126.1, 114.7, 85.2, 29.2. **IR** v_{max} 3729 (w), 3626 (w), 2972 (w), 2924 (w), 2362 (w), 2055 (w), 2018 (w), 1742 (w), 1564 (w), 1464 (w), 1439 (w), 1379 (w), 1378 (w), 1366 (w), 1277 (w), 1276 (w), 1256 (w), 1181 (w), 1154 (m), 1112 (w), 1048 (w), 1003 (w), 982 (w), 943 (m), 866 (m), 808 (w), 790 (w), 789 (w), 762 (s), 745 (w), 724 (w), 718 (w). NMR data correspond to the reported values.[1]

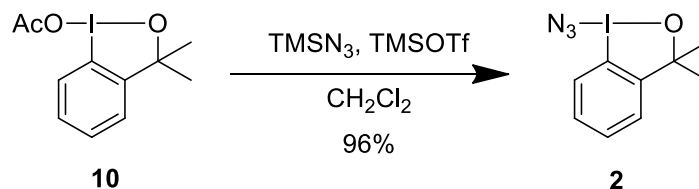**1-Acetoxy-1,3-dihydro-3,3-dimethyl-1,2-benziodoxole (10)**

Following a reported procedure [1] 1-Chloro-1,3-dihydro-3,3-dimethyl-1,2-benziodoxole (**9**) (2.60 g, 8.77 mmol) was dissolved in dry acetonitrile (25 mL) under N_2 atmosphere. The reaction flask was covered with aluminum foils and protected from light. Silver acetate (1.46 g, 8.77 mmol, 1.00 equiv) was then added in one portion. The reaction mixture was stirred in the dark at room temperature for 16 h. Filtration over a Celite plug and evaporation of the solvent yielded compound **10** (2.6 g, 8.8 mmol, 93%) as a light brownish solid.

¹H NMR (400 MHz, $CDCl_3$) δ 7.79 (dd, 1 H, *J* = 8.0, 1.3 Hz, C*H*Ar), 7.47 (m, 2H, C*H*Ar), 7.18 (dd, 1 H, *J* = 7.2, 1.7 Hz, C*H*Ar), 2.11 (s, 3 H, COC*H₃*), 1.52 (s, 6 H, (C*H₃)₂*). **¹³C NMR** (101

MHz, CDCl$_3$) δ 177.4, 149.4, 130.4, 130.0, 129.9, 126.2, 115.7, 84.6, 29.2, 21.5. **IR** ν_{max} 3099 (w), 3057 (w), 2975 (w), 2930 (w), 2930 (w), 2865 (w), 1740 (w), 1640 (s), 1588 (w), 1566 (w), 1462 (w), 1438 (m), 1363 (s), 1294 (s), 1259 (m), 1158 (m), 1114 (w), 1047 (w), 1033 (w), 1009 (w), 949 (m), 926 (w), 866 (w), 761 (s), 723 (w). NMR data correspond to the reported values.[4]

1-Azido-3,3-dimethyl-3-(*1H*)-1,2-benziodoxole (2)

Caution: This reaction should be carried out behind a safety shield! Following a reported procedure[2] 1-Acetoxy-1,3-dihydro-3,3-dimethyl-1,2-benziodoxole (**10**) (2.30 g, 7.18 mmol) was dissolved in dry CH$_2$Cl$_2$ (36 mL) under N$_2$ atmosphere. The reaction was placed in an iced bath and trimethylsilylazide (0.954 mL, 7.18 mmol, 1.00 equiv) was added via syringe, followed by TMSOTf (0.065 mL, 0.36 mmol, 0.050 equiv). The reaction was stirred for 15 min then the ice bath was removed and the stirring was continued for 1 h. The solvent was evaporated and the solid obtained was washed with *n*-hexane (2 x 30 mL, HLPC purity) to afford **2** as a yellow crystalline solid (2.10 g, 7.18 mmol, 96%).

¹H NMR (400 MHz, CDCl$_3$) δ 7.77 (d, 1 H, *J* = 8.0 Hz, C*H*Ar), 7.55 (m, 2 H, C*H*Ar), 7.23 (d, 1 H, *J* = 7.2 Hz, C*H*Ar), 1.53 (s, 7 H, (C*H₃*)$_2$). **¹³C NMR** (101 MHz, CDCl$_3$) δ 149.2, 130.9, 130.4, 127.8, 126.8, 114.0, 83.2, 29.6. **IR** ν_{max} 3254 (w), 3085 (w), 3051 (w), 2976 (w), 2928 (w), 2860 (w), 2486 (w), 2026 (s), 1918 (w), 1764 (w), 1697 (w), 1651 (w), 1589 (w), 1562 (w), 1462 (m), 1428 (m), 1380 (w), 1364 (w), 1312 (w), 1273 (w), 1248 (s), 1182 (w), 1151 (m), 1111 (m), 1031 (w), 1004 (w), 943 (m), 910 (m), 880 (w), 863 (m). NMR data correspond to the reported values.[2]

2.2 Synthesis of 1-azido-1,2-benziodoxole-3-(*1H*)-one (6)

### 1-Hydroxy-1,2-benziodoxol-3-(1*H*)-one (12)
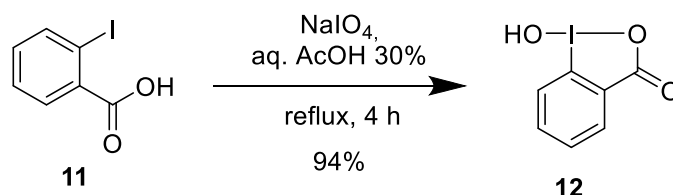
Caution: reaction carried out behind a safety shield! Following a reported procedure,[3] NaIO$_4$ (7.24 g, 33.8 mmol, 1.00 equiv) and 2-iodo benzoic acid (**11**) (8.00 g, 32.2 mmol, 1.00 equiv) were suspended in 30% (v:v) aq AcOH (48 mL) under air. The mixture was vigorously stirred and refluxed for 4 h. the reaction mixture was then diluted with cold water (180 mL) and allowed to cool to room temperature, protecting it from light. The mixture is then filtered and further washed with ice water and cold acetone, air dried in the dark overnight to give the pure compound **12** (8.14 g, 30.4 mmol, 94%) as a colorless solid.

¹H NMR (400 MHz, (CD$_3$)$_2$SO) 8.02 (dd, *J* = 7.7, 1.4 Hz, 1 H, Ar*H*), 7.97 (m, 1 H, Ar*H*), 7.85 (dd, *J* = 8.2, 0.7 Hz, 1 H, Ar*H*), 7.71 (td, *J* = 7.6, 1.2 Hz, 1 H, Ar*H*). **¹³C NMR** (100 MHz, (CD$_3$)$_2$SO) 167.7, 134.5, 131.5, 131.1, 130.4, 126.3, 120.4. **IR** ν_{max} 3083 (w), 3060 (w), 2867 (w),

2402 (w), 1601 (m), 1585 (m), 1564 (m), 1440 (m), 1338 (s), 1302 (m), 1148 (m), 1018 (w), 834 (m), 798 (w), 740 (s), 694 (s), 674 (m), 649 (m). NMR data correspond to the reported values. [3]

1-Acetoxy-1,2-benziodoxol-3-(1*H*)-one (13)
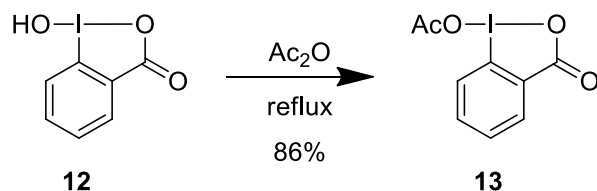
Following a reported procedure,[4] compound **12** (3.00 g, 11.3 mmol, 1.00 equiv) was heated in Ac$_2$O (10 mL) to reflux until the solution turned clear (without suspension). The mixture was then left to cool down and white crystals started to form. The crystallization was continued at -18 °C. The crystal were then collected and dried overnight under high vacuum to give compound **13** (3.06 g, 10.0 mmol, 86%).

^{1}H NMR (400 MHz, CDCl$_3$) δ 8.25 (dd, 1 H, *J* = 7.6, 1.4 Hz, Ar*H*), 8.00 (dd, 1 H, *J* = 8.3, 0.5 Hz, Ar*H*), 7.92 (dt, 1 H, *J* = 7.0, 1.7 Hz, Ar*H*), 7.71 (td, 1 H, *J* = 7.6, 0.9 Hz, Ar*H*), 2.25 (s, 3 H, COC*H$_3$*). NMR data correspond to the reported values.[4]

Synthesis of 1-azido-1,2-benziodoxole-3-(1*H*)-one (6)
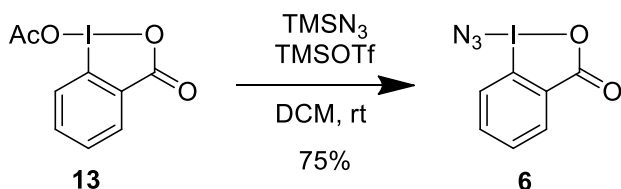
Caution: reaction carried out behind a safety shield! Following a reported procedure,[2] compound **13** (1.00 g, 3.28 mmol, 1.00 equiv) was stirred in dry DCM (3 mL) then TMSN$_3$ (0.66 mL, 4.9 mmol, 1.5 equiv) was cautiously added. A catalytic amount of TMSOTf (3 µL, 0.02 mmol, 0.005 equiv) was added last to the mixture which was then stirred for 30 minutes. The reaction mixture was then died in vacuo to give a yellow precipitate, which was washed a few times with hexanes to give compound **6** (0.70 g, 2.4 mmol, 74%) as a pure pale yellow crystal.

^{1}H NMR (400 MHz, CDCl$_3$:CH$_3$CN; 10:1) δ 8.17 (dd, 1 H, *J* = 7.5, 1.3 Hz, Ar*H*), 7.93 (m, 2 H, Ar*H*), 7.70 (m, 1 H, Ar*H*). **^{13}C NMR** (101 MHz, CDCl$_3$:CH$_3$CN; 10:1) δ 166.2, 134.8, 131.8, 130.4, 125.4, 116.6, 115.4. **IR** v_{max} 2049 (s), 1639 (s), 1565 (m), 1440 (w), 1347 (w), 1295 (m).The *analysis data* for the characterization of **6** correspond to the ones reported in the literature.[2]

3. Synthesis of starting materials

General procedure for the synthesis of β-keto esters.

Following a slightly modified procedure,[5] a spatula of sodium *tert*-butoxide was added to a suspension of NaH (2.2 equiv) in dimethyl carbonate (5.0 equiv). The ketone (1 equiv) was then added carefully at 0 °C. The reaction was stirred at room temperature and followed by TLC (using the solvent mixture indicated below for the R_f value and UV or *p*-anisaldehyde for visualization). Then 1 M HCl was added until the pH of the solution became neutral or slightly acidic. The organic layers were collected and washed with brine (2 x 20 mL), dried over MgSO$_4$ and concentrated in vacuum. The crude product was purified by column chromatography, using the solvent indicated for the **R_f** value.

Methyl 5-methoxy-1-oxo-2,3-dihydro-*1H*-indene-2-carboxylate (1a)
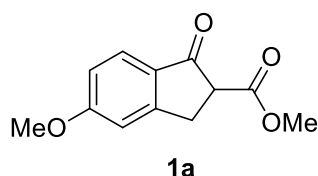
Starting from 5-methoxy-2,3-dihydro-*1H*-inden-1-one (1.0 g, 6.2 mmol), methyl 5-methoxy-1-oxo-2,3-dihydro-*1H*-indene-2-carboxylate (**1a**) (0.94 g, 4.2 mmol, 69 % yield) was obtained as a yellow solid. **R_f** 0.3 (pentane:ethyl acetate 3:2). **^{1}H NMR** (400 MHz, CDCl$_3$) δ 7.70 (m, 1 H, C*H*Ar), 6.92 (m, 2 H, C*H*Ar), 3.89 (s, 3 H, O*Me*), 3.79 (s, 3 H, O*Me*), 3.72 (dd, 1 H, *J* = 8.2, 4.0 Hz, C*H*), 3.51 (dd, 1 H, *J* = 17.3, 3.9 Hz, C*H₂*), 3.31 (dd, 1 H, *J* = 17.3, 8.2 Hz, C*H₂*). **^{13}C NMR** (101 MHz, CDCl$_3$) δ 197.5, 169.9, 165.9, 156.8, 128.4, 126.4, 116.0, 109.6, 55.8, 53.4, 52.8, 30.3. NMR data correspond to the reported values.[6]

Methyl 1-oxo-2,3-dihydro-*1H*-indene-2-carboxylate (1b)
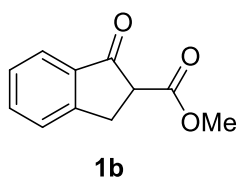
Starting from 1-indanone (0.80 g, 6.0 mmol), methyl 1-oxo-2,3-dihydro-*1H*-indene-2-carboxylate (**1b**) (0.77 g, 3.0 mmol, 73 % yield) was obtained as a yellow solid. **R_f** 0.2 (pentane:ethyl acetate 10:1). **^{1}H NMR** (400 MHz, CDCl$_3$) δ 7.78 (d, 1 H, *J* = 7.7 Hz, Ar*H*), 7.63 (dt, 1 H, *J* = 4.0, 8.0 Hz, Ar*H*), 7.50 (dd, 1 H, *J* = 7.7, 0.8 Hz, Ar*H*), 7.40 (t, 1 H, *J* = 8.0 Hz, Ar*H*), 3.79 (s, 3 H), 3.74 (dd, 1 H, *J* = 8.3, 4.1 Hz, C*H*), 3.57 (dd, 1 H, *J* = 17.3, 4.0 Hz, C*H₂*), 3.38 (dd, 1 H, *J* = 17.3, 8.3 Hz, C*H₂*). **^{13}C NMR** (101 MHz, CDCl$_3$) δ 199.4, 169.6, 153.6, 135.5, 135.2, 127.9, 126.6, 124.8, 53.2, 52.8, 30.3. **IR** v_{max} 2954 (w), 1743 (m), 1711 (s), 1654 (w), 1608 (w), 1572 (w), 1462 (w), 1439 (m), 1373 (w), 1329 (w), 1295 (w), 1261 (m), 1210 (m), 1155 (m), 1125 (w), 1093 (w), 1040 (w), 1020 (w), 990 (m), 962 (w), 915 (w), 850 (w). NMR data correspond to the reported values.[7]

5-Fluoro-1-oxo-2,3-dihydro-*1H*-indene-2-carboxylate (1c)
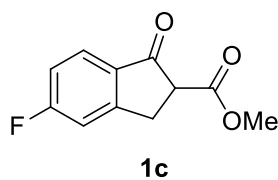
Starting from 5-fluoro-2,3-dihydro-*1H*-inden-1-one (0.70 g, 4.7 mmol), methyl 5-fluoro-1-oxo-2,3-dihydro-*1H*-indene-2-carboxylate (**1c**) (0.80 g, 4.0 mmol, 85 % yield) was obtained as an orangeish solid. **R_f**: 0.3 (pentane:EtOAc 10:2). **Mp**: 55.9-60.7°C. **^{1}H NMR** (400 MHz, CDCl$_3$) ratio ketone/enol 8/1: ketone δ 7.78 (dd, 1 H, *J* = 8.5, 5.3 Hz, C*H*Ar), 7.17 (dd, 1 H, *J* = 8.3, 0.7 Hz, , C*H*Ar), 7.10 (td, 1 H, *J* = 8.6, 1.9 Hz, , C*H*Ar), 3.80 (s, 3 H, O*Me*), 3.77 (dd, 1 H, *J* = 8.3, 4.0 Hz, C*H*), 3.57 (dd, 1 H, *J* = 17.5, 4.0 Hz,

CH_2), 3.36 (dd, 1 H, J = 17.5, 8.2 Hz, CH_2); enol δ 10.41 (m, 1 H, OH), 7.61 (dd, 1 H, J = 8.4, 5.2 Hz, CHAr), 7.12 (td, 2 H, J = 8.6, 1.9 Hz, CHAr), 3.87 (s, 3 H, OMe), 3.53 (s, 2 H, CH_2). ^{13}C NMR (101 MHz, CDCl$_3$) ketone: δ 197.4, 169.3, 167.6 (d, $J_{C\text{-}F}$ = 258 Hz), 156.6 (d, $J_{C\text{-}F}$ = 11 Hz), 131.6 (d, $J_{C\text{-}F}$ = 1 Hz), 127.1 (d, $J_{C\text{-}F}$ = 11 Hz), 116.3 (d, $J_{C\text{-}F}$ = 23 Hz), 113.3 (d, $J_{C\text{-}F}$ = 22 Hz), 53.4, 52.9, 30.1. **IR** v_{max} 3075 (w), 3066 (w), 2955 (w), 1745 (s), 1716 (s), 1658 (w), 1618 (m), 1596 (m), 1483 (w), 1449 (w), 1437 (w), 1370 (w), 1331 (m), 1303 (w), 1252 (s), 1230 (m), 1197 (m), 1162 (m), 1134 (w), 1087 (m), 1018 (w), 990 (w), 963 (w), 937 (w), 874 (w), 861 (w), 820 (w), 782 (w), 739 (w). **HRMS (ESI)** calcd for C$_{11}$FH$_{10}$O$_3^+$ [M+H]$^+$ 209.0608; found 209.0607.

Methyl 6-chloro-1-oxo-2,3-dihydro-1H-indene-2-carboxylate (1d)

1d
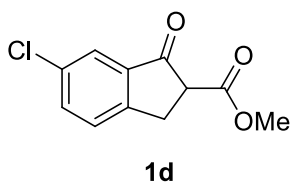
Starting from 6-chloro-2,3-dihydro-1H-inden-1-one (1.0 g, 6.0 mmol), methyl 6-chloro-1-oxo-2,3-dihydro-1H-indene-2-carboxylate (**1d**) (0.51 g, 2.3 mmol, 38 % yield) was obtained as an orange solid. **R$_f$:** 0.3 (pentane:EtOAc 10:1). **Mp:** 119.4-124-6°C. ^{1}**H NMR** (400 MHz, CDCl$_3$) ratio ketone/enol 0.7/ 1: ketone δ 7.74 (d, 1 H, J = 1.7 Hz, CHAr), 7.59 (dd, 1 H, J = 8.2, 1.9 Hz, CHAr), 7.45 (d, 1 H, J = 8.2 Hz, CHAr), 3.80 (s, 3 H, OMe), 3.78 (dd, 1 H, J = 8.4, 4.1 Hz, CH), 3.54 (dd, 1 H, J = 17.4, 4.0 Hz, CH_2), 3.35 (dd, 1 H, J = 17.4, 8.2 Hz, CH_2); enol δ 10.26 (m, 1 H, OH), 7.62 (s, 1 H, CHAr), 7.39 (s, 2 H, CHAr), 3.86 (s, 3 H, OMe), 3.50 (s, 2 H, CH_2). ^{13}**C NMR** ketone: δ 198.1, 169.1, 151.6, 138.6, 135.5, 133.1, 127.8, 124.5, 53.6, 53.0, 29.9. **IR** v_{max} 3372 (w), 3353 (w), 3322 (w), 3307 (w), 3297 (w), 3285 (w), 3257 (w), 2953 (w), 1746 (w), 1719 (w), 1665 (s), 1619 (m), 1618 (m), 1596 (m), 1572 (s), 1445 (s), 1395 (w), 1353 (m), 1307 (w), 1258 (s), 1239 (s), 1211 (s), 1195 (m), 1164 (m), 1129 (s), 1106 (m), 1068 (w), 1004 (w), 911 (w), 899 (w), 885 (w), 805 (w), 775 (m), 733 (w). **HRMS (ESI)** calcd for C$_{11}$H$_9$ClNaO$_3^+$ [M+Na]$^+$ 247.0132; found 247.0132.

Tert-butyl 1-oxo-2,3-dihydro-*1H*-indene-2-carboxylate (1e)

1e
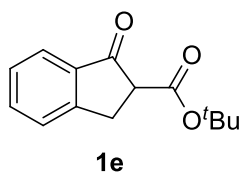
Following a reported procedure,[8] starting from 1-indanone (2.0 g, 15 mmol), *tert*-butyl 1-oxo-2,3-dihydro-*1H*-indene-2-carboxylate (**1e**) (1.63 g, 7.02 mmol, 46% yield) was obtained as a purple oil. **R$_f$:** 0.4 (pentane:EtOAc 8:2). ^{1}**H NMR** (400 MHz, CDCl$_3$) δ 7.71 (d, 1 H, J = 7.7 Hz, ArH), 7.57 (t, 1 H, J = 8 Hz, ArH), 7.45 (d, 1 H, J = 7.4 Hz, ArH), 7.34 (t, 1 H, J = 7.1 Hz), 3.58 (dd, 1 H, J = 8.2, 4.0 Hz, CH), 3.46 (dd, 1 H, J = 8.2, 4.0 Hz, CH_2), 3.29 (dd, 1 H, J = 17.2, 8.2 Hz, CH_2), 1.46 (s, 9 H, (CH_3)$_3$). ^{13}**C NMR** (101 MHz, CDCl$_3$) δ 200.4, 168.7, 154.1, 135.9, 135.6, 128.1, 126.9, 124.9, 82.4, 54.8, 30.7, 28.4(3C). **IR** v_{max} 2979 (w), 2933 (w), 1734 (s), 1733 (s), 1713 (s), 1645 (w), 1627 (w), 1608 (w), 1595 (w), 1574 (w), 1476 (w), 1464 (w), 1408 (w), 1393 (w), 1382 (w), 1369 (m), 1329 (w), 1298 (w), 1291 (w), 1270 (w), 1254 (w), 1226 (w), 1211 (w), 1149 (s), 1131 (m), 1092 (w), 1022 (w), 1014 (w), 989 (w), 845 (w), 773 (w), 759 (w), 740 (m), 723 (m), 680 (w), 669 (w), 642 (w), 630 (w). NMR data correspond to the reported values.[8]

Adamantan-1-yl 1-oxo-2,3-dihydro-*1H*-indene-2-carboxylate (1f)

1f
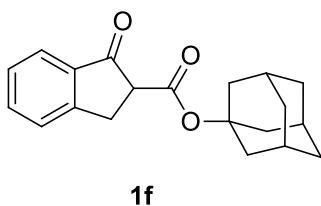
Following a reported procedure,[9] starting from methyl 1-oxo-2,3-dihydro-*1H*-indene-2-carboxylate (1.0 g, 5.0 mmol, 1.0 equiv), adamantan-1-yl 1-oxo-2,3-dihydro-1H-indene-2-carboxylate (**1f**)

(788 mg, 2.54 mmol, 48%) was obtained as a pink powder. **R**$_f$: 0.6 (pentane:EtOAc 4:1). **^{1}H NMR** (400 MHz, CDCl$_3$) δ 7.74 (d, 1 H, *J* = 7.6 Hz, Ar*H*), 7.58 (t, 1 H, *J* = 6.9 Hz, Ar*H*), 7.47 (d, 1 H, *J* = 7.6 Hz, Ar*H*), 7.36 (t, 1 H, *J* = 8, 12 Hz, Ar*H*), 3.59 (dd, 1 H, *J* = 8.2, 3.9 Hz, C*H*), 3.47 (m, 1 H, C*H*$_2$), 3.31 (dd, 1 H, *J* = 17.2, 8.2 Hz, C*H*$_2$), 2.13 (m, 12 H, C*H*$_2$), 1.64 (m, 3 H, C*H*). **^{13}C NMR** (101 MHz, CDCl$_3$) δ 200.1, 168.0, 153.7, 135.5, 135.2, 127.7, 126.5, 124.6, 82.2, 54.6, 41.3 (3C), 36.2 (3C), 30.9 (3C), 30.4. **IR** v_{max} 2913 (s), 2854 (w), 1712 (s), 1640 (w), 1599 (w), 1571 (w), 1519 (w), 1495 (w), 1460 (w), 1383 (w), 1351 (w), 1330 (w), 1291 (w), 1259 (m), 1210 (m), 1189 (w), 1159 (w), 1130 (w), 1095 (w), 1056 (m), 1017 (w), 990 (w), 968 (w), 937 (w), 910 (w), 862 (w), 861 (w), 816 (w). NMR data correspond to the reported values, except the peak at 30.9 in the ^{13}C spectrum (reported as 32.9).[9]

N-(4-fluorophenyl)-1-oxo-2,3-dihydro-*1H*-indene-2-carboxamide (1g)
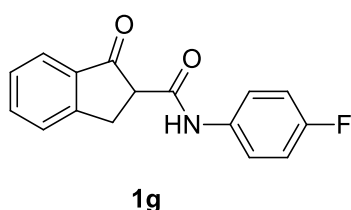
Following a slightly modified procedure,[10] Starting from methyl 1-oxo-2,3-dihydro-1H-indene-2-carboxylate (1.0 g, 5.0 mmol, 1.0 equiv), N-(4-fluorophenyl)-1-oxo-2,3-dihydro-*1H*-indene-2-carboxamide (**1g**) (515 mg, 1.91 mmol, 36%) was obtained as a pink powder. **R**$_f$: 0.63 (pentane:EtOAc 1:1). **^{1}H NMR** (400 MHz, CDCl$_3$) δ 9.09 (s, 1 H,N*H*), 7.73 (d, 1 H, *J* = 7.7 Hz, Ar*H*), 7.60 (td, 1 H, *J* = 7.6, 1.1 Hz, Ar*H*), 7.49 (m, 3 H, Ar*H*), 7.35 (t, 1 H, *J* = 8 Hz, Ar*H*), 6.96 (m, 2 H, Ar*H*), 3.79 (dd, 1 H, *J* = 17.7, 4.1 Hz, C*H*), 3.67 (dd, 1 H, *J* = 8.3, 4.1 Hz, C*H*$_2$), 3.38 (dd, 1 H, *J* = 17.8, 8.3 Hz, C*H*$_2$). **^{13}C NMR** (101 MHz, CDCl$_3$) δ 203.6, 164.4, 159.4 (d, *J*$_{C-F}$ = 244 Hz), 154.2, 136.2, 135.2, 133.8 (d, *J*$_{C-F}$ = 2 Hz), 127.9, 126.8, 124.6, 121.7 (d, *J*$_{C-F}$ = 8 Hz, 2C), 115.7 (d, *J*$_{C-F}$ = 23 Hz, 2C), 53.2, 28.5. **IR** v_{max} 3339 (w), 2980 (w), 2939 (w), 2356 (w), 2355 (w), 2343 (w), 1717 (s), 1651 (m), 1607 (w), 1530 (s), 1515 (s), 1463 (w), 1408 (m), 1380 (w), 1330 (w), 1276 (m), 1221 (m), 1164 (m), 1099 (w), 1040 (w), 1010 (w), 930 (w), 838 (s). HRMS (ESI) calcd for C$_{16}$H$_{13}$NO$_2$F$^+$ (M+H) 270.0930, found 270.0922.

Methyl 2-methyl-3-oxo-3-phenylpropanoate (1h)
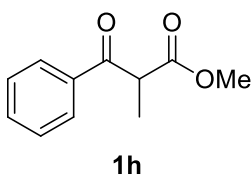
Starting from propiophenone (0.800 mL, 5.96 mmol), methyl 2-methyl-3-oxo-3-phenylpropanoate (**1h**) (0.917 g, 4.77 mmol, 80 % yield) (was obtained as a yellow liquid. **R**$_f$: 0.4 (pentane:EtOAc 4:1). **^{1}H NMR** (400 MHz, CDCl$_3$) δ 7.97 (m, 2 H, ArH), 7.58 (m, 1 H, ArH), 7.47 (m, 2 H, ArH), 4.41 (q, 1 H, *J* = 7.1 Hz, C*H*), 3.67 (s, 3 H, O*Me*), 1.49 (d, 3 H, *J* = 7.1 Hz, CH*Me*). **^{13}C NMR** (101 MHz, CDCl$_3$) δ 195.9, 171.3, 135.8, 133.6, 128.8 (2C), 128.6 (2C), 52.5, 48.1, 13.9. NMR data correspond to the reported values.[11]

Methyl 2-methyl-3-oxo-3-(4-(trifluoromethyl)phenyl) propanoate (1i)
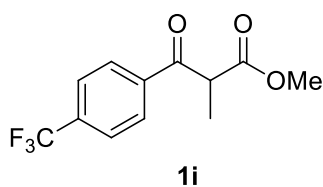
Starting from 1-(4-(trifluoromethyl)phenyl)propan-1-one (0.70 g, 3.5 mmol), methyl 2-methyl-3-oxo-3-(4-(trifluoromethyl)phenyl) propanoate (**1i**) (0.740 g, 2.84 mmol, 82 % yield) was obtained as a colorless liquid. **R**$_f$: 0.3 (pentane:EtOAc 1:1). **^{1}H NMR** (400 MHz, CDCl$_3$) δ 8.08 (d, 2 H, *J* = 8.2 Hz, C*H*Ar), 7.75 (d, 2 H, *J* = 8.2 Hz, C*H*Ar), 4.40 (q, 1 H, *J* = 7.1 Hz, C*H*), 3.70 (s, 1 H, O*Me*), 1.52 (d, 2 H, *J* = 7.1 Hz, C*H*$_3$. **^{13}C**

NMR (101 MHz, CDCl$_3$) δ 194.8, 170.9, 138.5, 134.8 (q, J = 32 Hz), 128.9 (2C), 125.9 (q, J = 4 Hz, 2C), 123.5 (q, J = 273 Hz), 52.7, 48.4, 13.6. **IR** ν_{max} 2997 (w), 2957 (w), 1745 (m), 1696 (m), 1582 (w), 1513 (w), 1456 (w), 1438 (w), 1411 (w), 1325 (s), 1223 (w), 1171 (s), 1132 (s), 1067 (s), 1017 (w), 980 (w), 950 (w), 853 (m), 822 (w), 741 (w), 729 (w), 714 (w). NMR data correspond to the reported values.[11]

3-(4-Bromophenyl)-2-methyl-3-oxopropanoate (1j)
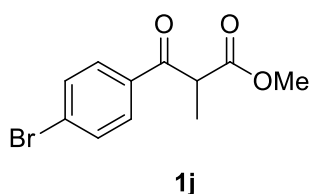
Starting from 1-(4-bromophenyl)propan-1-one (0.80 g, 6.0 mmol), methyl 3-(4-bromophenyl)-2-methyl-3-oxopropanoate (**1j**) (0.52 g, 1.9 mmol, 41 % yield) was obtained as a colorless liquid. **R$_f$**: 0.4 (pentane:EtOAc 1:1). **^{1}H NMR** (400 MHz, CDCl$_3$) δ 7.84 (m, 2 H, C*H*Ar), 7.62 (d, 2 H, J = 8.4 Hz, C*H*Ar), 4.34 (q, 1 H, J = 7.0 Hz, C*H*), 3.68 (m, 3 H, O*Me*), 1.49 (d, 3 H, J = 7.0 Hz, C*H$_3$*). **^{13}C NMR** (101 MHz, CDCl$_3$) δ 194.7, 171.0, 134.5, 132.2 (2C), 130.1 (2C), 128.9, 52.7, 48.1, 13.7. NMR data correspond to the reported values.[12]

Methyl 2-methyl-3-oxo-3-(thiophen-2-yl)propanoate (1k)
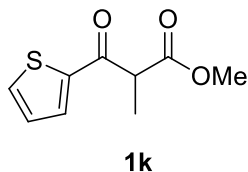
Starting from 1-(thiophen-2-yl)propan-1-one (0.70 g, 4.9 mmol), methyl 2-methyl-3-oxo-3-(thiophen-2-yl)propanoate (**1k**) (0.96 g, 4.8 mmol, 97 % yield) was obtained as an orange liquid. **R$_f$**: 0.3 (pentane:EtOAc 3:2). **^{1}H NMR** (400 MHz, CDCl$_3$) δ 7.78 (m, 1 H, C*H*Ar), 7.69 (dd, 1 H, J = 4.9, 0.9 Hz, C*H*Ar), 7.15 (m, 1 H, C*H*Ar), 4.26 (q, 1 H, J = 7.1 Hz, C*H*), 3.71 (s, 3 H, O*Me*), 1.51 (d, 3 H, J = 7.1 Hz, C*H$_3$*). **^{13}C NMR** (101 MHz, CDCl$_3$) δ 188.5, 170.9, 143.0, 134.8, 132.9, 128.4, 52.7, 49.3, 14.0. NMR data correspond to the reported values.[11]

Tert-butyl 1-oxo-1,2,3,4-tetrahydronaphthalene-2-carboxylate (15)
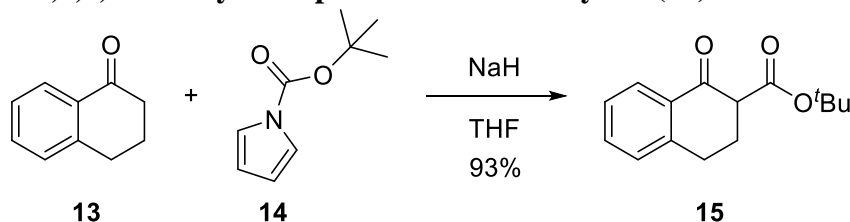
Compound **15** was synthetized following a reported procedure.[8] α-tetralone (**13**) (1.0 g, 6.8 mmol) in dry THF (5 mL) was added to a suspension of NaH (0.547 mg, 13.7 mmol, 2.00 equiv, 60% dispersion in mineral oil) in dry THF (25 mL) at rt. The solution was warmed to reflux and *tert* butyl pyrrole-1-carboxylate (**14**) (2.29 g, 13.7 mmol, 2.00 equiv) in dry THF (3 mL) was added dropwise and the solution was stirred at reflux until completion as indicated by TLC. After cooling to 0 °C, the solution was acidified with 1 N HCl. The solution was extracted with EtOAc (30 mL) and the organic layer was washed with brine (30 mL), dried (Na$_2$SO$_4$) and concentrated under reduced pressure. The residue was purified by flash silica gel chromatography (R$_f$: 0.3; 6:4 Pentane/ethylacetate).
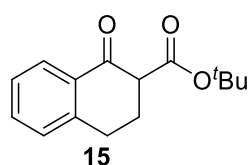
¹H NMR (400 MHz, CDCl₃) <u>enol</u> δ 12.65 (s, 1 H, enol H), 7.81 (dd, *J* = 7.5, 1.6 Hz, 1 H, Ar H), 7.31 (td, *J* = 7.2, 1.7 Hz, 2 H, Ar H), 7.18 (ddd, *J* = 6.6, 1.9, 1.0 Hz, 1 H, Ar H), 2.81 (dd, *J* = 8.8, 6.7 Hz, 2 H, CH₂), 2.56 – 2.51 (m, 2H, CH₂), 1.57 (s, 9 H, *t*Bu). <u>ketone:</u> δ 8.07 (dd, *J* = 7.9, 1.4 Hz, 1 H, Ar H), 7.51 (td, *J* = 7.5, 1.5 Hz, 1 H, Ar H), 7.31 (td, *J* = 7.2, 1.7 Hz, 1 H, Ar H), 7.28 (m, 1 H, Ar H), 3.52 (dd, *J* = 9.9, 4.7 Hz, 1 H, CH), 3.13 – 2.95 (m, 2 H, CH₂), 2.51 – 2.44 (m, 1 H, CH₂), 2.36 (ddt, *J* = 13.5, 6.2, 4.8 Hz, 1 H, CH₂), 1.50 (s, 9 H, *t*Bu).

NMR data correspond to the reported values.[13]

Methyl 2-oxocyclopentane-1-carboxylate (17)
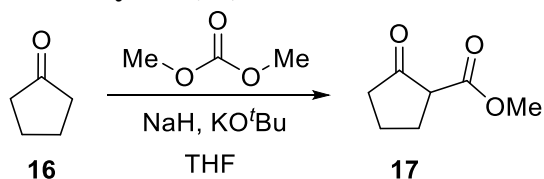
Compound **17** was synthesized following a reported procedure.[5] In a 50 mL flask, NaH (1.05 g, 26.2 mmol, 2.2 equiv) was suspended in THF (12 mL). Dimethyl carbonate (5.00 mL, 59.4 mmol, 5.00 equiv) was added to the mixture together with a catalytic amount of potassium *tert*-butoxide (67 mg, 0.59 mmol, 0.050 equiv). The solution was stirred for 1-2 minutes and then cyclopentanone (**16**) (1.0 g, 12 mmol) was added dropwise. The reaction was stirred at room temperature for 5 h. Water was then added carefully to quench the reaction. The aqueous layer was washed with Et₂O (2 x 50 mL) and ethylacetate (2 x 50 mL). The organic layers were collected and washed with brine (2 x 50 mL). The solvent was evaporated under reduced pressure and the crude product was purified by flash chromatography (95:5 Pentane/ethylacetate) to give compound **17** (0.318 g, 2.24 mmol, 19%).
¹H NMR (400 MHz, CDCl₃) δ 3.73 (s, 3 H, O*Me*), 3.16 (t, *J* = 9.0 Hz, 1 H, C*H*), 2.35 – 2.24 (m, 4 H, C*H₂*), 2.18 – 2.07 (m, 1 H, CH₂), 1.93 – 1.78 (m, 1 H, C*H₂*).
NMR data correspond to the reported values.[14]

Synthesis of silyl enol ethers

Silyl enol ethers **4a-h** are synthesized following reported procedures.

((*1H*-Inden-3-yl)oxy)trimethylsilane (4a)
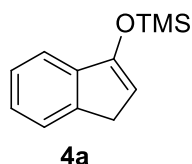
Following a reported procedure,[15] starting from 1-indanone (0.50 g, 3.8 mmol), ((*1H*-inden-3-yl)oxy)trimethylsilane (**4a**) (0.69 g, 3.4 mmol, 90% yield) was obtained as a yellow liquid. **¹H NMR** δ 7.38 (m, 2 H, C*H*Ar), 7.29 (m, 1 H, C*H*Ar), 7.21 (m, 1 H, C*H*Ar), 5.43 (t, 1 H, *J* = 2.4 Hz, C*H*), 3.27 (d, 2 H, *J* = 2.4 Hz, C*H₂*), 0.31 (m, 9 H, *TMS*). NMR data correspond to the reported values.[16]

((*1H*-Inden-3-yl)oxy)triethylsilane (4b)
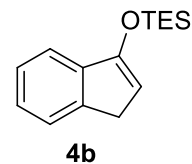
Starting from 1-indanone (0.50 g, 3.8 mmol), ((*1H*-inden-3-yl)oxy)triethylsilane (**4b**) (0.9 g, 3.8 mmol, 99% yield) was obtained as a colorless liquid. **¹H NMR** δ 7.39 (m, 2 H, C*H*Ar), 7.28 (m, 1 H, C*H*Ar), 7.21 (m, 1 H, C*H*Ar), 5.42 (t, 1 H, *J*

= 2.2 Hz, C*H*), 3.27 (d, 2 H, *J* = 2.1 Hz, C*H₂*), 1.03 (t, 9 H, *J* = 8.0 Hz, CH₂*(CH₃)₃*), 0.79 (q, 6 H, *J* = 7.7 Hz, *CH₂*(CH₃)₃). NMR data correspond to the reported values.[17]

((*1H*-Inden-3-yl)oxy)tri*iso*propylsilane (4c)
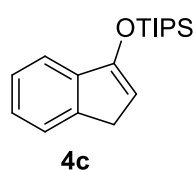
Starting from 1-indanone (1.0 g, 7.6 mmol), ((*1H*-inden-3-yl)oxy)triisopropylsilane (**4b**) (1.05 g, 3.64 mmol, 48% yield) was obtained as a colorless liquid. **¹H NMR** δ 7.42 (dd, 2 H, *J* = 19.5, 7.4 Hz, C*H*Ar), 7.31 (t, 1 H, *J* = 7.3 Hz, C*H*Ar), 7.22 (t, 1 H, *J* = 7.3 Hz, C*H*Ar), 5.42 (t, 1 H, *J* = 2.1 Hz, C*H*), 3.27 (d, 2 H, *J* = 1.9 Hz, C*H₂*), 1.34 (m, 3 H, TIPSC*H*), 1.15 (d, 18 H, *J* = 7.4 Hz, TIPSC*H₃*). NMR data correspond to the reported values.[18]

((3,4-Dihydronaphthalen-1-yl)oxy)trimethylsilane (4d)
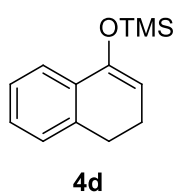
Starting from 1-tetralone (0.50 g, 3.4 mmol), ((3,4-dihydronaphthalen-1-yl)oxy)trimethylsilane (**4d**) (0.74 g, 3.4 mmol, 99% yield) was obtained as a colorless liquid. **¹H NMR** δ 7.41 (m, 1 H, C*H*Ar), 7.19 (dd, 1 H, *J* = 7.3, 1.6 Hz, C*H*Ar), 7.15 (td, 1 H, *J* = 7.4, 1.8 Hz, C*H*Ar), 7.11 (m, 1 H, C*H*Ar), 5.19 (t, 1 H, *J* = 4.6 Hz, C*H*), 2.77 (t, 2 H, *J* = 7.8 Hz, C*H₂*), 2.32 (m, 2 H, C*H₂*), 0.26 (m, 9 H, *TMS*). NMR data correspond to the reported values.[19]

Trimethyl((2-methyl-*1H*-inden-3-yl)oxy)silane (4e)
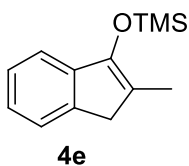
Starting from 2-methyl-2,3-dihydro-*1H*-inden-1-one (0.470 ml, 3.42 mmol), trimethyl((2-methyl-*1H*-inden-3-yl)oxy)silane (**4e**) (0.62 g, 3.1 mmol, 90% yield) was obtained as a colorless liquid. **¹H NMR** δ 7.31 (d, 1 H, *J* = 7.3 Hz, C*H*Ar), 7.23 (d, 1 H, *J* = 7.3 Hz, C*H*Ar), 7.18 (m, 1 H, C*H*Ar), 7.12 (td, 1 H, *J* = 7.3, 1.2 Hz, C*H*Ar), 3.19 (s, 2 H, C*H₂*), 1.97 (s, 3 H, C*H₃*), 0.27 (s, 9 H, *TMS*). NMR data correspond to the reported values.[20]

Trimethyl((2-methyl-3,4-dihydronaphthalen-1-yl)oxy)silane (4f)
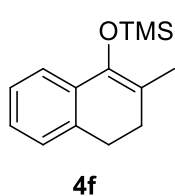
Starting from 2-methyl-3,4-dihydronaphthalen-1(*2H*)-one (0.50 g, 3.1 mmol), trimethyl((2-methyl-3,4-dihydronaphthalen-1-yl)oxy)silane (**4f**) (0.38 g, 1.6 mmol, 52% yield) was obtained as a colorless liquid. **¹H NMR** δ 7.31 (d, 1 H, *J* = 7.5 Hz, C*H*Ar), 7.16 (m, 1 H, C*H*Ar), 7.09 (m, 2 H, C*H*Ar), 2.74 (t, 2 H, *J* = 7.8 Hz, C*H₂*), 2.26 (t, 2 H, *J* = 8.0 Hz, C*H₂*), 1.82 (s, 3 H, C*H₃*), 0.21 (s, 9 H, *TMS*). NMR data correspond to the reported values.[20]

Trimethyl((1-phenylvinyl)oxy)silane (4g)
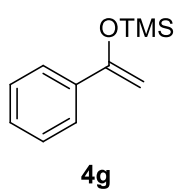
Starting from acetophenone (0.58 g, 4.8 mmol), trimethyl((1-phenylvinyl)oxy)silane (**4g**) (0.86 g, 4.5 mmol, 93% yield) was obtained as a colorless liquid. **¹H NMR** δ 7.60 (m, 2 H, C*H*Ar), 7.32 (m, 3 H, C*H*Ar), 4.92 (d, 1 H, *J* = 1.6 Hz, C*H₂*), 4.43 (d, 1 H, *J* = 1.6 Hz, C*H₂*), 0.27 (s, 9 H, *TMS*). NMR data correspond to the reported values.[21]

(*Z*)-Trimethyl((1-phenylprop-1-en-1-yl)oxy)silane (4h)

4h
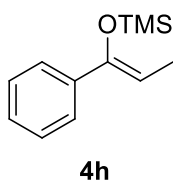
Starting from propiophenone (0.53 g, 4.0 mmol), (*Z*)-trimethyl((1-phenylprop-1-en-1-yl)oxy)silane (**4h**) (1.05 g, 5.10 mmol, 85% yield) was obtained as a colorless liquid. **^{1}H NMR** δ 7.46 (m, 2 H, C*H*Ar), 7.29 (m, 2 H, C*H*Ar), 7.23 (d, 1 H, *J* = 7.1 Hz, C*H*Ar), 5.33 (q, 1 H, *J* = 6.9 Hz, C*H*), 1.74 (d, 3 H, *J* = 6.9 Hz, C*H$_3$*), 0.14 (s, 9 H, *TMS*). NMR data correspond to the reported values.[21]

General procedure for the synthesis of silyl enol ethers.

The ketone (1.00 equiv) dissolved in anhydrous THF (0.33 M in ketone) was added in an oven-dried flask sealed with a septum and under N$_2$ atmosphere. The solution was cooled down to 0 °C and a 2 M solution of NaHMDS (1.22 eq) or freshly prepared LDA (1.05 equiv) was added dropwise. The cold bath is removed and the yellow solution was stirred for 1 hour at room temperature. The reaction was cooled again at 0 °C and trimethyl silyl chloride (1.20 eq) was added dropwise. The reaction was stirred at room temperature for 5 hours after what the solvent was directly removed under reduced pressure. The resulting oil was purified by plug or by column chromatography on silica using the solvent indicated for the **R$_f$** value.

(*Z*)-((1-(4-Bromophenyl)prop-1-en-1-yl)oxy)trimethylsilane (4i)

4i
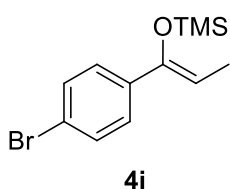
Starting from 1-(4-bromophenyl)propan-1-one (0.50 g, 2.4 mmol), (*Z*)-((1-(4-bromophenyl)prop-1-en-1-yl)oxy)trimethylsilane (**4i**) (0.54 g, 1.9 mmol, 81 % yield) was obtained as a yellow liquid. **R$_f$**: 0.2 (100% pentane). **^{1}H NMR** (400 MHz, CDCl$_3$) δ 7.41 (m, 2 H, C*H*Ar), 7.33 (m, 2 H, C*H*Ar), 5.33 (q, 1 H, *J* = 6.9 Hz, CC*H*), 1.73 (d, 3 H, *J* = 6.9 Hz, C*H$_3$*), 0.14 (m, 9 H, (C*H$_3$)$_3$*). **^{13}C NMR** (101 MHz, CDCl$_3$) δ 148.9, 138.2, 131.2 (2C), 126.8 (2C), 121.1, 106.1, 11.8, 0.6 (3C). **IR** v_{max} 3061 (w), 3041 (w), 2960 (w), 2914 (w), 2859 (w), 1652 (m), 1590 (w), 1446 (w), 1397 (w), 1379 (w), 1323 (m), 1251 (s), 1181 (w), 1118 (w), 1105 (w), 1069 (s), 1009 (m), 972 (w), 878 (s), 846 (s), 821 (s), 795 (w), 759 (m), 721 (w), 704 (w). **HRMS (APPI)** calcd for C$_{12}$H$_{17}$^{79}BrOSi [M+] 284.0232; found 284.0240.

(*Z*)-Trimethyl((1-(4-(trifluoromethyl)phenyl)prop-1-en-1-yl)oxy)silane (4j)

4j
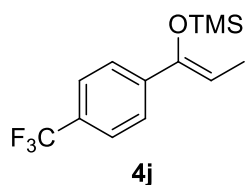
Starting from 1-(4-(trifluoromethyl)phenyl)propan-1-one (0.50 g, 2.5 mmol), (*Z*)-trimethyl((1-(4-(trifluoromethyl)phenyl)prop-1-en-1-yl)oxy)silane (**4j**) (0.30 g, 1.2 mmol, 47 % yield) was obtained as a yellow liquid. **R$_f$**: 0.2 (100% pentane). **^{1}H NMR** (400 MHz, CDCl$_3$) δ 7.56 (m, 4 H, C*H*Ar), 5.45 (q, 1 H, *J* = 6.9 Hz, CC*H*), 1.77 (d, 3 H, *J* = 6.9 Hz, C*H$_3$*), 0.16 (m, 9 H, (C*H$_3$)$_3$*). **^{13}C NMR** (101 MHz, CDCl$_3$) δ 148.7, 142.6, 129.2 (q, $J_{C\text{-}F}$ = 32 Hz), 125.2 (2C), 125.1 (q, $J_{C\text{-}F}$ = 4 Hz, 2C), 124.3 (q, *J* = 272 Hz), 107.7, 11.8, 0.6 (3C). **IR** v_{max} 3067 (w), 3052 (w), 2962 (w), 2918 (w), 2863 (w), 1651 (w), 1618 (w), 1448 (w), 1411 (w), 1381 (w), 1290 (w), 1255 (m), 1167 (m), 1124 (s), 1113 (s), 1067 (s), 972 (w), 957 (w), 877 (s), 844 (s), 797 (m), 758 (m), 704 (w). **HRMS (APPI)** calcd for C$_{13}$H$_{17}$F$_3$OSi [M+] 274.1001; found 274.1009.

(*Z*)-Trimethyl((1-(thiophen-2-yl)prop-1-en-1-yl)oxy)silane (4k)
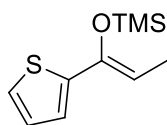
4k

Starting from 1-(thiophen-2-yl)propan-1-one (0.50 mL, 4.0 mmol) (**1k**) (Z)-trimethyl((1-(thiophen-2-yl)prop-1-en-1-yl)oxy)silane (**4k**) (0.648 g, 3.05 mmol, 76 % yield) was obtained as a yellow liquid. **R$_f$:** 0.3 (pentane:EtOAc 4:1). **^{1}H NMR** (400 MHz, CDCl$_3$) δ 7.10 (dd, 1 H, J = 5.0, 1.1 Hz, C$\underline{H}$Ar), 7.02 (dd, 1 H, J = 3.6, 1.0 Hz, C$\underline{H}$Ar), 6.93 (dd, 1 H, J = 5.0, 3.6 Hz, C$\underline{H}$Ar), 5.32 (q, 1 H, J = 6.9 Hz, C$\underline{H}$), 1.71 (d, 3 H, J = 6.9 Hz, C$\underline{H_3}$), 0.22 (s, 9 H, $\underline{TMS}$). **^{13}C NMR** (101 MHz, CDCl$_3$) δ 144.3, 143.1, 126.4, 123.0, 122.0, 104.2, 11.0, 0.0 (3C). **IR** ν_{max} 2961 (w), 2914 (w), 2860 (w), 1650 (w), 1523 (w), 1437 (w), 1413 (w), 1382 (w), 1357 (w), 1326 (m), 1312 (w), 1250 (s), 1215 (w), 1104 (w), 1062 (s), 1039 (m), 960 (w), 938 (w), 912 (w), 868 (s), 846 (s), 796 (w), 755 (m), 738 (w), 705 (w). **HRMS (ESI)** calcd for C$_{10}$H$_{17}$OSSi$^+$ [M+H]$^+$ 213.0764; found 213.0762.

4. Azidation of β-keto ester
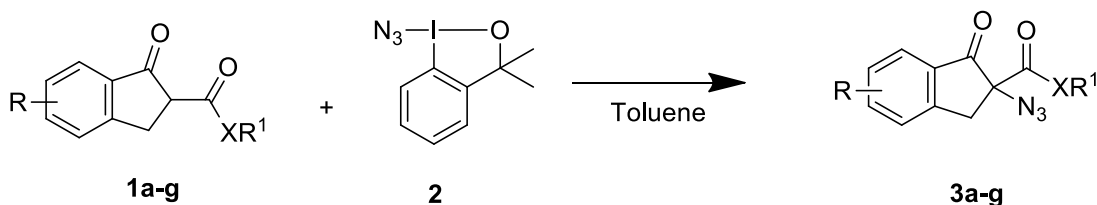
General procedure for the azidation of cyclic β-keto esters.

The cyclic β-keto ester (0.40 mmol) was dissolved in a 2 mL essay tube in toluene (1 M in keto ester). The reaction was stirred for 1 minute before adding dimethyl azido benziodoxole **2** (0.52 mmol, 1.3 equiv) in one portion. The reaction was followed by TLC (using the solvent indicated for the R$_f$ value, visualization with UV or *p*-anisaldehyde stain) until complete consumption of the starting material (1-3 h). The crude mixture was purified by column chromatography using the solvent indicated for the **R$_f$** value.

Methyl 2-azido-5-methoxy-1-oxo-2,3-dihydro-*1H*-indene-2-carboxylate (3a)
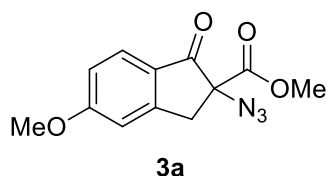
Starting from methyl 5-methoxy-1-oxo-2,3-dihydro-*1H*-indene-2-carboxylate (**1a**) (0.089 g, 0.40 mmol), methyl 2-azido-5-methoxy-1-oxo-2,3-dihydro-*1H*-indene-2-carboxylate (**3a**) (0.10 g, 0.38 mmol, 94 % yield) was obtained as a yellow oil. **R$_f$**: 0.6 (DCM/Pentane 4:1). **^{1}H NMR** (400 MHz, CDCl$_3$) δ 7.72 (d, 1 H, *J* = 8.6 Hz, C*H*Ar), 6.95 (dd, 1 H, *J* = 8.6, 2.0 Hz, C*H*Ar), 6.87 (s, 1 H, C*H*Ar), 3.89 (s, 3 H, O*Me*), 3.77 (s, 3 H, O*Me*), 3.60 (d, 1 H, *J* = 17.4 Hz, C*H$_2$*), 2.95 (d, 1 H, *J* = 17.4 Hz, C*H$_2$*). **^{13}C NMR** (101 MHz, CDCl$_3$) δ 195.2, 169.2, 166.8, 155.2, 127.5, 126.0, 116.7, 109.6, 70.6, 55.9, 53.5, 38.5. **IR** v_{max} 2956 (w), 2844 (w), 2108 (m), 2108 (m), 1750 (m), 1710 (m), 1598 (s), 1493 (w), 1447 (w), 1438 (w), 1342 (w), 1311 (m), 1265 (s), 1239 (m), 1198 (w), 1181 (w), 1151 (w), 1099 (w), 1089 (m), 1053 (w), 1025 (w), 960 (w), 930 (w), 900 (w), 850 (w), 832 (w), 788 (w), 751 (w). **HRMS (ESI)** calcd for C$_{12}$H$_{11}$N$_3$O$_4^+$ [M]$^+$ 262.0828; found 262.0830.

Methyl 2-azido-1-oxo-2,3-dihydro-*1H*-indene-2-carboxylate (3b)
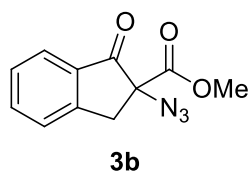
Starting from methyl 1-oxo-2,3-dihydro-*1H*-indene-2-carboxylate (**1b**) (0.077 g, 0.40 mmol), methyl 2-azido-1-oxo-2,3-dihydro-*1H*-indene-2-carboxylate (**3b**) (0.074 g, 0.32 mmol, 79 % yield) was obtained as a yellow oil. R$_f$: 0.47 (hexanes:EtOAc 4:1). **^{1}H NMR** (400 MHz, CDCl$_3$) δ 7.81 (dd, 1 H, *J* = 7.7, 0.2 Hz, C*H*Ar), 7.68 (m, 1 H, C*H*Ar), 7.45 (m, 2 H, C*H*Ar), 3.79 (s, 3 H, O*Me*), 3.67 (d, 1 H, *J* = 17.4 Hz, C*H$_2$*), 3.03 (d, 1 H, *J* = 17.4 Hz, C*H$_2$*). **^{13}C NMR** (101 MHz, CDCl$_3$) δ 197.4, 169.0, 152.1, 136.6, 133.0, 128.5, 126.5, 125.6, 70.2, 53.6, 38.5. **IR** v_{max} 2110 (s), 1749 (s), 1718 (s), 1607 (w), 1464 (w), 1432 (w), 1334 (w), 1269 (s), 1233 (s), 1181 (m), 1088 (w), 1051 (s), 959 (m), 910 (m), 863 (w), 811 (w). **HRMS (APPI)** calcd for C$_{11}$H$_{10}$NO$_3^+$ [M-N$_2$+H]$^+$ 204.0655; found 204.0666.

Methyl 2-azido-5-fluoro-1-oxo-2,3-dihydro-1H-indene-2-carboxylate (3c)

3c
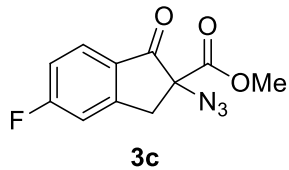
Starting from methyl 5-fluoro-1-oxo-2,3-dihydro-*1H*-indene-2-carboxylate (**1c**) (0.083 g, 0.40 mmol), methyl 2-azido-5-fluoro-1-oxo-2,3-dihydro-1H-indene-2-carboxylate (**3c**) (0.1 g, 0.4 mmol, quant.) was obtained as a white crystalline solid. **Mp** 98.4-100.7°C. **R$_f$:** 0.6 (DCM/pentane 4:1). **^{1}H NMR** (400 MHz, CDCl$_3$) δ 7.84 (dd, 1 H, *J* = 8.3, 5.3 Hz, C*H*Ar), 7.16 (m, 2 H, C*H*Ar), 3.81 (s, 3 H, O*Me*), 3.66 (d, 1 H, *J* = 17.6 Hz, C*H$_2$*), 3.02 (d, 1 H, *J* = 17.6 Hz, C*H$_2$*). **^{13}C NMR** (101 MHz, CDCl$_3$) δ 195.5, 168.7, 168.1 (d, *J$_{C-F}$* = 260 Hz), 155.1 (d, *J$_{C-F}$* = 11 Hz), 129.4 (d, *J$_{C-F}$* = 2 Hz), 128.2 (d, *J$_{C-F}$* = 11 Hz), 117.0 (d, *J$_{C-F}$* = 24 Hz), 113.4 (d, *J$_{C-F}$* = 23 Hz), 70.4, 53.7, 38.4. **IR** v_{max} 2959 (w), 2109 (s), 1753 (s), 1721 (s), 1484 (w), 1428 (w), 1336 (w), 1258 (s), 1199 (m), 1180 (m), 1133 (w), 1053 (m), 961 (w), 905 (w), 863 (m), 833 (w), 788 (w), 739 (w). **HRMS (ESI)** calcd for C$_{11}$FH$_9$NO$_3$$^+$ [M-N$_2$+H]$^+$ 222.0561; found 222.0562.

Methyl 2-azido-6-chloro-1-oxo-2,3-dihydro-*1H*-indene-2-carboxylate (3d)

3d

Starting from methyl 6-chloro-1-oxo-2,3-dihydro-*1H*-indene-2-carboxylate (**1d**) (0.0916 g, 0.408 mmol), methyl 2-azido-6-chloro-1-oxo-2,3-dihydro-*1H*-indene-2-carboxylate (**3d**) (0.10 g, 0.38 mmol, 92 % yield) was obtained as a white solid. **Mp** 141.6-146.3°C. R$_f$: 0.66 (DCM/pentane 4:1). **^{1}H NMR** (400 MHz, CDCl$_3$) δ 7.77 (d, 1 H, *J* = 1.5 Hz, C*H*Ar), 7.63 (dd, 1 H, *J* = 8.2, 1.9 Hz, C*H*Ar), 7.42 (d, 1 H, *J* = 8.2 Hz, C*H*Ar), 3.80 (s, 3 H, O*Me*), 3.63 (d, 1 H, *J* = 17.4 Hz, C*H$_2$*), 3.00 (d, 1 H, *J* = 17.5 Hz, C*H$_2$*). **^{13}C NMR** (101 MHz, CDCl$_3$) δ 196.3, 168.5, 150.1, 136.5, 134.9, 134.5, 127.7, 125.3, 70.6, 53.7, 38.2. **IR** v_{max} 2959 (w), 2107 (s), 1746 (s), 1720 (s), 1599 (w), 1470 (w), 1427 (m), 1327 (w), 1290 (w), 1276 (m), 1251 (s), 1237 (s), 1200 (s), 1176 (m), 1129 (w), 1108 (w), 1053 (m), 1035 (w), 955 (w), 939 (w), 908 (w), 881 (w), 832 (m), 791 (w), 741 (w), 713 (m). **HRMS (ESI)** calcd for C$_{11}$ClH$_9$NO$_3$$^+$ [M-N$_2$+H]$^+$ 238.0265; found 238.0280.
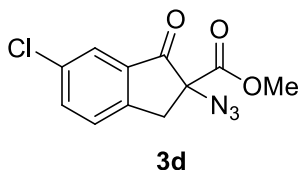
Tert-butyl 2-azido-1-oxo-2,3-dihydro-*1H*-indene-2-carboxylate (3e)

3e
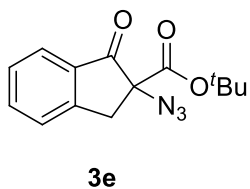
Starting from tert-butyl 1-oxo-2,3-dihydro-1H-indene-2-carboxylate (**1e**) (0.094 g, 0.40 mmol), *tert*-butyl 2-azido-1-oxo-2,3-dihydro-*1H*-indene-2-carboxylate (**3e**) (0.11 g, 0.40 mmol, quant.) was obtained as a white solid. R$_f$: 0.70 (DCM/pentane 4:1). **^{1}H NMR** (400 MHz, CDCl$_3$) δ 7.79 (d, 1 H, *J* = 7.7 Hz, C*H*Ar), 7.65 (td, 1 H, *J* = 7.6, 1.1 Hz, C*H*Ar), 7.43 (m, 2 H, C*H*Ar), 3.62 (d, 1 H, *J* = 17.2 Hz, C*H$_2$*), 2.98 (d, 1 H, *J* = 17.2 Hz, C*H$_2$*), 1.44 (s, 9 H, *^{t}Bu*). **^{13}C NMR** (101 MHz, CDCl$_3$) δ 198.0, 167.3, 152.3, 136.3, 133.2, 128.3, 126.4, 125.4, 84.5, 70.5, 38.5, 27.9 (3C). **IR** v_{max} 2981 (w), 2915 (w), 2856 (w), 2114 (s), 1741 (s), 1716 (s), 1608 (w), 1591 (w), 1465 (w), 1428 (w), 1396 (w), 1371 (w), 1344 (w), 1263 (m), 1248 (s), 1236 (s), 1216 (m), 1184 (m), 1152 (s), 1106 (w), 1091 (w), 1049 (m), 964 (w), 911 (s), 878 (w), 864 (w), 839 (m), 809 (w), 792 (w), 733 (s). NMR data correspond to the reported values.[22]

Adamantan-1-yl 2-azido-1-oxo-2,3-dihydro-*1H*-indene-2-carboxylate (3f)
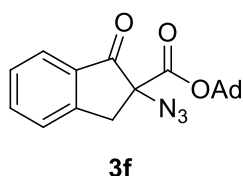
Starting from adamantan-1-yl 1-oxo-2,3-dihydro-*1H*-indene-2-carboxylate (**1f**) (0.125 g, 0.402 mmol), adamantan-1-yl 2-azido-1-oxo-2,3-dihydro-*1H*-indene-2-carboxylate (**3f**) (0.14 g, 0.39 mmol, 98 % yield) was obtained as a colorless oil. R_f: 0.77 (DCM/pentane 4:1). ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.79 (d, 1 H, J = 7.7 Hz, CHAr), 7.64 (td, 1 H, J = 7.6, 1.2 Hz, CHAr), 7.42 (m, 2 H, CHAr), 3.62 (d, 1 H, J = 17.2 Hz, CH_2), 2.97 (d, 1 H, J = 17.2 Hz, CH_2), 2.13 (s, 3 H, AdCH), 2.05 (m, 6 H, AdCH_2), 1.61 (m, 6 H, AdCH_2). ^{13}C NMR (101 MHz, CDCl$_3$) δ 198.1, 166.9, 152.3, 136.2, 133.2, 128.3, 126.4, 125.4, 84.5, 70.5, 41.1 (3C), 38.6, 36.0 (3C), 30.9 (3C). **IR** ν_{max} 2915 (m), 2857 (w), 2115 (m), 1741 (s), 1718 (s), 1610 (w), 1463 (w), 1428 (w), 1353 (w), 1321 (w), 1267 (m), 1234 (s), 1188 (m), 1157 (w), 1130 (w), 1105 (w), 1049 (m), 964 (w), 910 (s), 877 (w), 865 (w), 837 (w), 808 (w), 733 (s). **HRMS (APPI)** calcd for C$_{20}$H$_{21}$NO$_3$ [M-N$_2$]$^+$ 323.1521; found 323.1514.

2-Azido-N-(4-fluorophenyl)-1-oxo-2,3-dihydro-1H-indene-2-carboxamide (3g)
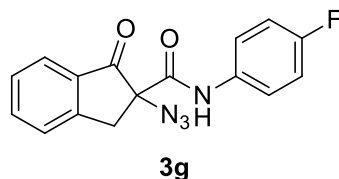
Starting from N-(4-fluorophenyl)-1-oxo-2,3-dihydro-*1H*-indene-2-carboxamide (**1g**) (0.11 g, 0.40 mmol), 2-azido-N-(4-fluorophenyl)-1-oxo-2,3-dihydro-1H-indene-2-carboxamide (**3g**) (0.083 g, 0.27 mmol, 67 % yield) was obtained as a white solid. **Mp** 133.3-135.1°C. R_f: 0.43 (DCM/pentane 4:1). ^{1}H NMR (400 MHz, CDCl$_3$) δ 8.53 (s, 1 H, NH), 7.83 (d, 1 H, J = 7.7 Hz, CHAr), 7.71 (m, 1 H, CHAr), 7.52 (m, 3 H, CHAr), 7.46 (t, 1 H, J = 7.4 Hz, CHAr), 7.02 (m, 2 H, CHAr), 4.11 (d, 1 H, J = 17.4 Hz, CH_2), 3.32 (d, 1 H, J = 17.4 Hz, CH_2). ^{13}C NMR (101 MHz, CDCl$_3$) δ 198.0, 164.1, 159.8 (d, J_{C-F} = 245 Hz), 152.4, 137.0, 133.3, 132.9 (d, J = 2 Hz), 128.6, 126.5, 125.6, 122.0 (d, J = 8 Hz, 2C), 115.8 (d, J = 23 Hz, 2C), 73.2, 37.5. **IR** ν_{max} 3384 (w), 3333 (w), 3075 (w), 2982 (w), 2926 (w), 2113 (s), 1717 (s), 1679 (m), 1608 (m), 1591 (w), 1530 (s), 1509 (s), 1468 (m), 1428 (w), 1409 (m), 1372 (w), 1325 (w), 1304 (m), 1277 (m), 1248 (m), 1214 (s), 1188 (w), 1156 (m), 1102 (w), 1091 (w), 1046 (m), 1017 (w), 991 (w), 962 (w), 911 (s), 877 (w), 862 (w), 835 (s), 813 (m), 793 (w), 733 (s). **HRMS (ESI)** calcd for C$_{16}$FH$_{12}$N$_4$O$_2^+$ [M+H]$^+$ 311.0939; found 311.0937.

Tert-butyl 2-azido-1-oxo-1,2,3,4-tetrahydronaphthalene-2-carboxylate (18) and *tert*-butyl 1-hydroxy-2-naphthoate (19)

Starting from ketoester **15** (98 mg, 0.40 mmol), azide **18** (11 mg, 0.038 mmol, 10% yield) was obtained as a colorless oil. The major product was naphthol **19** (56 mg, 0.23 mmol, 57%), isolated as a colorless oil.
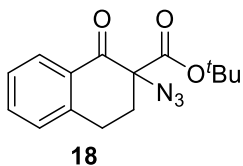
R_f 0.33 (100:1 Pentane/ethylacetate). ^{1}H NMR (400 MHz, CDCl$_3$) δ 8.07 (dd, J = 7.9, 1.4 Hz, 1 H, Ar H), 7.52 (td, J = 7.5, 1.5 Hz, 1 H, Ar H), 7.38 – 7.32 (m, 1 H, Ar H), 7.27 – 7.23 (m, 1 H, Ar H), 3.10 (ddd, J = 17.1, 8.8, 4.8 Hz, 1 H, CH$_2$), 2.99 – 2.89 (m, 1 H, CH$_2$), 2.57 (ddd, J = 13.6, 8.8, 4.7 Hz, 1 H, CH$_2$), 2.17 (ddd, J = 13.8, 6.6, 4.8 Hz, 1 H, CH$_2$), 1.47 (s, 9 H, ^{t}Bu). ^{13}C NMR (101 MHz, CDCl$_3$) δ 190.0, 167.4, 143.3, 134.4, 130.3, 128.7, 128.4, 127.2, 84.2, 71.0, 31.4, 27.9, 25.0. **IR** ν 2980 (w), 2934 (w), 2109 (s), 1740 (s), 1683 (m), 1602 (w), 1479 (w), 1456 (w), 1371 (w), 1277 (m), 1237 (s), 1153 (s), 1069 (w), 934 (w), 909 (m), 841 (w), 820 (w). NMR data correspond to the reported values.[23]

19
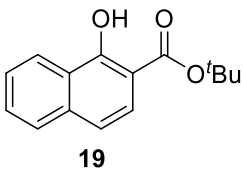
$\mathbf{R_f}$ 0.97 (100:1 Pentane/ethylacetate).**¹H NMR** (400 MHz, CDCl$_3$) δ 12.27 (s, 1 H, OH), 8.40 (ddt, *J* = 8.4, 1.5, 0.8 Hz, 1 H, Ar H), 7.77 – 7.74 (m, 1 H, Ar H), 7.72 (d, *J* = 8.8 Hz, 1 H, Ar H), 7.59 (ddd, *J* = 8.2, 6.9, 1.4 Hz, 1 H, Ar H), 7.51 (ddd, *J* = 8.2, 6.9, 1.3 Hz, 1 H, Ar H), 7.25 (d, *J* = 8.6 Hz, 1 H, Ar H), 1.65 (s, 9 H, *t*Bu). NMR data correspond to the reported values.[24]

Methyl 1-azido-2-oxocyclopentane-1-carboxylate (20)

Starting from ketoester **17** (73 mg, 0.40 mmol), azide **20** (39.5 mg, 0.216 mmol, 54% yield) was obtained as a colorless oil.

20
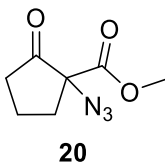
$\mathbf{R_f}$ 0.5 (6:4 Pentane/DCM). **¹H NMR** (400 MHz, CDCl$_3$) δ 3.83 (s, 3 H, O*Me*), 2.52 – 2.35 (m, 3 H, C*H₂*), 2.16 – 1.92 (m, 3 H, C*H₂*). **¹³C NMR** (101 MHz, CDCl$_3$) δ 208.9, 169.0, 70.9, 53.4, 36.5, 34.2, 19.2. **IR** *v* 2976 (w), 2959 (w), 2897 (w), 2159 (w), 2111 (s), 1753 (s), 1739 (s), 1438 (w), 1404 (w), 1317 (w), 1270 (m), 1230 (s), 1194 (w), 1162 (m), 1143 (m), 1127 (m), 1041 (w), 1004 (m), 961 (w), 917 (w), 844 (w), 819 (w), 797 (w), 765 (w), 738 (w). ¹H NMR data correspond to the reported

values.[25]

5. Zinc-catalyzed azidation of linear β-keto esters.
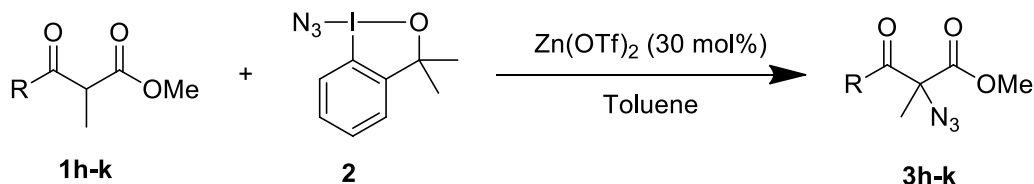
1h-k   **2**   **3h-k**

General procedure

Zn(OTf)$_2$ (0.021 g, 0.058 mmol, 0.030 equiv) was suspended in a 2 mL essay tube in toluene (0.5 M). The linear β-keto ester (**1h-k**) (0.40 mmol) was then added. The reaction mixture was stirred for one minute before adding in one portion the dimethyl azido benziodoxole **2** (0.15 g, 0.50 mmol, 1.3 equiv). The reaction was stirred at room and followed by TLC (using the solvent indicated for the R$_f$ value, visualization with UV or *p*-anisaldehyde stain) until complete consumption of the starting material (12-24 h). The crude mixture was purified by column chromatography, using the solvent indicated for the **R$_f$** value.

Methyl 2-azido-2-methyl-3-oxo-3-phenylpropanoate (3h)

3h
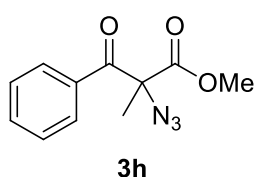
Starting from methyl methyl 2-methyl-3-oxo-3-phenylpropanoate (0.078 g, 0.406 mmol) (**1h**), methyl 2-azido-2-methyl-3-oxo-3-phenylpropanoate (0.069 g, 0.296 mmol, 73 % yield, > 95% pure by NMR) (**3h**) was obtained as a yellow oil. **R$_f$**: 0.3 (Pentane/ethyl acetate 10:1). **^{1}H NMR** (400 MHz, CDCl$_3$) δ 7.97 (m, 2 H, C*H*Ar), 7.57 (m, 1 H, C*H*Ar), 7.45 (m, 2 H, C*H*Ar), 3.75 (s, 3 H, O*Me*), 1.82 (s, 3 H, C*H*$_3$). **^{13}C NMR** (101 MHz, CDCl$_3$) δ 190.9, 170.3, 133.8, 133.5, 129.4 (2C), 128.7 (2C), 71.1, 53.5, 20.3. **IR** v_{max} 3069 (w), 3068 (w), 3007 (w), 2957 (w), 2111 (s), 1749 (s), 1696 (s), 1598 (w), 1582 (w), 1515 (w), 1450 (m), 1411 (w), 1379 (w), 1355 (w), 1235 (s), 1189 (w), 1120 (s), 1062 (w), 1002 (w), 967 (m), 912 (m), 864 (w), 799 (w), 786 (w), 733 (s). NMR data correspond to the reported values.[26]

Methyl 2-azido-2-methyl-3-oxo-3-(4-(trifluoromethyl)phenyl)propanoate (3i)

3i
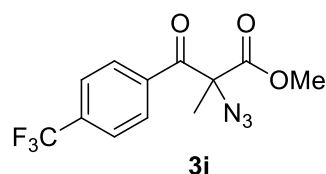
Starting from methyl 2-methyl-3-oxo-3-(4-(trifluoromethyl)phenyl) propanoate (**1i**) (0.103 g, 0.396 mmol), methyl 2-azido-2-methyl-3-oxo-3-(4-(trifluoromethyl)phenyl)propanoate (**3i**) (0.069 g, 0.23 mmol, 58% yield) was obtained as a yellow oil. **R$_f$**: 0.3 (Pentane/diethyl ether 10:1). **^{1}H NMR** (400 MHz, CDCl$_3$) δ 8.08 (dd, 2 H, *J* = 8.9, 0.7 Hz, C*H*Ar), 7.71 (d, 2 H, *J* = 8.3 Hz, C*H*Ar), 3.76 (s, 3 H, O*Me$_3$*), 1.84 (s, 3 H, C*H$_3$*). **^{13}C NMR** (101 MHz, CDCl$_3$) δ 190.0, 170.1, 136.3, 134.8 (q, J_{C-F} = 32 Hz), 129.8 (2C), 125.7 (q, J_{C-F} = 4 Hz, 2C), 123.4 (q, J_{C-F} = 272 Hz), 71.0, 53.7, 20.0. **IR** v_{max} 3081 (w), 3062 (w), 3011 (w), 2960 (w), 2849 (w), 2117 (m), 1752 (m), 1706 (m), 1582 (w), 1514 (w), 1453 (w), 1440 (w), 1411 (w), 1380 (w), 1329 (s), 1246 (m), 1236 (m), 1172 (s), 1119 (s), 1068 (s), 1018 (m), 972 (m), 912 (m), 854 (m), 795 (w), 767 (w), 736 (m), 711 (w). **HRMS (ESI)** calcd for C$_{12}$F$_3$H$_{11}$NO$_3$$^+$ [M-N$_2$+H]$^+$ 274.0686; found 274.0685.

Methyl 2-azido-3-(4-bromophenyl)-2-methyl-3-oxopropanoate (3j)

Starting from methyl 3-(4-bromophenyl)-2-methyl-3-oxopropanoate (**1j**) (0.104 g, 0.385 mmol), methyl 2-azido-3-(4-bromophenyl)-2-methyl-3-oxopropanoate (**3j**) (0.066 g, 0.21 mmol, 55% yield, > 95% pure by NMR) was obtained as a yellow oil. **R$_f$**: 0.3 (pentane:ethyl acetate 6:4). **^{1}H NMR** (400 MHz, CDCl$_3$) δ 7.86 (m, 2 H, C*H*Ar), 7.61 (m, 2 H, C*H*Ar), 3.77 (s, 3 H, *OMe*), 1.83 (s, 3 H, *CH$_3$*). **^{13}C NMR** (101 MHz, CDCl$_3$) δ 189.9, 170.2, 132.2, 132.0 (2C), 130.9 (2C), 129.2, 71.0, 53.6, 20.1. **IR** v_{max} 3358 (w), 3343 (w), 3332 (w), 2120 (s), 1752 (w), 1698 (s), 1600 (m), 1534 (s), 1447 (m), 1413 (w), 1377 (w), 1357 (w), 1327 (s), 1250 (s), 1174 (m), 1134 (s), 1069 (m), 1017 (w), 970 (w), 911 (w), 857 (w), 758 (m), 743 (m). **HRMS (APPI)** calcd for C$_{11}$^{79}BrH$_{11}$NO$_3$$^+$ [M-N$_2$+H]$^+$ 283.9917; found 283.9932.
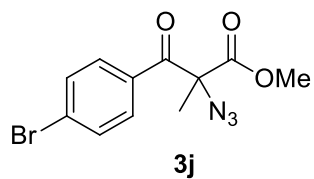
Methyl 2-azido-2-methyl-3-oxo-3-(thiophen-2-yl)propanoate (3k)
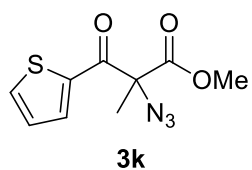
Starting from methyl 2-methyl-3-oxo-3-(thiophen-2-yl)propanoate (**1k**) (0.079 g, 0.40 mmol), methyl 2-azido-2-methyl-3-oxo-3-(thiophen-2-yl)propanoate (**3k**) (0.062 g, 0.26 mmol, 64% yield) was obtained as a yellow oil. **R$_f$**: 0.3 (pentane:ethyl acetate 6:4). **^{1}H NMR** (400 MHz, CDCl$_3$) δ 7.88 (dd, 1 H, J = 3.9, 1.0 Hz, C*H*Ar), 7.71 (dd, 1 H, J = 5.0, 1.0 Hz, C*H*Ar), 7.13 (dd, 1 H, J = 4.9, 4.0 Hz, CHAr), 3.78 (s, 3 H, *OMe*), 1.80 (s, 3 H, C*H$_3$*). **^{13}C NMR** (101 MHz, CDCl$_3$) δ 184.5, 169.7, 139.4, 135.5, 134.4, 128.5, 71.9, 53.6, 20.5. **IR** v_{max} 3104 (w), 3006 (w), 2957 (w), 2110 (s), 1748 (s), 1673 (s), 1515 (w), 1452 (w), 1436 (w), 1379 (w), 1265 (s), 1238 (s), 1118 (s), 1084 (w), 1061 (m), 975 (w), 925 (w), 863 (w), 833 (w), 781 (w), 767 (m), 729 (s). **HRMS (ESI)** calcd for C$_9$H$_{10}$N$_3$O$_3$S$^+$ [M+H]$^+$ 240.0437; found 240.0444.

6. Complete optimization table for silyl enol ether azidation.
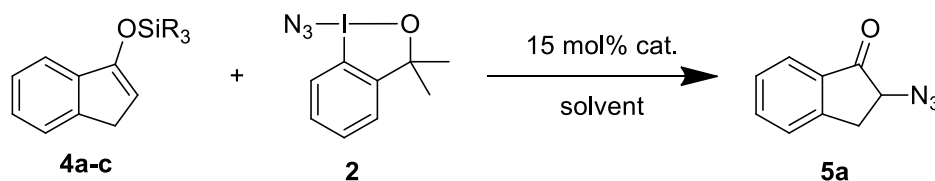
The Lewis Acid (15 mol %) was suspended in a test tube of 2 mL in toluene (0.05 M). Silyl enol ether **4a-c** (0.1 mmol) was added and the reaction was stirred for 1 minute. Then dimethyl azido benziodoxole **2** (0.13 mmol, 1.3 equiv) was added in one portion. The reaction was followed by TLC (using the solvent indicated for the R_f value, visualization with UV or *p*-anisaldehyde stain) until disappearance of the starting material.

Without further purification a sample of 0.2 mL was dried under high vacuum. A known amount of trimethoxybenzene (1.7 mg, 0.010 mmol, external standard) was added to the crude mixture. The yield was determined by ^{1}HNMR analysis comparison with 1,3,5-trimethoxybenzene peak at 6.2 ppm and the product peak at 4.32 ppm.

Calibration curve with 1,3,5-trimethoxybenzene.
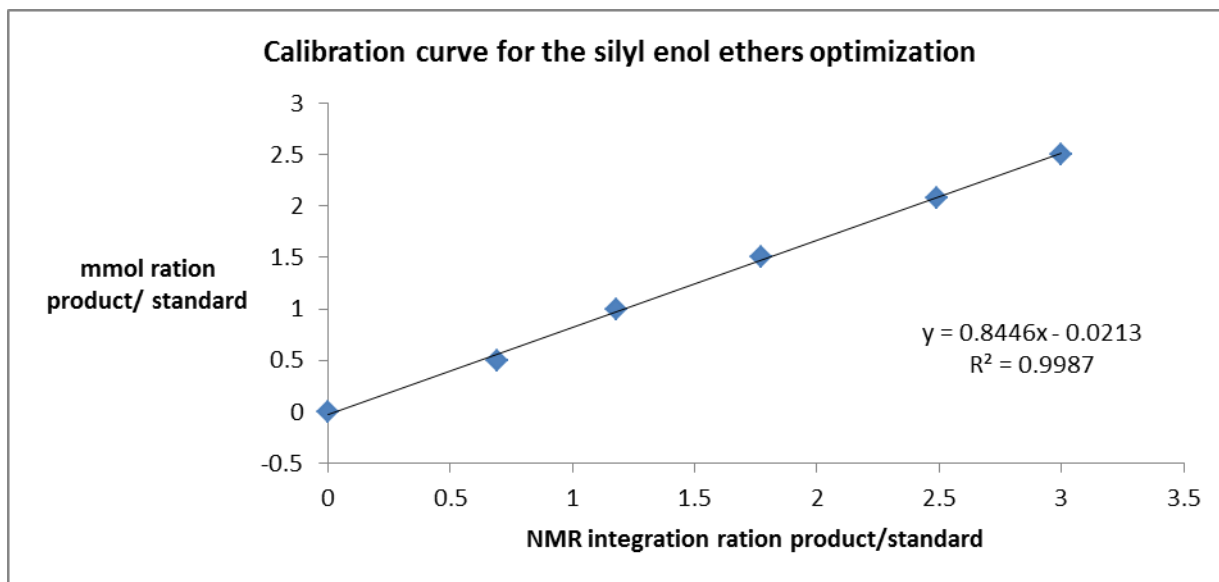
Solvent and temperature optimization.

Solvent With Zn(OTf)₂	Temperature	^{1}HNMR yields %
Toluene	**rt**	**67**
Et₂O	rt	52
CH₃CN	rt	53
iPrOH	rt	0
DMF	rt	10
DMSO	rt	30
DCM	rt	30

THF	rt	26
0°C	0°C	22

Lewis acid optimization.

Lewis Acid In toluene at r.t.	^{1}HNMR yields %
Zn(OTf)$_2$	**67**
Sc(OTf)$_3$	23
Cu(OTf)$_2$	36
In(OTf)$_3$	58
Sn(OTf)$_2$	68
Yb(OTf)$_3$	19
AgOTf	25
Hf(OTf)$_4$	71
AlCl$_3$	0
(CuOTf)$_2$ Tol	38
CuCl$_2$	n.d
SnCl$_4$	30

Zinc salts optimization.

Zinc salts	^{1}HNMR yields %
Zn(OTf)$_2$	**67%**
Zn(HNTf$_2$)$_2$	41%
Zn(OAc)$_2$	22%
Zn(CF$_3$CO$_2$)$_2$	26%
Zn(BF$_4$)$_2$	47%
ZnBr$_2$	28%
ZnCl$_2$	18%

7. Zinc-catalyzed azidation of silyl enol ethers.
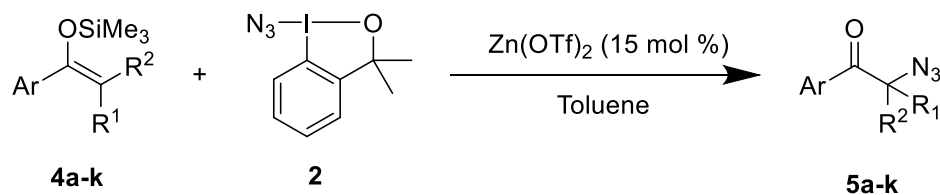
General procedure

Zn(OTf)$_2$ (0.021 g, 0.058 mmol, 0.030 equiv) was suspended in a 2 mL essay tube in toluene (0.5 M in silyl enol ether). The silyl enol ether (**4a-k**) (0.40 mmol) was then added. The reaction mixture was stirred for one minute before adding in one portion the dimethyl azido benziodoxole **2** (0.15 g, 0.50 mmol, 1.3 equiv). The reaction mixture was stirred at room temperature and followed by TLC (using the solvent indicated for the R$_f$ value, visualization with UV or *p*-anisaldehyde stain) until complete consumption of the starting material (12-24 h). The crude was purified by column chromatography, using the solvent indicated for the **R$_f$** value.

2-Azido-2,3-dihydro-*1H*-inden-1-one (5a)
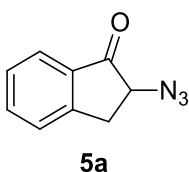
Starting from ((*1H*-inden-3-yl)oxy)trimethylsilane (**4a**) (0.0794 g, 0.389 mmol), 2-azido-2,3-dihydro-*1H*-inden-1-one (**5a**) (0.0388 g, 0.224 mmol, 58% yield) was obtained as a yellow oil. **R$_f$**: 0.3 (Hexane/DCM 1:1). **¹H NMR** (400 MHz, CDCl$_3$) δ 7.80 (d, 1 H, *J* = 7.8 Hz, C*H*Ar), 7.66 (td, 1 H, *J* = 7.6, 1.2 Hz, C*H*Ar)), 7.44 (m, 2 H, C*H*Ar)), 4.33 (dd, 1 H, *J* = 8.2, 4.7 Hz, *CH*), 3.51 (dd, 1 H, *J* = 17.2, 8.3 Hz, *CH$_2$*), 2.94 (dd, 1 H, *J* = 17.1, 4.6 Hz, *CH$_3$*). **¹³C NMR** (101 MHz, CDCl$_3$) δ 201.8, 151.2, 136.1, 134.2, 128.3, 126.6, 124.7, 62.0, 33.0. **IR** v_{max} 2349 (w), 2103 (s), 1721 (s), 1610 (m), 1609 (m), 1469 (w), 1432 (w), 1304 (w), 1303 (w), 1270 (m), 1226 (m), 1225 (m), 1170 (w), 1158 (w), 1089 (w), 1088 (w), 1046 (m), 1037 (m), 1001 (m), 1000 (m), 956 (w), 896 (w), 860 (w). NMR data correspond to the reported values.[27]

2-Azido-3,4-dihydronaphthalen-1(*2H*)-one (5d)
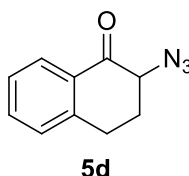
Starting from ((3,4-dihydronaphthalen-1-yl)oxy)trimethylsilane (**4d**) (0.0883 g, 0.404 mmol), 2-azido-3,4-dihydronaphthalen-1(*2H*)-one (**5d**) (0.044 g, 0.24 mmol, 58% yield) was obtained as a yellow oil. **R$_f$**: 0.3 (DCM/pentane 7:3). **¹H NMR** (400 MHz, CDCl$_3$) δ 8.06 (dd, 1 H, *J* = 7.8, 1.2 Hz, C*H*Ar), 7.52 (td, 1 H, *J* = 7.5, 1.4 Hz, C*H*Ar), 7.34 (m, 1 H, C*H*Ar), 7.25 (m, 1 H, C*H*Ar), 4.23 (m, 1 H, *CH*), 3.07 (dd, 2 H, *J* = 7.7, 4.3 Hz, *CH$_2$*), 2.37 (m,1H, *CH$_2$*), 2.13 (m, 1 H, *CH$_2$*). **¹³C NMR** (101 MHz, CDCl$_3$) δ 193.9, 143.4, 134.3, 131.1, 128.8, 128.0, 127.2, 64.4, 29.4, 27.6. **IR** v_{max} 2943 (w), 2873 (w), 2842 (w), 2101 (s), 1730 (w), 1692 (s), 1602 (m), 1481 (w), 1456 (w), 1435 (w), 1357 (w), 1343 (w), 1314 (w), 1267 (m), 1227 (s), 1160 (w), 1114 (w), 1089 (w), 1026 (w), 972 (w), 916 (m), 890 (w), 871 (w), 821 (w), 779 (w), 744 (s), 734 (s). NMR data correspond to the reported values.[27]

2-Azido-2-methyl-2,3-dihydro-1H-inden-1-one (5e)
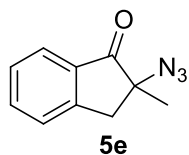
Starting from trimethyl((2-methyl-1H-inden-3-yl)oxy)silane (**4e**) (0.0873 g, 0.400 mmol), 2-azido-2-methyl-2,3-dihydro-1H-inden-1-one (**5e**) (0.046 g, 0.25 mmol, 62% yield) was obtained as a yellow oil. **R$_f$**: 0.3 (DCM/pentane

3:2). **¹H NMR** (400 MHz, CDCl₃) δ 7.80 (d, 1 H, J = 8.0 Hz, CHAr), 7.64 (td, 1 H, J = 7.5, 1.1 Hz, CHAr), 7.41 (m, 2 H, CHAr), 3.13 (s, 2 H, CH_2), 1.60 (s, 3 H, CH_3). **¹³C NMR** (101 MHz, CDCl₃) δ 203.2, 150.8, 136.1, 133.5, 128.2, 126.6, 125.2, 65.3, 40.9, 21.2. **IR** v_{max} 2973 (w), 2929 (w), 2102 (s), 1720 (s), 1609 (m), 1590 (w), 1467 (w), 1433 (w), 1375 (w), 1330 (w), 1304 (w), 1287 (m), 1250 (m), 1217 (m), 1173 (w), 1134 (w), 1111 (w), 1092 (w), 1071 (w), 970 (m), 913 (w), 875 (w), 796 (w), 739 (m). **HRMS (ESI)** calcd for $C_{10}H_{10}NO^+$ [M-N₂+H]⁺ 160.0757; found 160.0772.

2-Azido-2-methyl-3,4-dihydronaphthalen-1(2H)-one (5f)
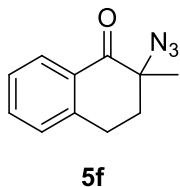
Starting from trimethyl((2-methyl-3,4-dihydronaphthalen-1-yl)oxy)silane (**4f**) (0.0952 g, 0.410 mmol), 2-azido-2-methyl-3,4-dihydronaphthalen-1(2H)-one (**5f**) (0.045 g, 0.224 mmol, 55% yield) was obtained as a yellow oil. R$_f$: 0.5 (Pentane/diethyl ether 10:1). **¹H NMR** (400 MHz, CDCl₃) δ 8.02 (dd, 1 H, J = 7.9, 1.0 Hz, CHAr), 7.45 (td, 1 H, J = 7.5, 1.4 Hz, CHAr), 7.28 (m, 1 H, CHAr), 7.18 (d, 1 H, J = 7.7 Hz, CHAr), 3.08 (m, 1 H, CH_2), 2.84 (m, 1 H, CH_2), 2.15 (m, 1 H, CH_2), 2.02 (m, 1 H, CH_2), 1.51 (s, 3 H, CH_3). **¹³C NMR** (101 MHz, CDCl₃) δ 194.5, 143.3, 134.0, 130.3, 128.7, 128.6, 127.1, 64.4, 34.9, 25.6, 20.3. **IR** v_{max} 2977 (w), 2933 (w), 2106 (s), 1729 (w), 1685 (s), 1602 (m), 1485 (w), 1456 (m), 1434 (w), 1377 (w), 1358 (w), 1305 (m), 1253 (m), 1229 (s), 1158 (w), 1129 (w), 1088 (w), 1042 (w), 1018 (w), 993 (w), 967 (m), 909 (w), 896 (w), 875 (w), 800 (w), 778 (w), 705 (w). **HRMS (ESI)** calcd for $C_{11}H_{12}NO^+$ [M-N₂+H]⁺ 174.0913; found 174.0911.

2-Azido-1-phenylethanone (5g)
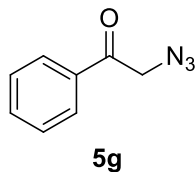
Starting from trimethyl((1-phenylvinyl)oxy)silane (**4g**) (0.077 g, 0.40 mmol), 2-azido-1-phenylethanone (**5g**) (0.047 g, 0.29 mmol, 73% yield) was obtained as a yellow oil. R$_f$: 0.3 (Pentane/diethyl ether 9:1). **¹H NMR** (400 MHz, CDCl₃) δ 7.91 (m, 2 H, CHAr), 7.64 (m, 1 H, CHAr), 7.49 (m, 2 H, CHAr), 4.56 (s, 2 H, CH_2). **¹³C NMR** (101 MHz, CDCl₃) δ 193.2, 134.4, 134.2, 129.0 (2C), 128.0 (2C), 54.9. NMR data correspond to the reported values.[27]

2-Azido-1-phenylpropan-1-one (5h)
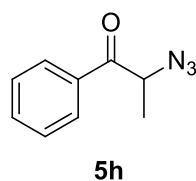
Starting from (Z)-trimethyl((1-phenylprop-1-en-1-yl)oxy)silane (**4h**) (0.0662 g, 0.321 mmol), 2-azido-1-phenylpropan-1-one (**5h**) (0.0405 g, 0.231 mmol, 72% yield) was obtained as a yellow oil. R$_f$: 0.3 (Pentane/ethyl acetate 10:1) **¹H NMR** (400 MHz, CDCl₃) δ 7.94 (m, 2 H, CHAr), 7.62 (m, 1 H, CHAr), 7.50 (t, 2 H, J = 7.9 Hz, CHAr), 4.71 (q, 1 H, J = 7.0 Hz, CHAr), 1.57 (d, 3 H, J = 7.0 Hz, CH_3). **¹³C NMR** (101 MHz, CDCl₃) δ 196.7, 134.3, 133.9, 128.9 (2C), 128.7 (2C), 58.4, 16.5. NMR data correspond to the reported values.[27]

2-Azido-1-(4-bromophenyl)propan-1-one (5i)
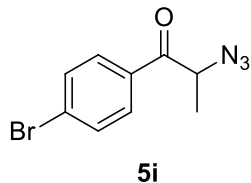
Starting from (E)-((1-(4-bromophenyl)prop-1-en-1-yl)oxy)trimethylsilane (**4i**) (0.114 g, 0.400 mmol), 2-azido-1-(4-bromophenyl)propan-1-one (**5i**) (0.0833 g, 0.328 mmol, 82% yield) was obtained as a yellow oil. R$_f$: 0.3 (Pentane/DCM 7:3). **¹H NMR** (400 MHz, CDCl₃) δ 7.80 (m, 2 H, CHAr), 7.63 (m, 2 H, CHAr), 4.63 (q, 1 H, J = 7.0 Hz, CHAr), 1.55 (d, 3 H, J = 7.0 Hz, CH_3) . **¹³C NMR** (101 MHz, CDCl₃) δ 195.7, 133.0, 132.3 (2C), 130.2 (2C), 129.3, 58.4, 16.3. **IR** v_{max} 2988 (w), 2987 (w), 2118 (m), 2102 (m), 1690 (m), 1569 (w), 1568 (w), 1486 (w), 1452 (w), 1399 (w), 1379 (w), 1357 (w), 1277 (w), 1277 (w), 1251 (w), 1213 (m), 1181 (w),

1115 (w), 1102 (w), 1101 (w), 1073 (m), 964 (m), 911 (m), 840 (m), 777 (w), 733 (s). **HRMS (APPI)** calcd for $C_9H_8{}^{79}BrNO$ $[M-N_2]^+$ 224.9784; found 224.9795.

2-Azido-1-(4-(trifluoromethyl)phenyl)propan-1-one (5j)
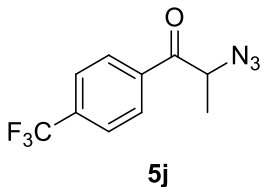
Starting from (*E*)-trimethyl((1-(4-(trifluoromethyl)phenyl)prop-1-en-1-yl)oxy)silane (**4j**) (0.106 g, 0.386 mmol), 2-azido-1-(4-(trifluoromethyl)phenyl)propan-1-one (**5j**) (0.0703 g, 0.289 mmol, 75% yield) was obtained as a yellow oil. R_f: 0.3 (Pentane/DCM 3:2). **¹H NMR** (400 MHz, CDCl₃) δ 8.05 (d, 2 H, *J* = 8.2 Hz, C*H*Ar), 7.76 (d, 2 H, *J* = 8.4 Hz, C*H*Ar), 4.70 (q, 1 H, *J* = 7.0 Hz, C*H*), 1.58 (d, 3 H, *J* = 7.0 Hz, *CH₃*). **¹³C NMR** (101 MHz, CDCl₃) δ 195.8, 137.1, 135.1 (q, J_{C-F} = 33 Hz), 129.1 (2C), 126.0 (q, J_{C-F} = 4 Hz, 2C), 123.4 (q, J_{C-F} = 273 Hz), 58.7, 16.0. **IR** v_{max} 2990 (w), 2121 (m), 2106 (m), 1789 (w), 1770 (w), 1699 (m), 1581 (w), 1513 (w), 1452 (w), 1381 (w), 1324 (s), 1251 (w), 1217 (m), 1171 (m), 1131 (s), 1068 (s), 1018 (m), 1000 (w), 967 (m), 913 (w), 855 (m), 791 (w), 767 (w), 739 (w), 707 (w). **HRMS (ESI)** calcd for $C_{10}F_3H_9NO^+$ $[M-N_2+H]^+$ 216.0631; found 216.0642.

2-Azido-1-(thiophen-2-yl)propan-1-one (5k)
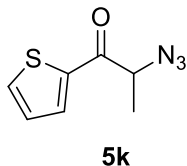
Starting from (*E*)-trimethyl((1-(thiophen-2-yl)prop-1-en-1-yl)oxy)silane (**4k**) (0.0868 g, 0.409 mmol), 2-azido-1-(thiophen-2-yl)propan-1-one (**5k**) (0.060 g, 0.33 mmol, 81% yield) was obtained as a yellow oil. R_f: 0.3 (Pentane/DCM 6:4). **¹H NMR** (400 MHz, CDCl₃) δ 7.79 (dd, 1 H, *J* = 4.0, 0.9 Hz, C*H*Ar), 7.73 (dd, 1 H, *J* = 4.7, 0.8 Hz, C*H*Ar), 7.17 (dd, 1 H, *J* = 4.9, 4.0 Hz, C*H*Ar), 4.52 (q, 1 H, *J* = 7.0 Hz, C*H*), 1.60 (d, 3 H, *J* = 7.0 Hz, C*H₃*). **¹³C NMR** (101 MHz, CDCl₃) δ 189.7, 140.9, 135.2, 133.2, 128.5, 59.8, 17.0. **IR** v_{max} 3102 (w), 3093 (w), 2989 (w), 2109 (s), 1670 (s), 1518 (w), 1450 (w), 1414 (s), 1378 (w), 1357 (w), 1323 (w), 1239 (s), 1223 (s), 1059 (m), 1043 (w), 1013 (w), 999 (w), 917 (w), 862 (w), 848 (w), 832 (w), 777 (w), 730 (s). **HRMS (ESI)** calcd for $C_7H_8NOS^+$ $[M-N_2+H]^+$ 154.0321; found 154.0325.

8. Enantioselective azidation of β-keto esters

1e + **2** → **3e**

51%, 49% ee

Reagents: 15 mol % (+)-2,2′-Isopropylidenebis[(4R)-4-benzyl-2-oxazoline], 15 mol % Cu(SbF$_6$)$_2$, toluene, 23 °C
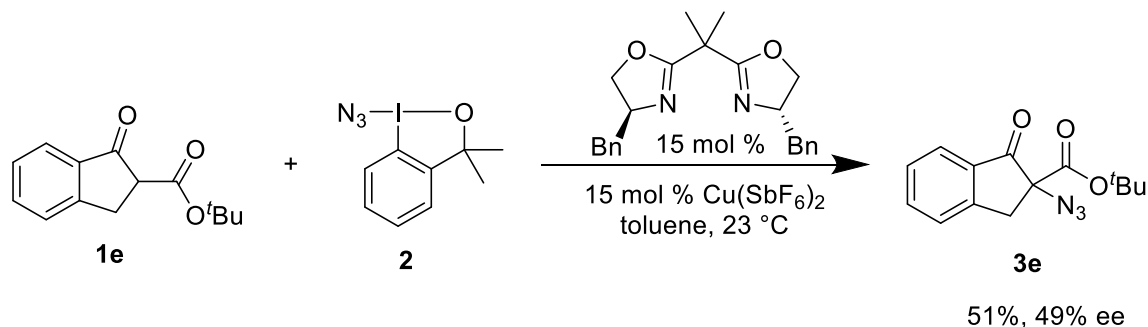
Preparation of the complex.

CuCl$_2$ (2.0 mg, 0.015 mmol, 1.0 equiv) and (+)-2,2′-Isopropylidenebis[(4R)-4-benzyl-2-oxazoline] (5.3 mg, 0.015 mmol, 1.0 equiv) were stirred in a microwave tube of 2 mL in CH$_2$Cl$_2$ (0.5 mL) for 2 h. Then the solution was transferred into another microwave tube where AgSbF$_6$ (10 mg, 0.030 mmol, 2.05 equiv) was previously placed. The reaction was stirred at room temperature for 5 h. The mixture was filtered and the solvent evaporated. The resulting complex was stored in a dry box and used as soon as possible.

Enantioselective protocol.

A solution of reagent **2** (15 mg, 0.055 mmol, 1.3 equiv) in toluene (0.43 mL, 0.1 M in **1e**) was added in a microwave tube of 2 mL to the preformed complex (5.7 mg, 6.0 10^{-3} mmol, 0.014 equiv) and the starting material **1e** (10 mg, 0.043 mmol). The reaction was stirred at room temperature and followed by TLC (using the solvent indicated for the R$_f$ value, visualization with UV or *p*-anisaldehyde stain) until disappearance of the starting material.
The solvent was removed by evaporation and the crude product was purified by flash chromatography (DCM/pentane 4:1) and product **3e** (0.056 g, 0.21 mmol, 51% yield).
A small sample of pure compound was analyzed by chiral HPLC: (IC, Hexane/^{i}PrOH = 99/1, 1 mL/ min, 254nm), t$_R$(major isomer)= 11.8 min, t$_R$(minor isomer)= 13.3 min (49% ee).

Racemic 3e
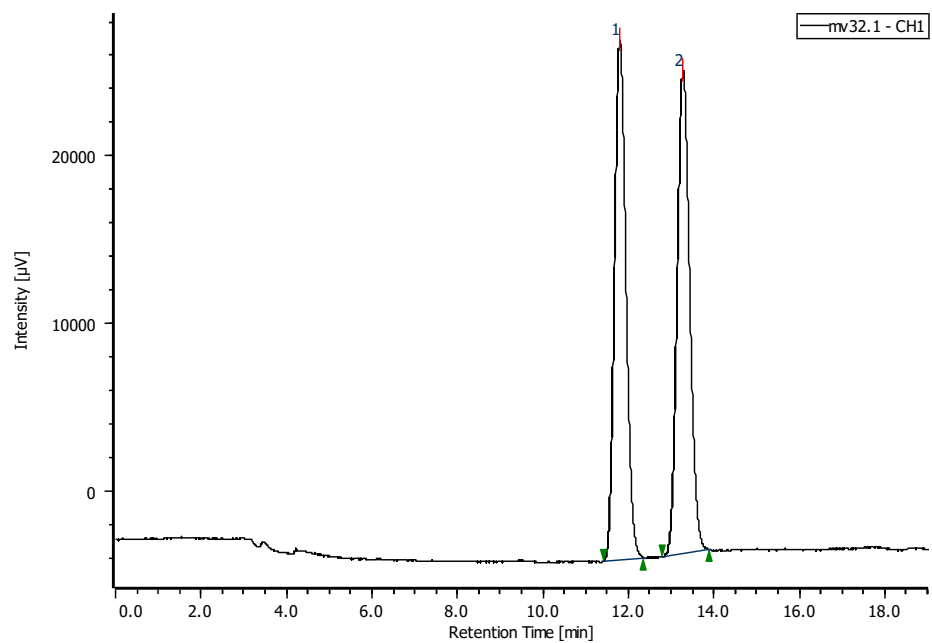
Enantioenriched 3e

S27
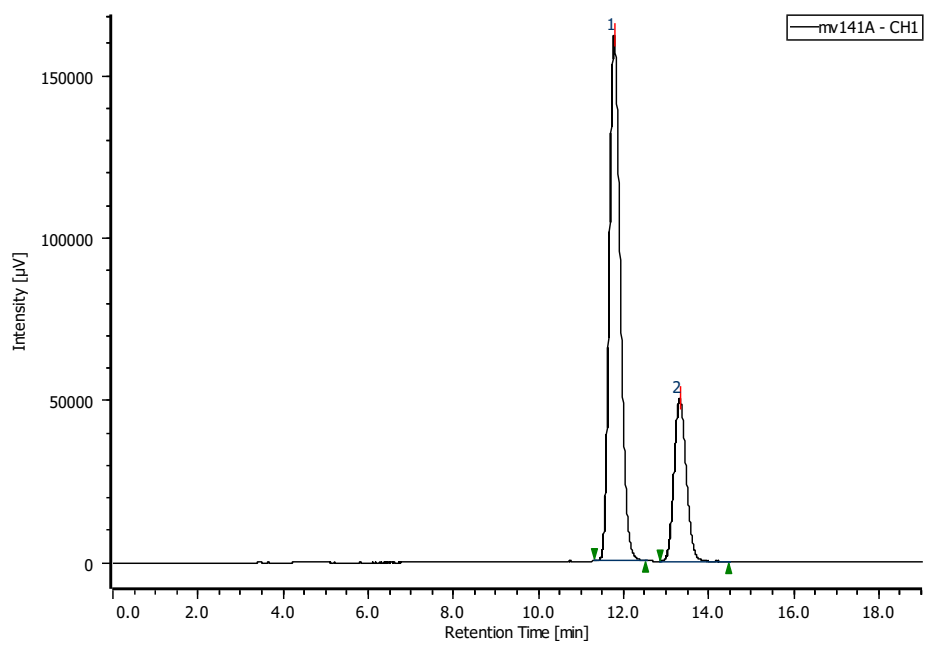
9. Reference

(1) Powers, D. C.; Lee, E.; Ariafard, A.; Sanford, M. S.; Yates, B. F.; Canty, A. J.; Ritter, T. *J. Am. Chem. Soc.* **2012**, *134*, 12002.

(2) Akai, S.; Okuno, T.; Egi, M.; Takada, T.; Tohma, H.; Kita, Y. *Heterocycles* **1996**, *42*, 47.

(3) Fernández González, D.; Brand, J. P.; Waser, J. *Chem. Eur. J.* **2010**, *16*, 9457.

(4) Eisenberger, P.; Gischig, S.; Togni, A. *Chem. Eur. J.* **2006**, 12, 2579.

(5) Emelen, K. V.; De Wit, T.; Hoornaert, G. J.; Compernolle, F. *Tetrahedron* **2002**, *58*, 4225

(6) Kobayashi, S.; Gustafsson, T.; Shimizu, Y; Kiyohara, H.; Matsubara, R. *Org. Lett*. **2006**, *8*, 4923.

(7) Hale, K. J.; Grabski, M.; Flasz, J.T**.** *Org. Lett*. **2013**, *15*, 370.

(8) Moss, T. A.; Fenwick, D. R.; Dixon, D. J. *J. Am. Chem. Soc.* **2008**, *130*, 10076.

(9) Smith, A. M. R.; Rzepa, H. S.; White, A. J. P.; Billen, D.; Hii, K. K. *J. Org. Chem.* **2010**, *75*, 3085.

(10) Fernandez Gonzalez, D.; Waser, J.; *Adv. Synth. Catal.* **2013**, *DOI: 10.1002/adsc.20130026*.

(11) Sato, K.; Isoda, M.; Ohata, S.; Morita, S.; Tarui, A.; Omote, M.; Kumadaki, I; Ando, A. *Adv. Syn. Catal.* **2012**, *354*, 510.

(12) Zhang, Z.; Liu, Y.; Gong, M.; Zhao, X.; Zhang, Y.; Wang, J. *Angew. Chem., Int. Ed.* **2010**, *49*, 1139.

(13) Poulsen, T. B.; Bernardi, L.; Aleman, J.; Overgaard, J.; Jorgensen, K. A. *J. Am. Chem. Soc* **2007**, *129*, 441.

(14) Jones, R. A.; Stokes, M. J. *Tetrahedron* **1984**, *40*, 1051.

(15) Sheridan, H.; Walsh, J J.; Cogan, C.; Jordan, M.; McCabe, T.; Passante, E.; Frankish, N. H. *Bioorg. Med. Chem. Lett.* **2009**, *19*, 5927.

(16) Aljarilla, A.; Cordoba, R.; Csaky, A. G.; Fernandez, I.; Ortiz, F. L.; Plumet, J.; Gomez, G. R., *Eur. J. Org. Chem*. **2006**, 3969.

(17) Einaga, H.; Nojima, M.; Abe, M. *J. Chem. Soc. Perkin Trans. 1* **1999**, *17*, 2507.

(18) Luttikhedde, H. J. G; Leino, R.; Lehtonen, A.; Naesman, J. H. *J. Organomet. Chem.* **1998**, *555*, 127.

(19) Pouliot, M.; Renaud, P.; Studer, A.; Vogler, T.; Schenk, K., *Angew. Chem. Int. Ed.* **2009**, *48*, 6037.

(20) Cheon, C.H.; Kanno, O.; Toste, F. D. *J. Am. Chem. Soc*. **2011**, *133*, 13248.

(21) Eames, J.; Coumbarides, Gregory S.; Suggate, Michael J.; Weerasooriya, N., *Eur. J. Org. Chem*. **2003** , 4, 634 – 641.

(22) Shibatomi, K.; Soga, Y.; Narayama, A.; Fujisawa, I.; Iwasa, S. *J. Am. Chem. Soc.* **2012**, *134*, 9836.

(23) Deng, Q-H.; Bleith, T.; Wadepohl, H.; Gade, L. H. *J. Am. Chem. Soc.* **2013**, *135,* 5356.

(24) Youn, S. W.; Kim, B. S.; Jagdale, A. R. *J. Am. Chem. Soc.* **2012**, *134*, 11308.

(25) Benati, L.; Nanni, D.; Sangiorgi, C.; Spagnolo, P. *J. Org. Chem.* **1999**, *64*, 7836.

(26) Harschneck, T.; Hummel, S.; Kirsch, S. F.; Klahn, P. *Chem. Eur. J.* **2012**, *18*, 1187.

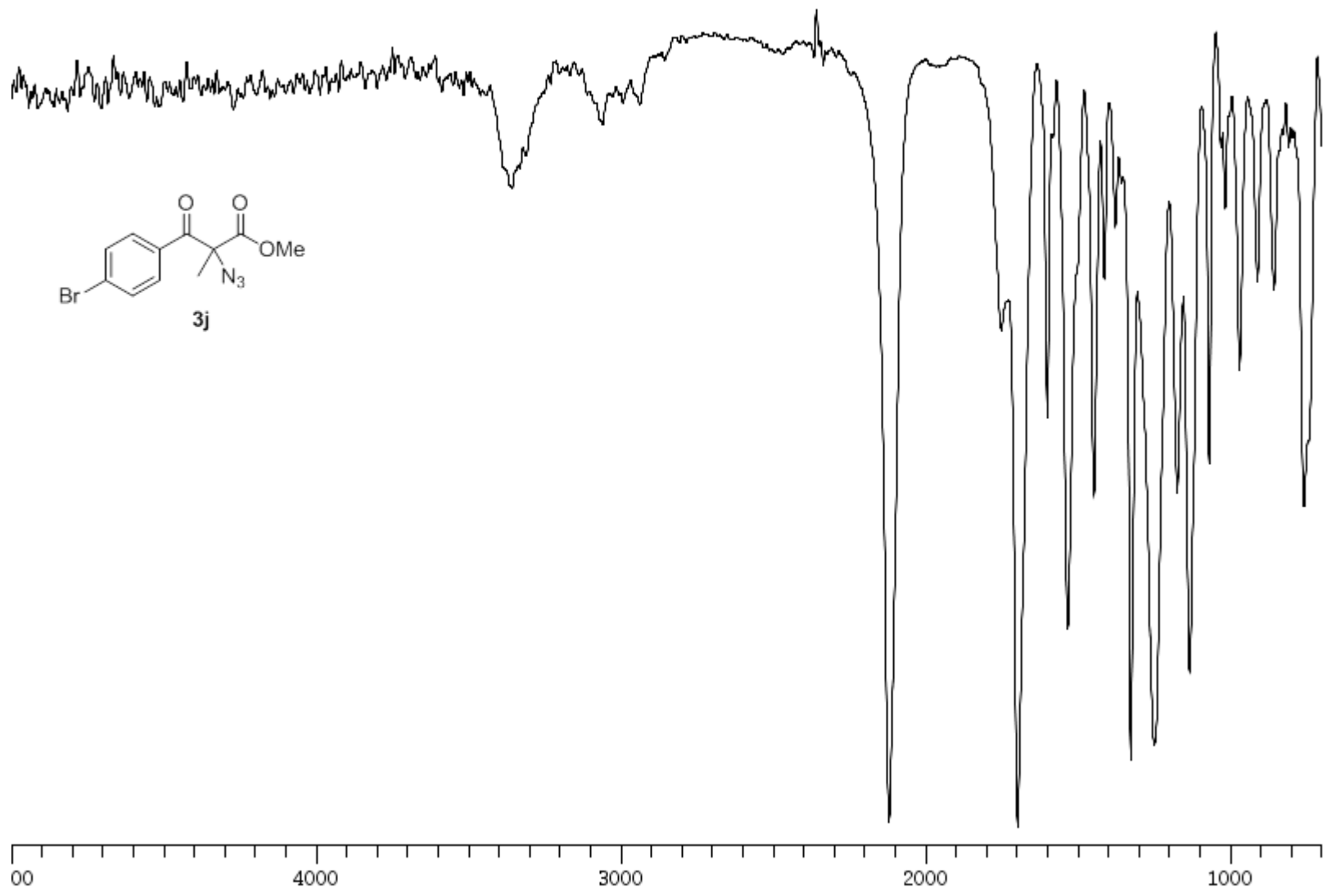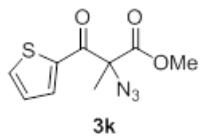(27) Patonay, T.; Hoffman, R. V. *J. Org. Chem*. **1994**, *59*, 2902.
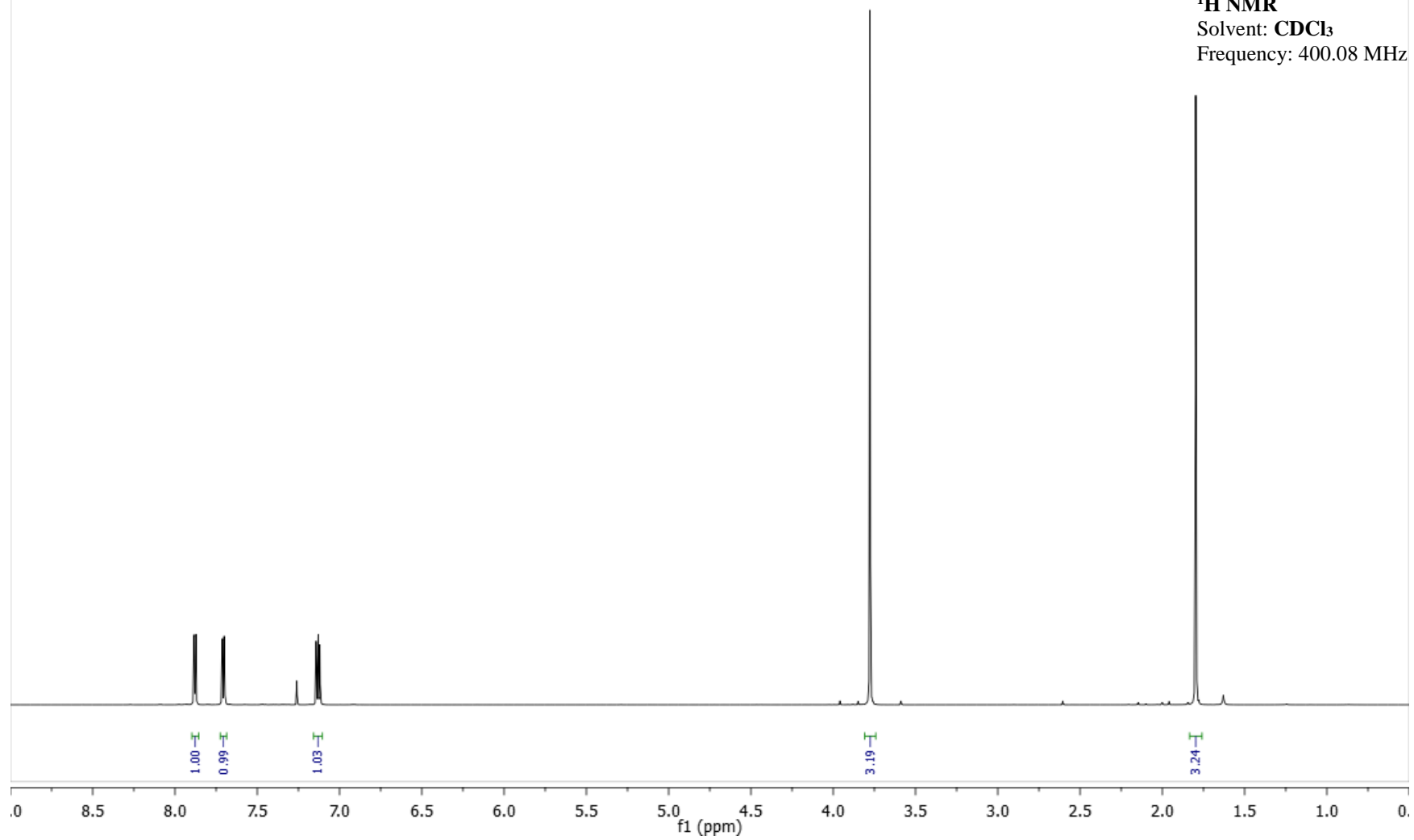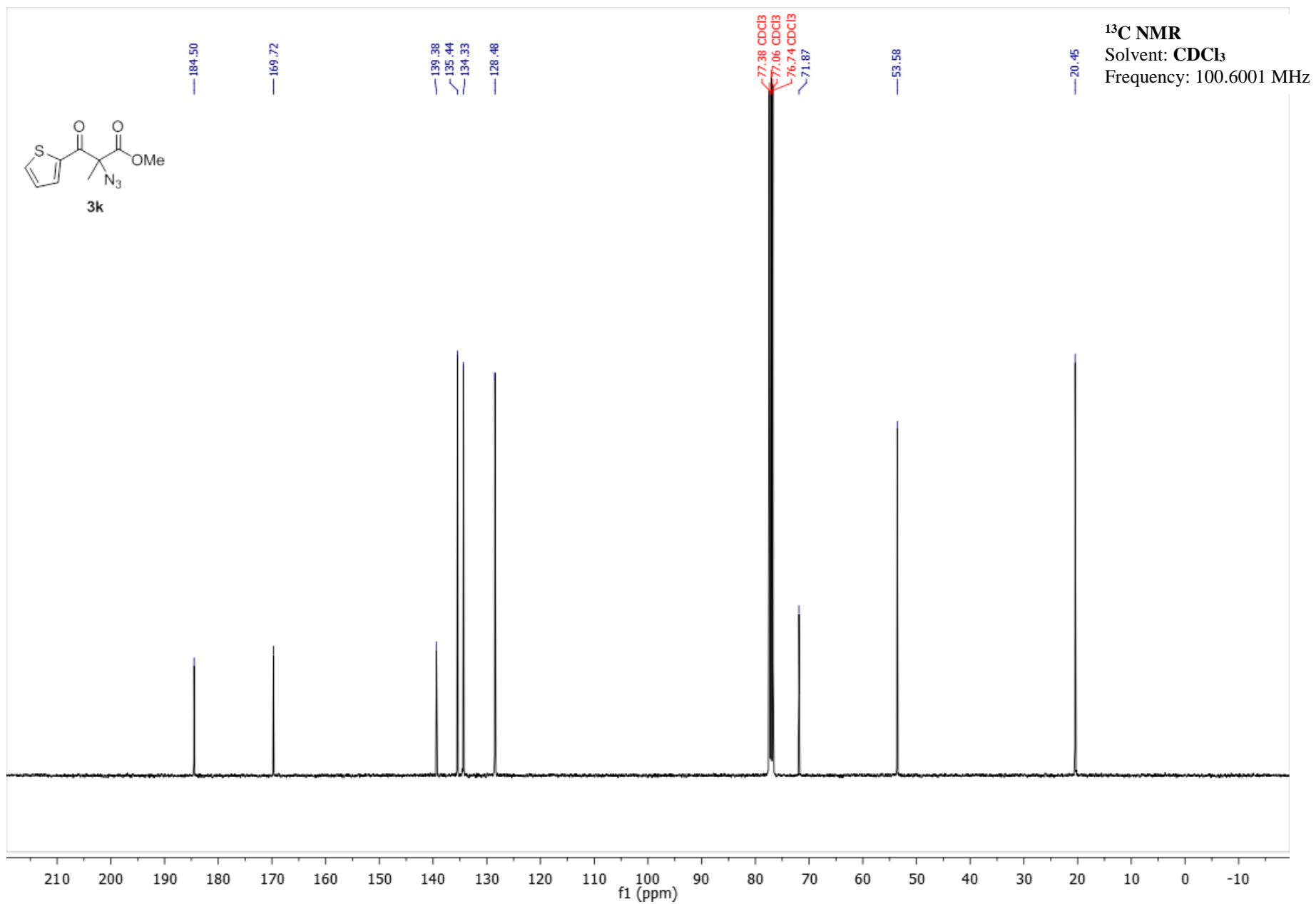
10.Spectra ds (^{1}HNMR, ^{13}CNMR, IR)
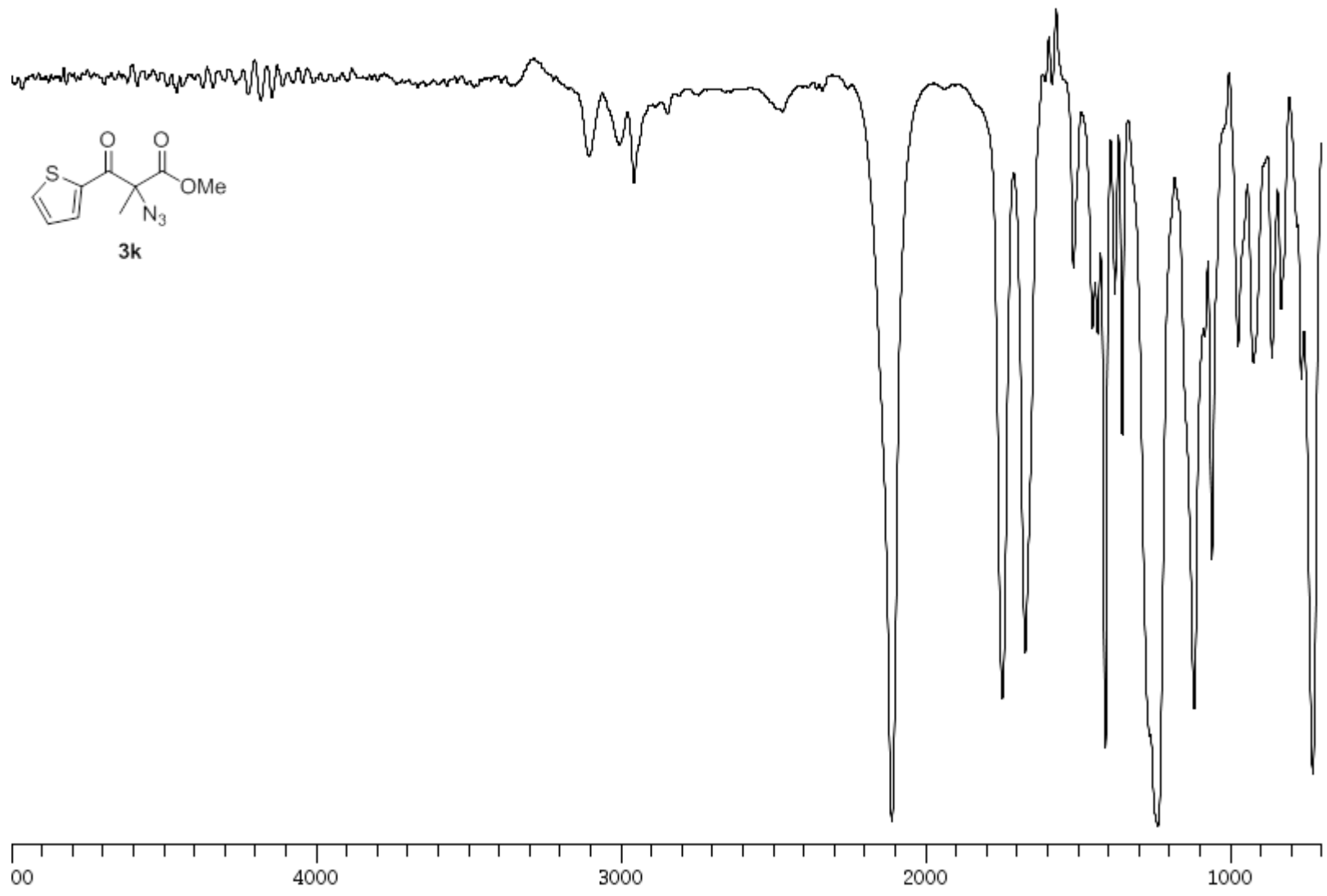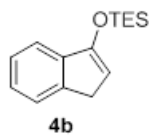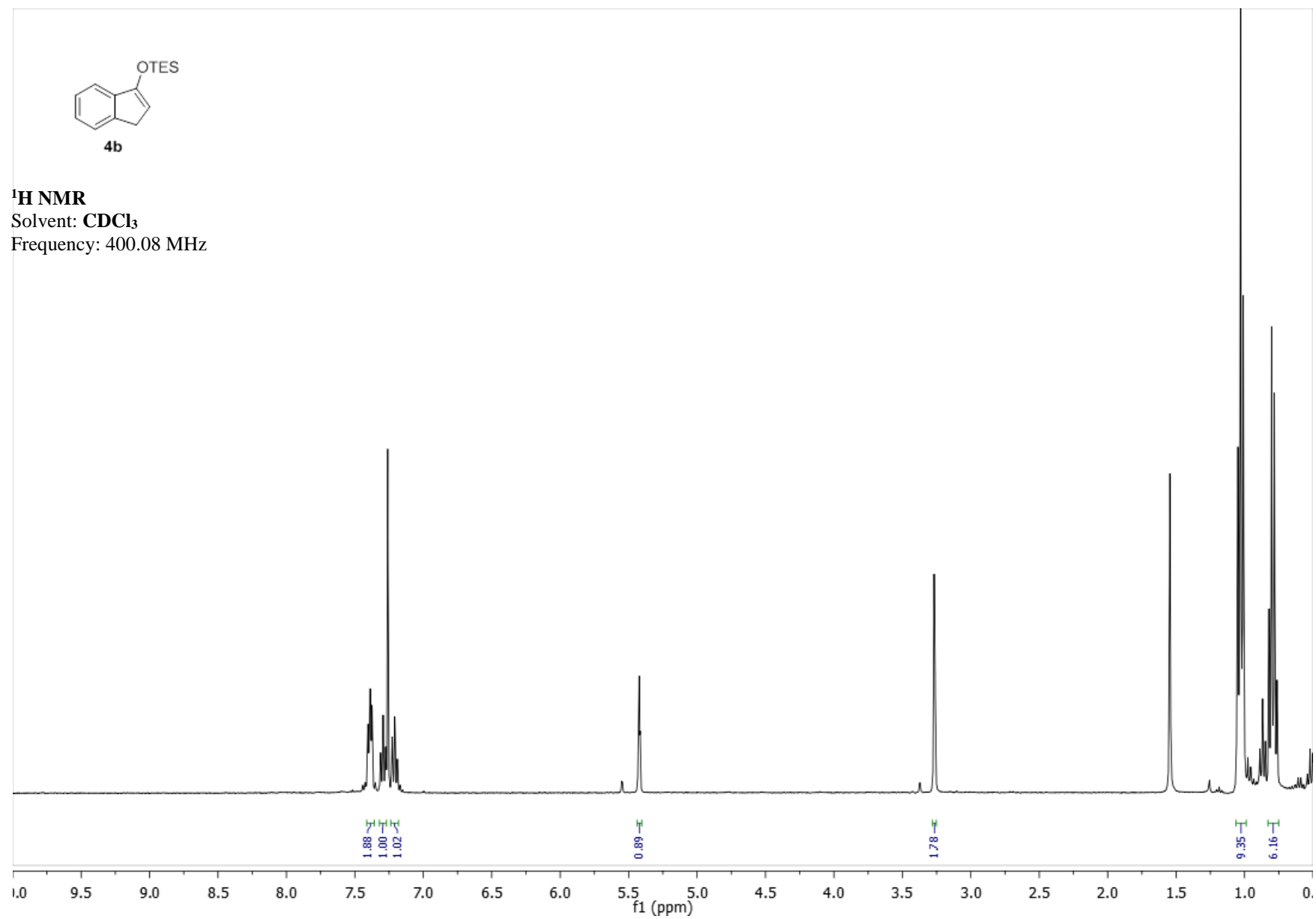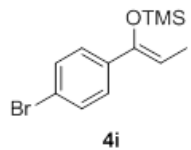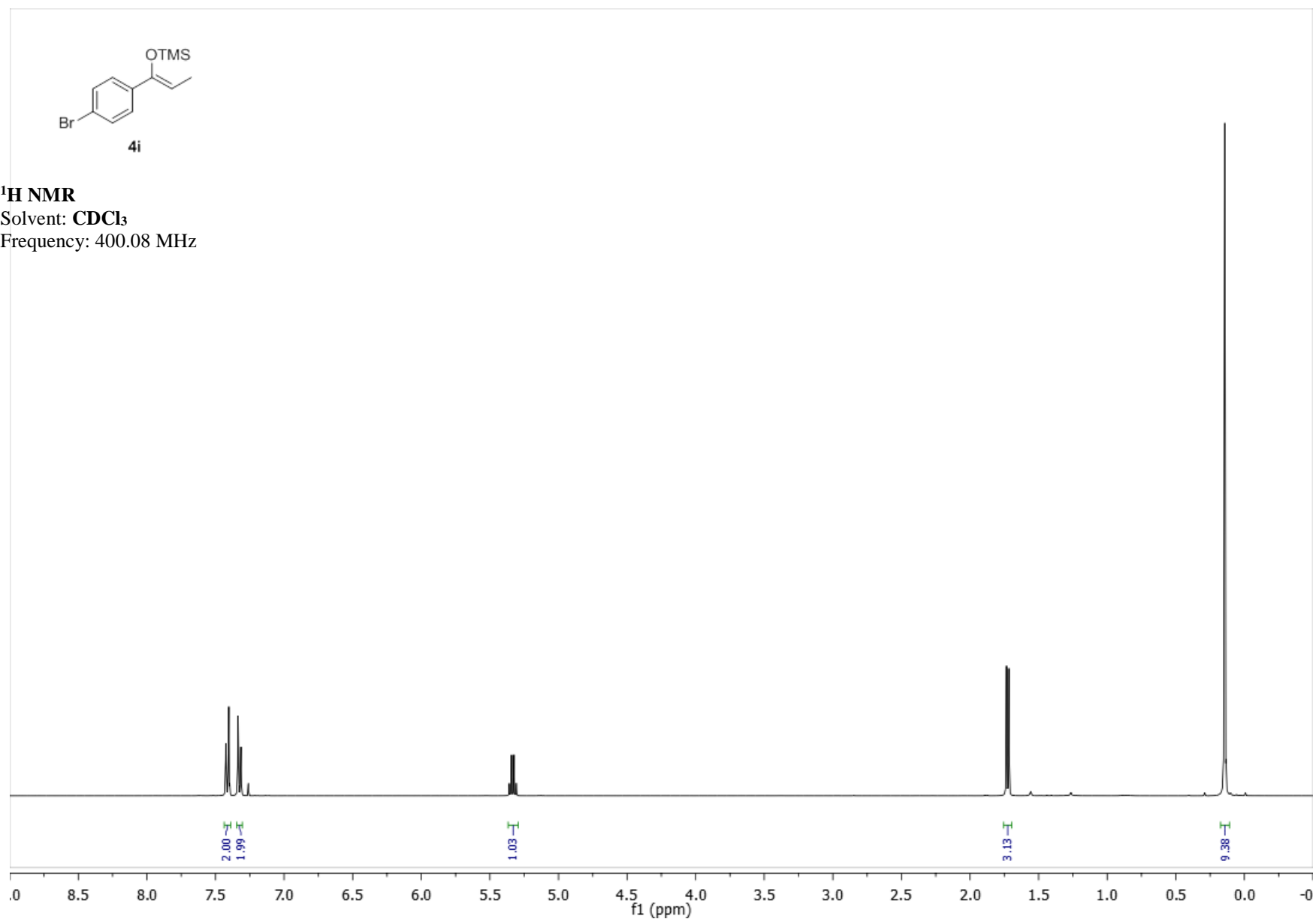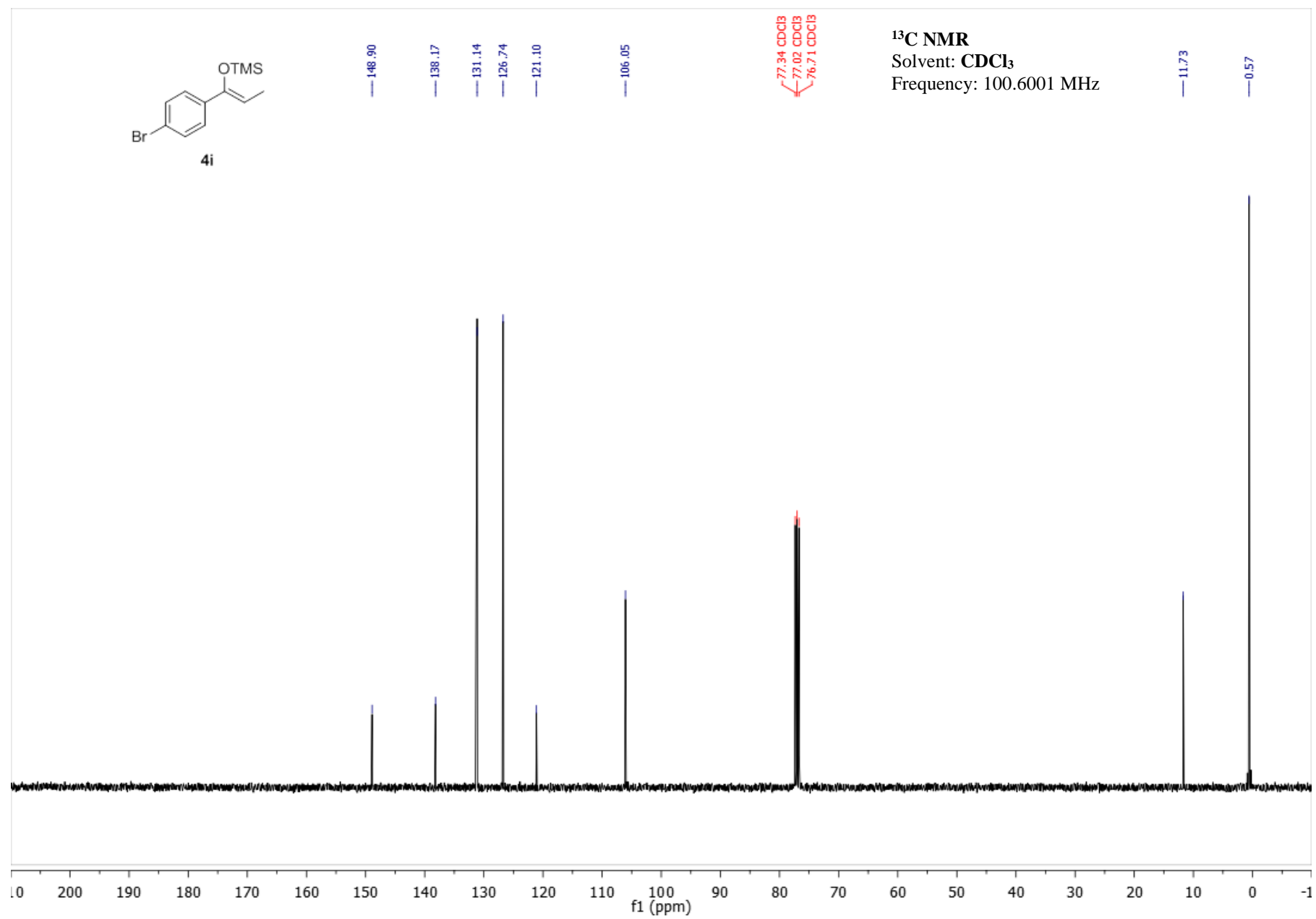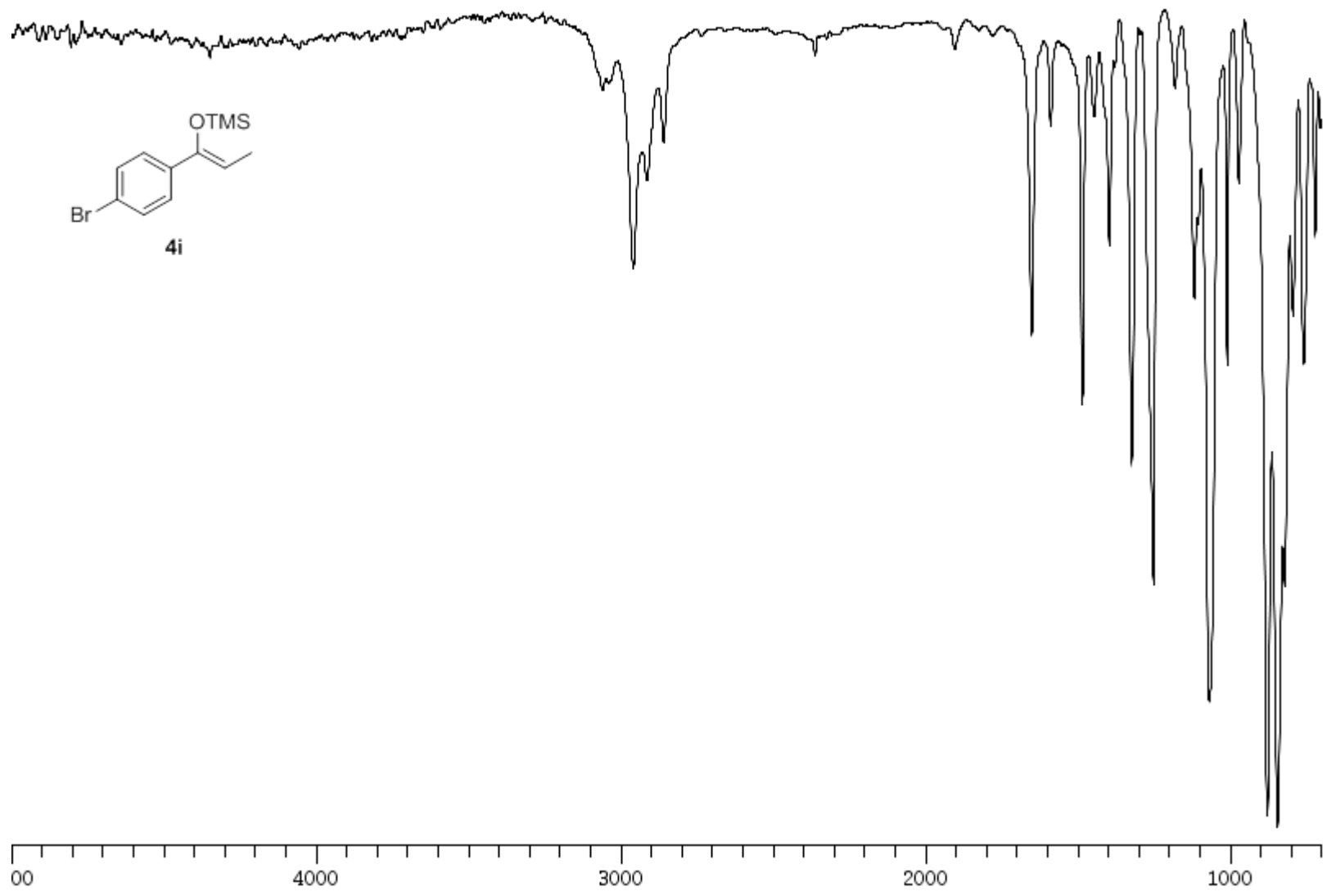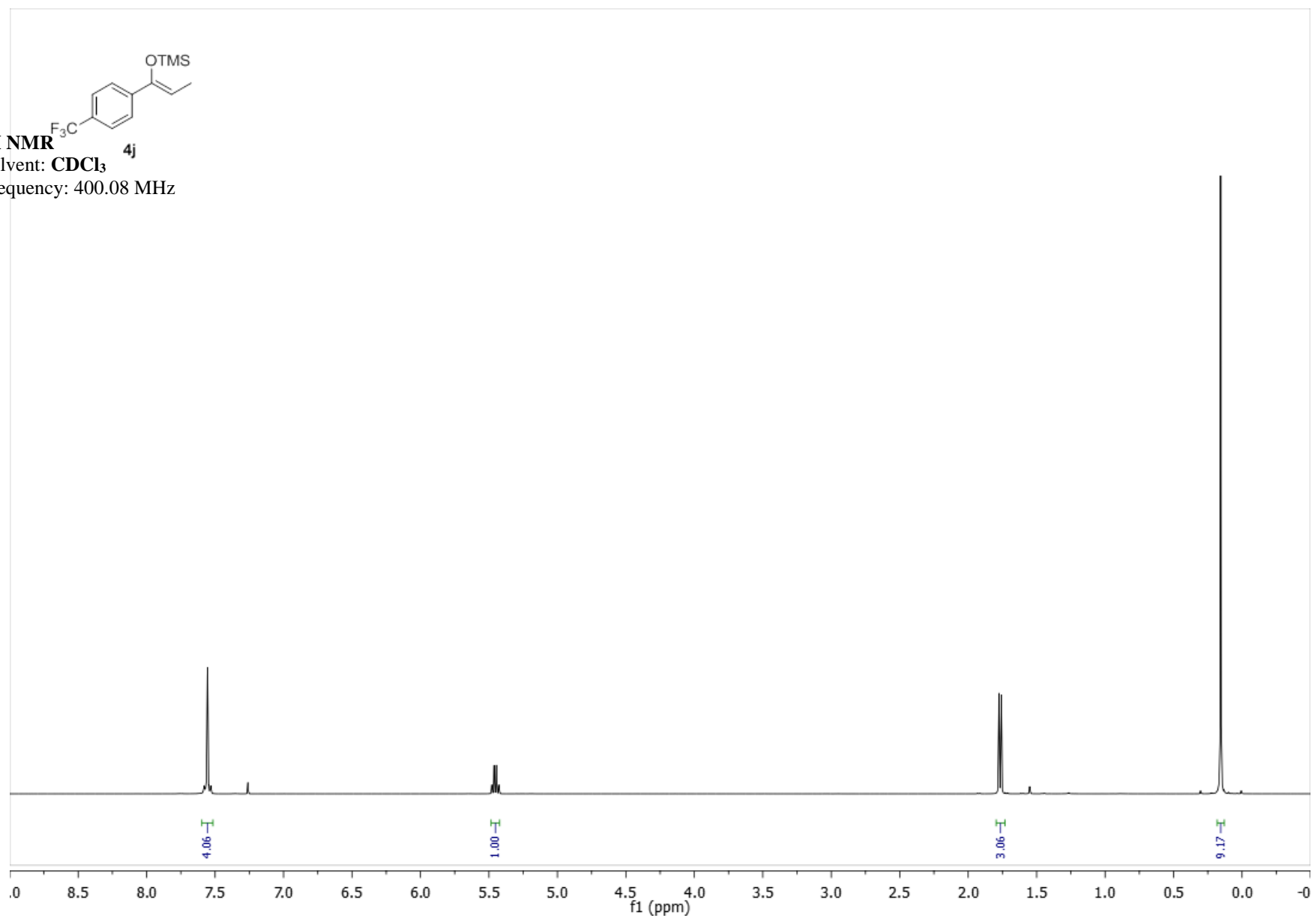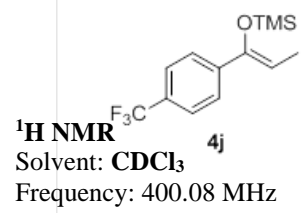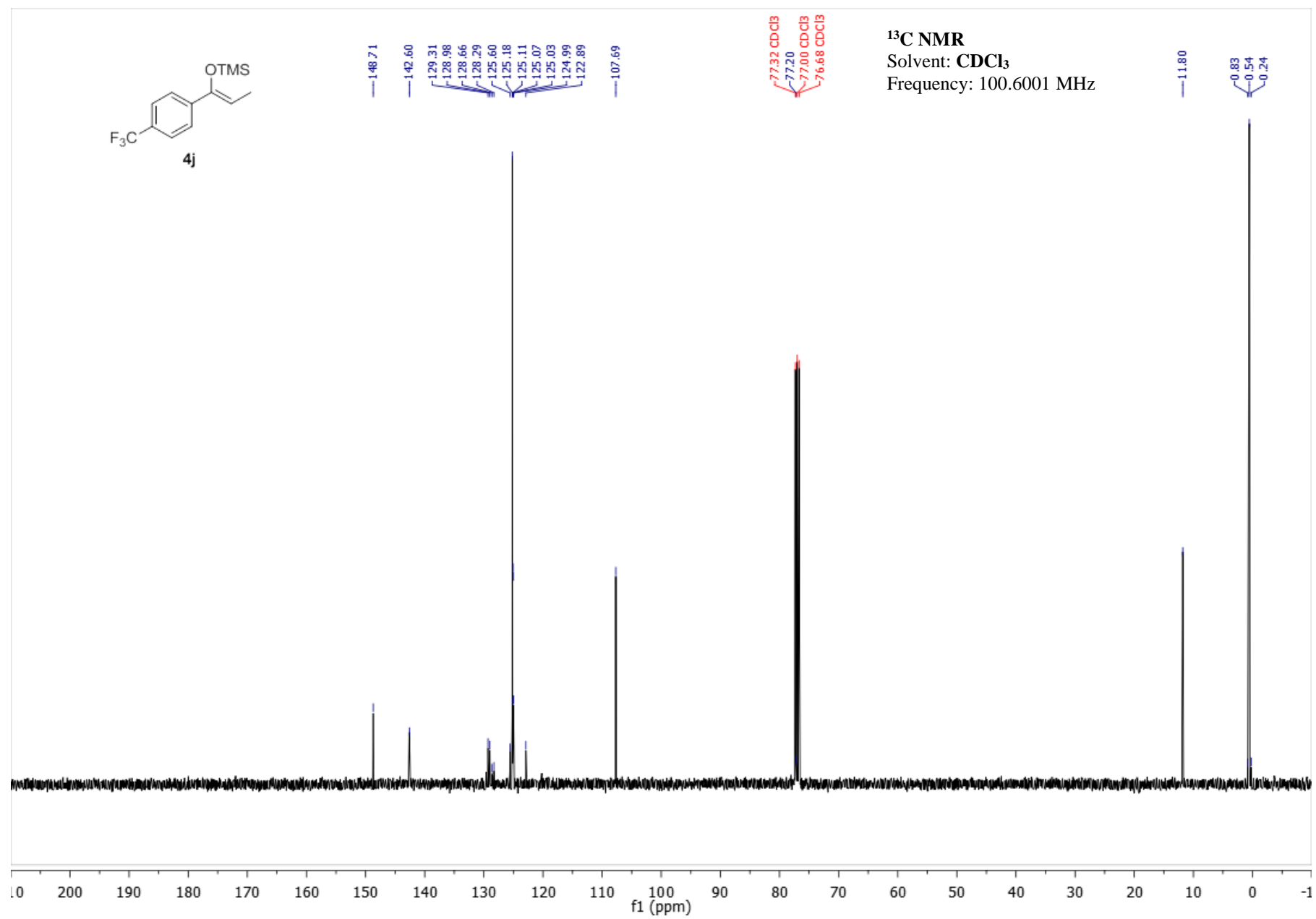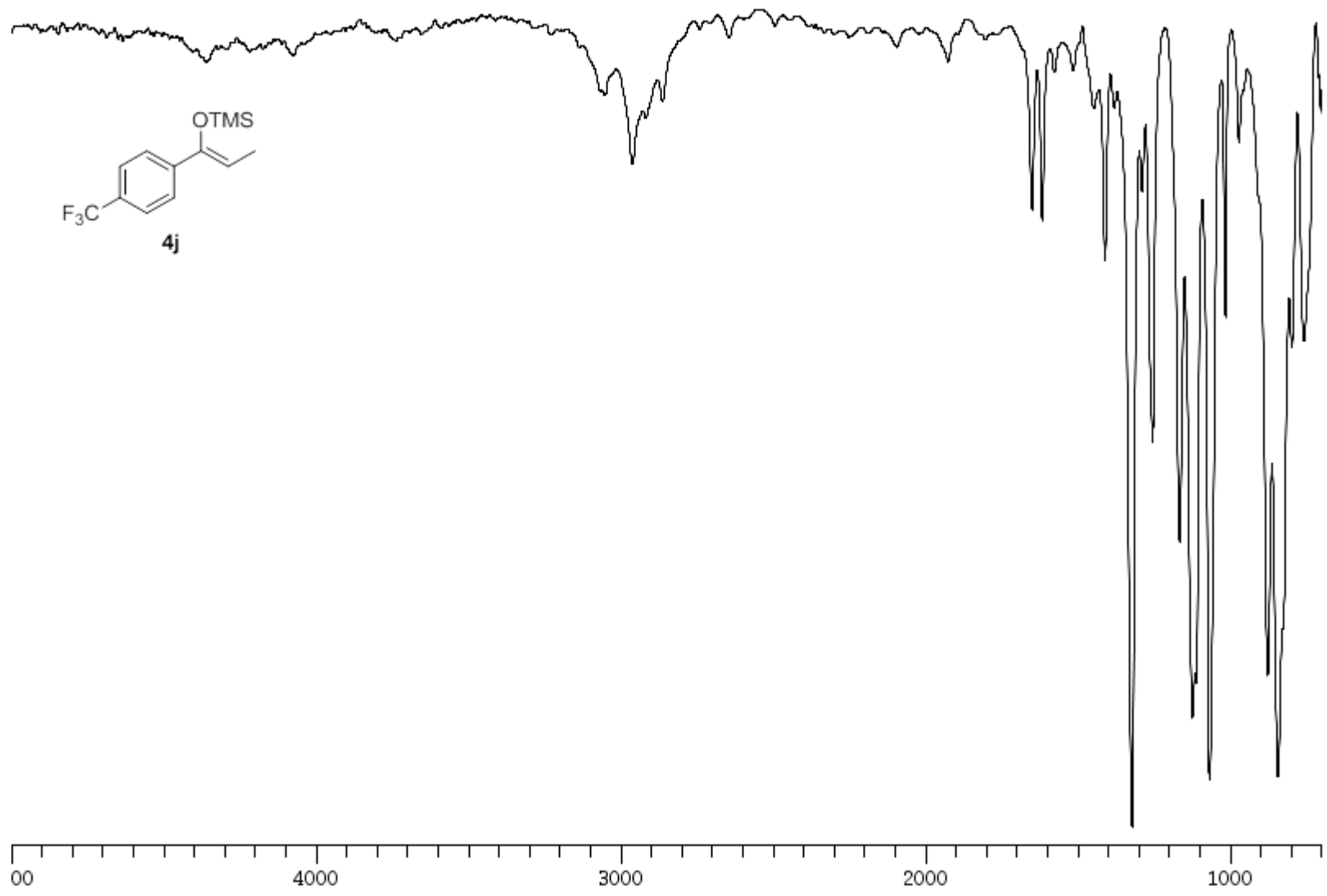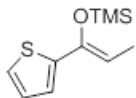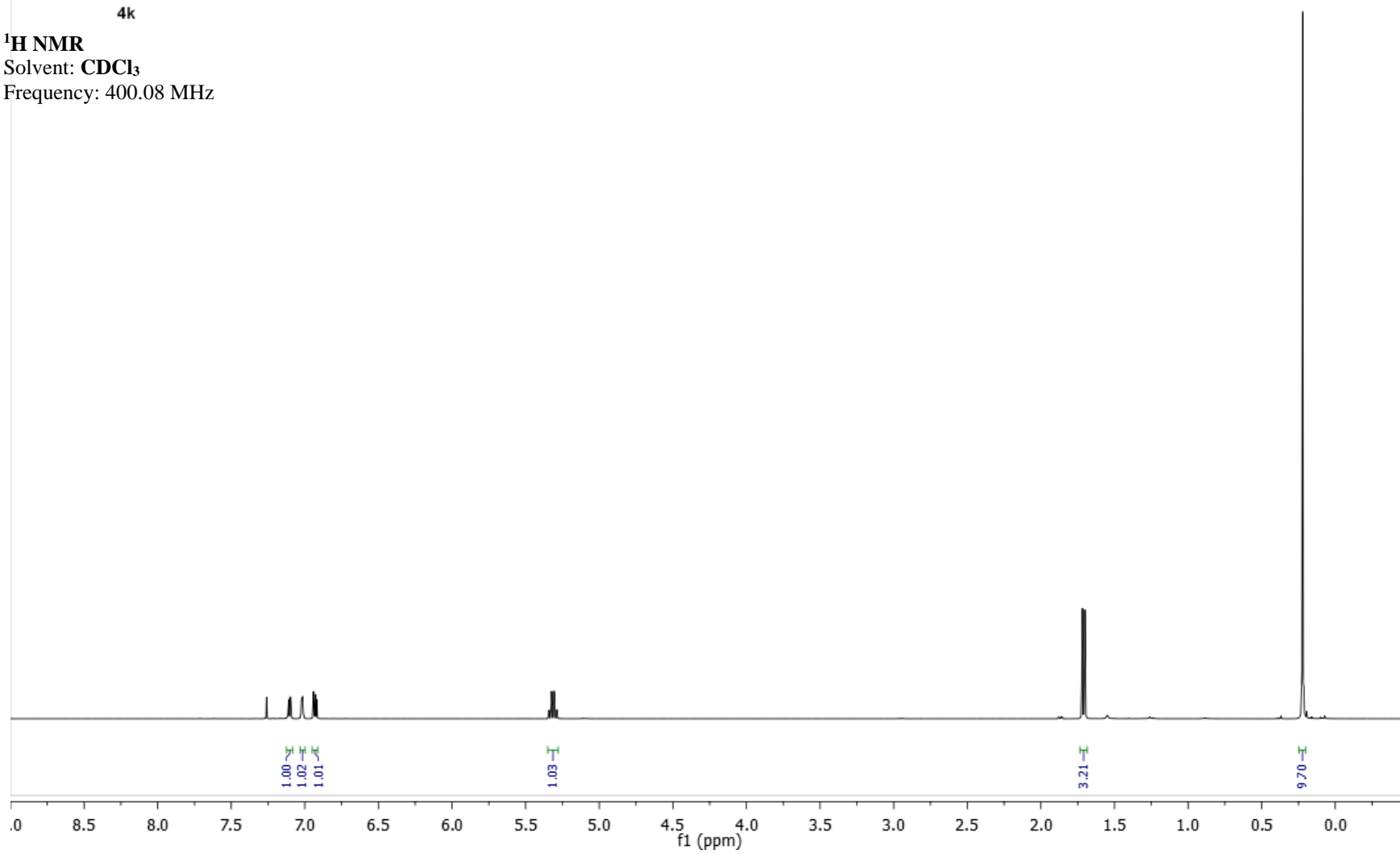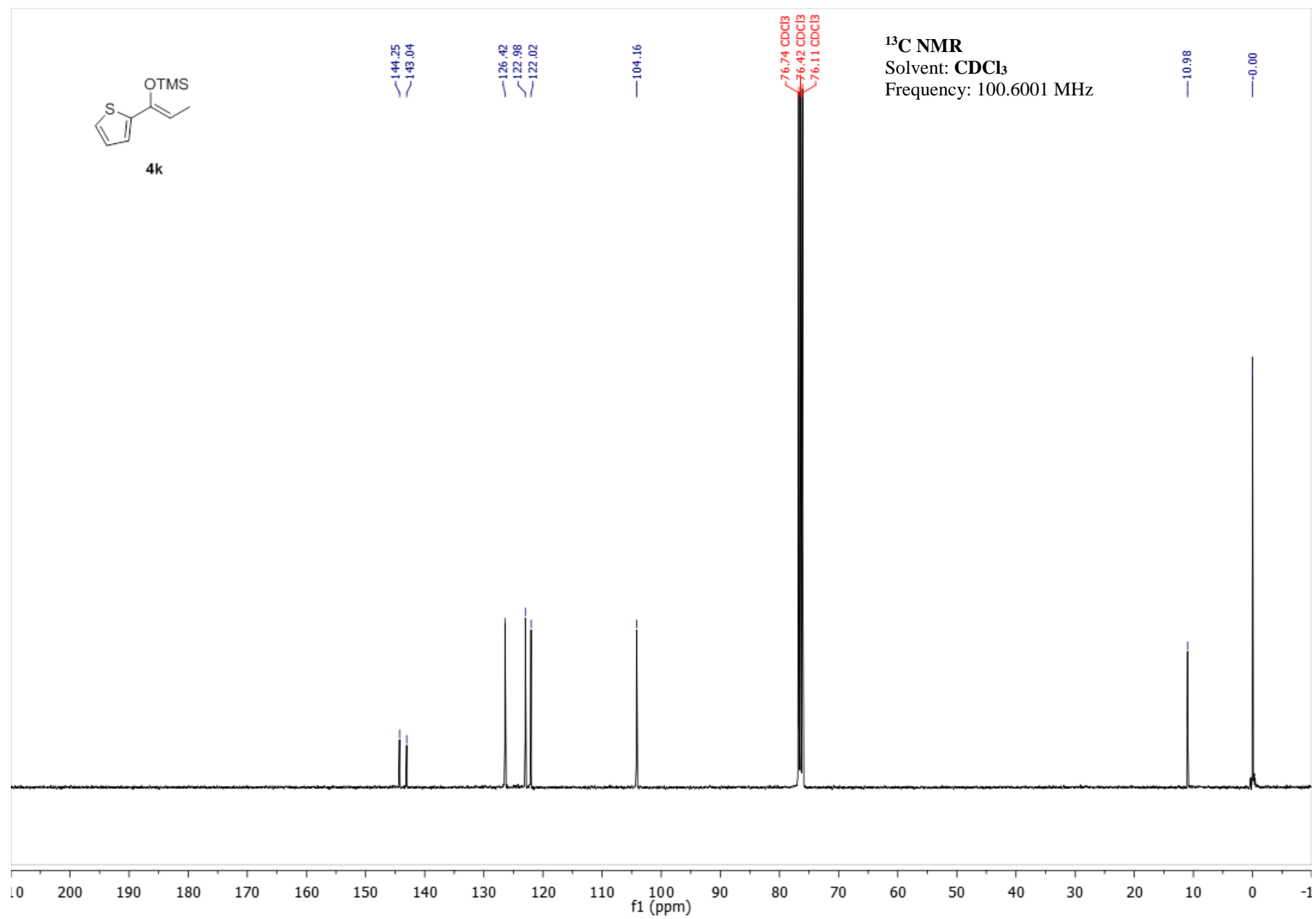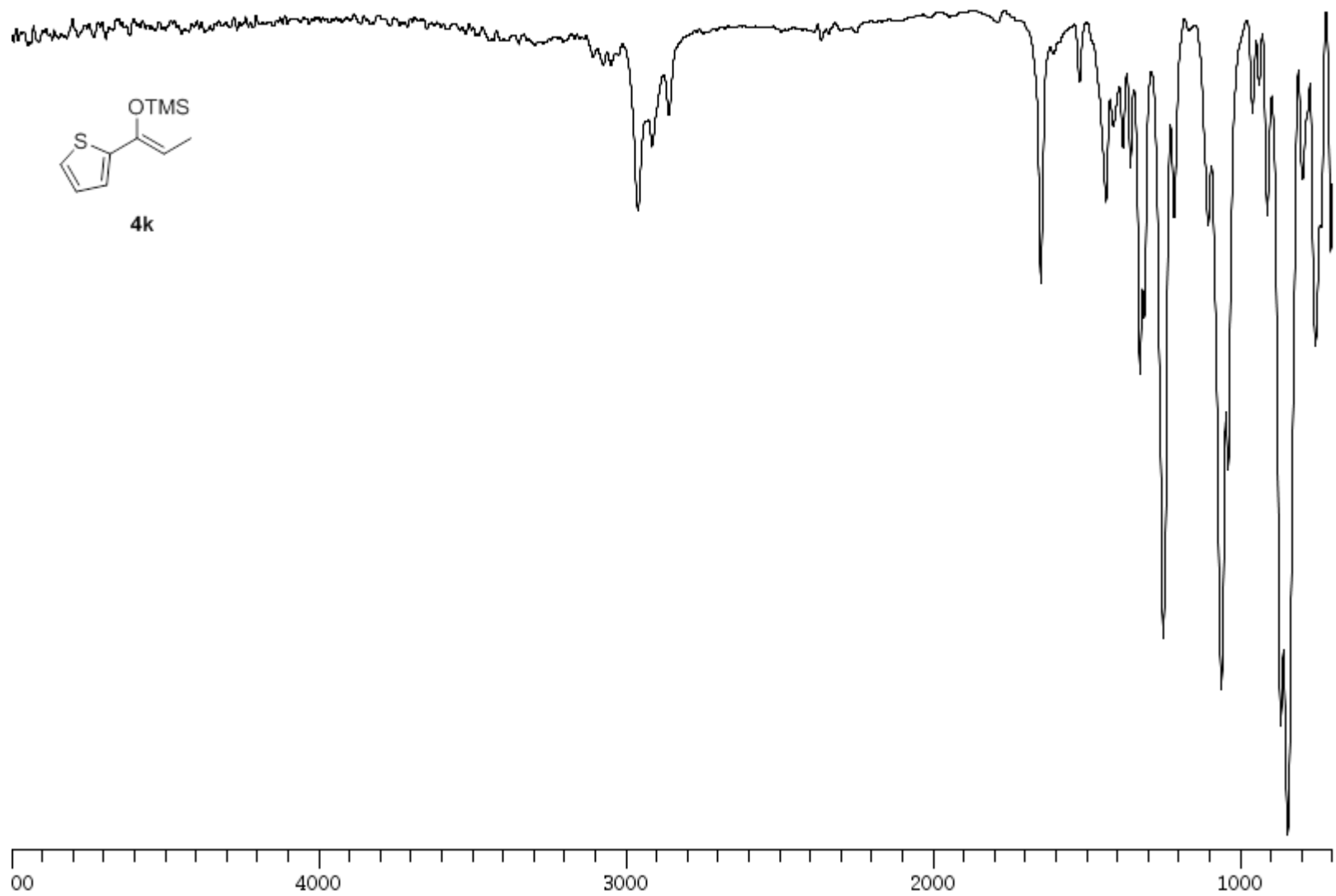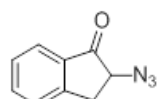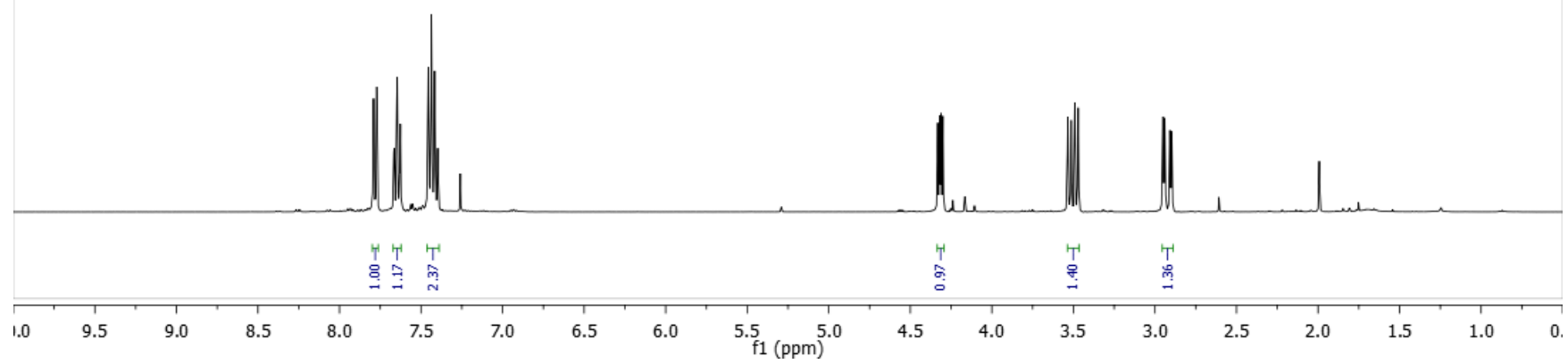
1c

¹H NMR
Solvent: **CDCl₃**
Frequency: 400.08 MHz

S31

^{13}C NMR
Solvent: CDCl$_3$
Frequency: 100.6001 MHz

198.05
169.16
151.69
141.15
138.66
136.85
135.50
134.45
133.32
129.48
127.75
125.94
124.46
120.97
103.73
77.35 CDCl3
77.34
77.03 CDCl3
76.71 CDCl3
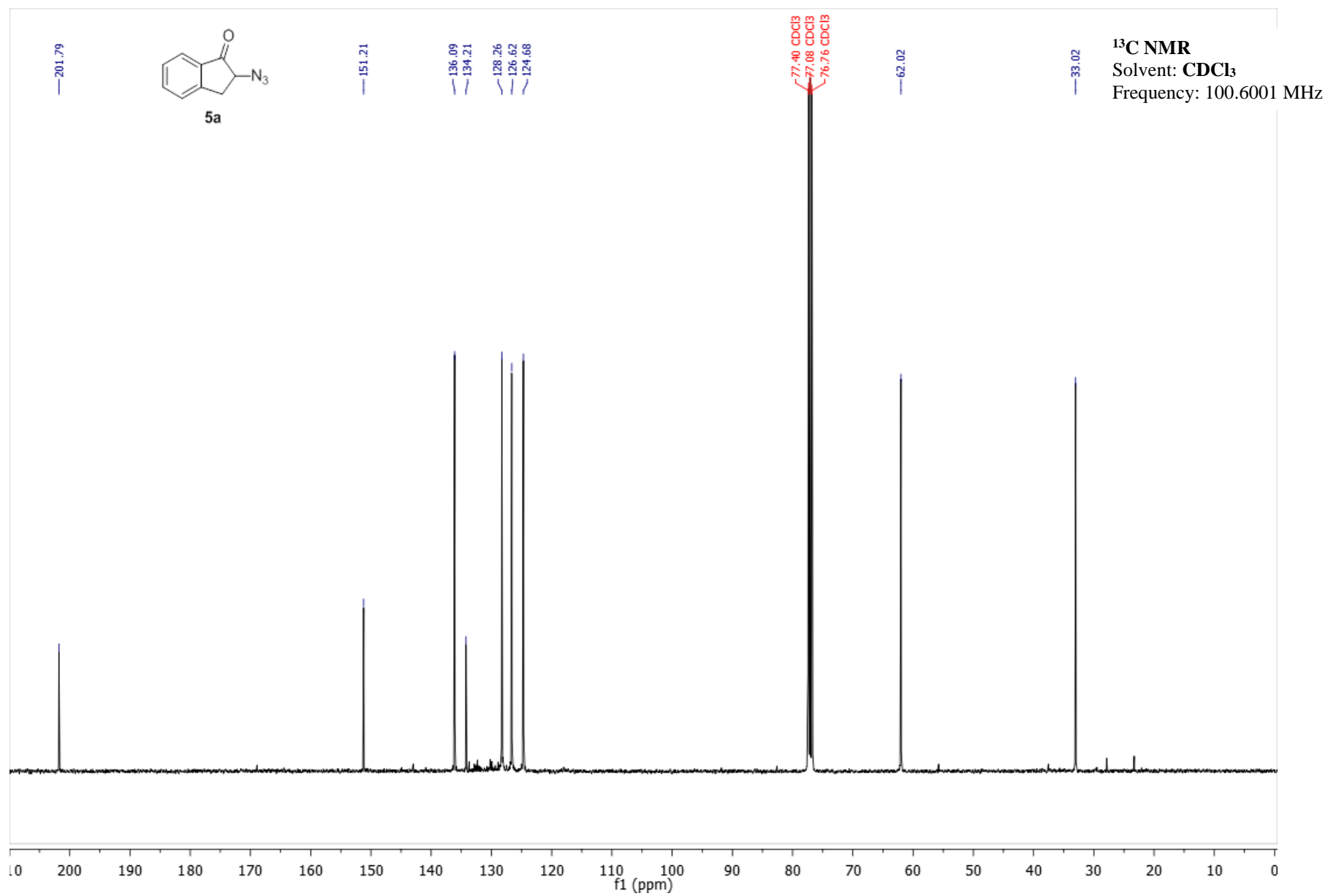53.58
52.94
51.56
32.28
29.87

1c

f1 (ppm)

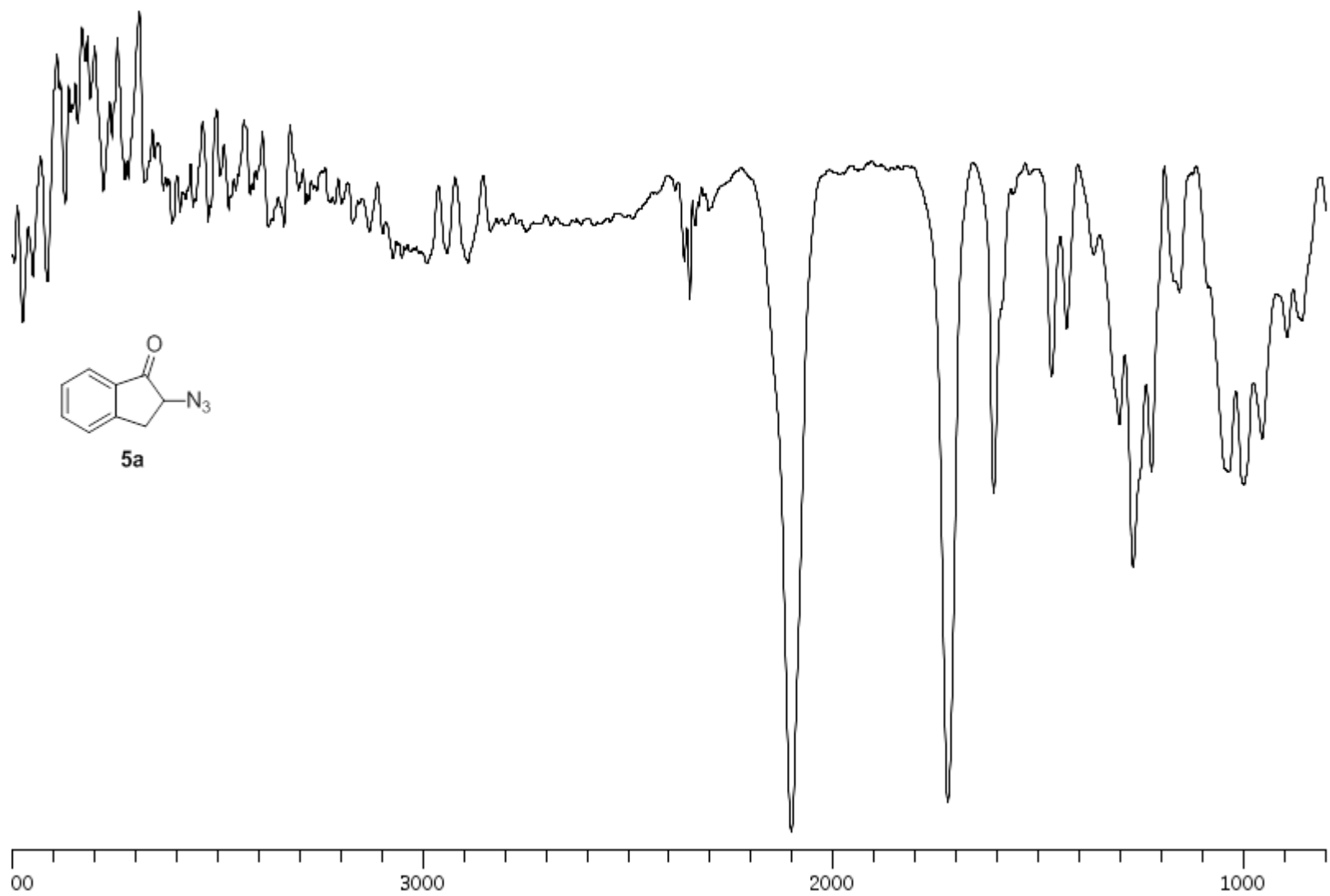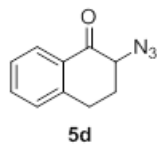S32

1c

1d

¹H NMR
Solvent: **CDCl₃**
Frequency: 400.08 MHz

¹³C NMR
Solvent: CDCl₃
Frequency: 100.6001 MHz

1d

¹H NMR
Solvent: **CDCl₃**
Frequency: 400.08 MHz

3a

^{13}C NMR
Solvent: **CDCl₃**
Frequency: 100.6001 MHz

195.17
169.20
166.73
155.21
127.43
125.99
116.65
109.55
77.37 CDCl3
77.05 CDCl3
76.73 CDCl3
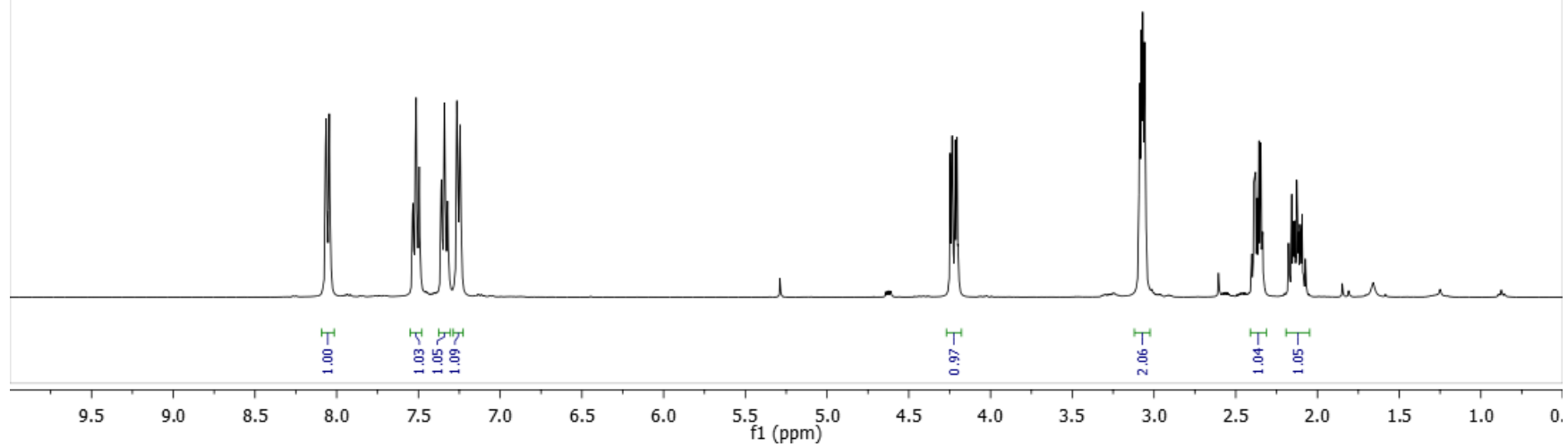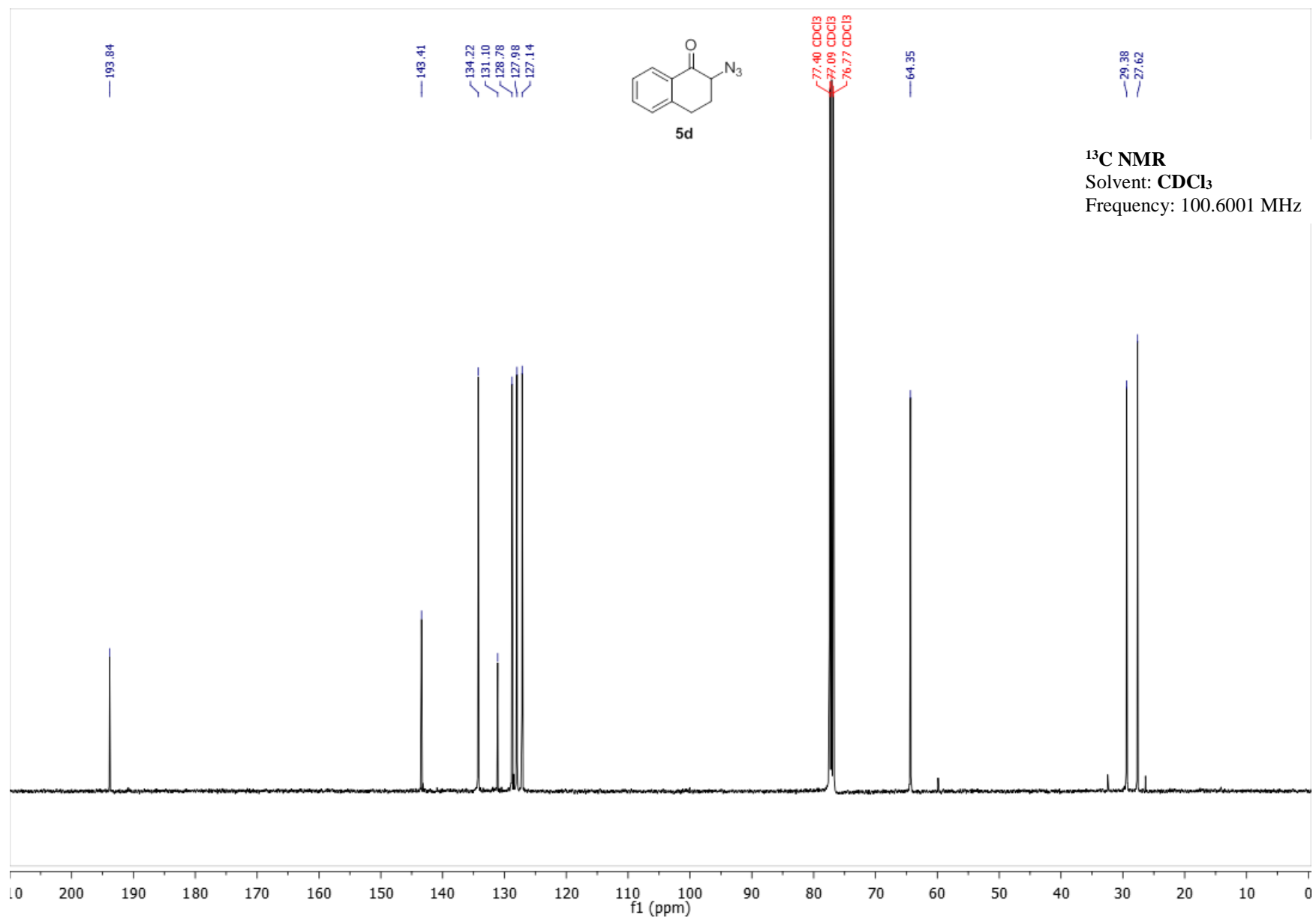70.54
55.90
53.51
38.47

3a

3a

¹H NMR
Solvent: **CDCl₃**
Frequency: 400.08 MHz

^{13}C NMR
Solvent: CDCl$_3$
Frequency: 100.6001 MHz

197.33
168.93
152.04
136.53
132.97
128.46
126.48
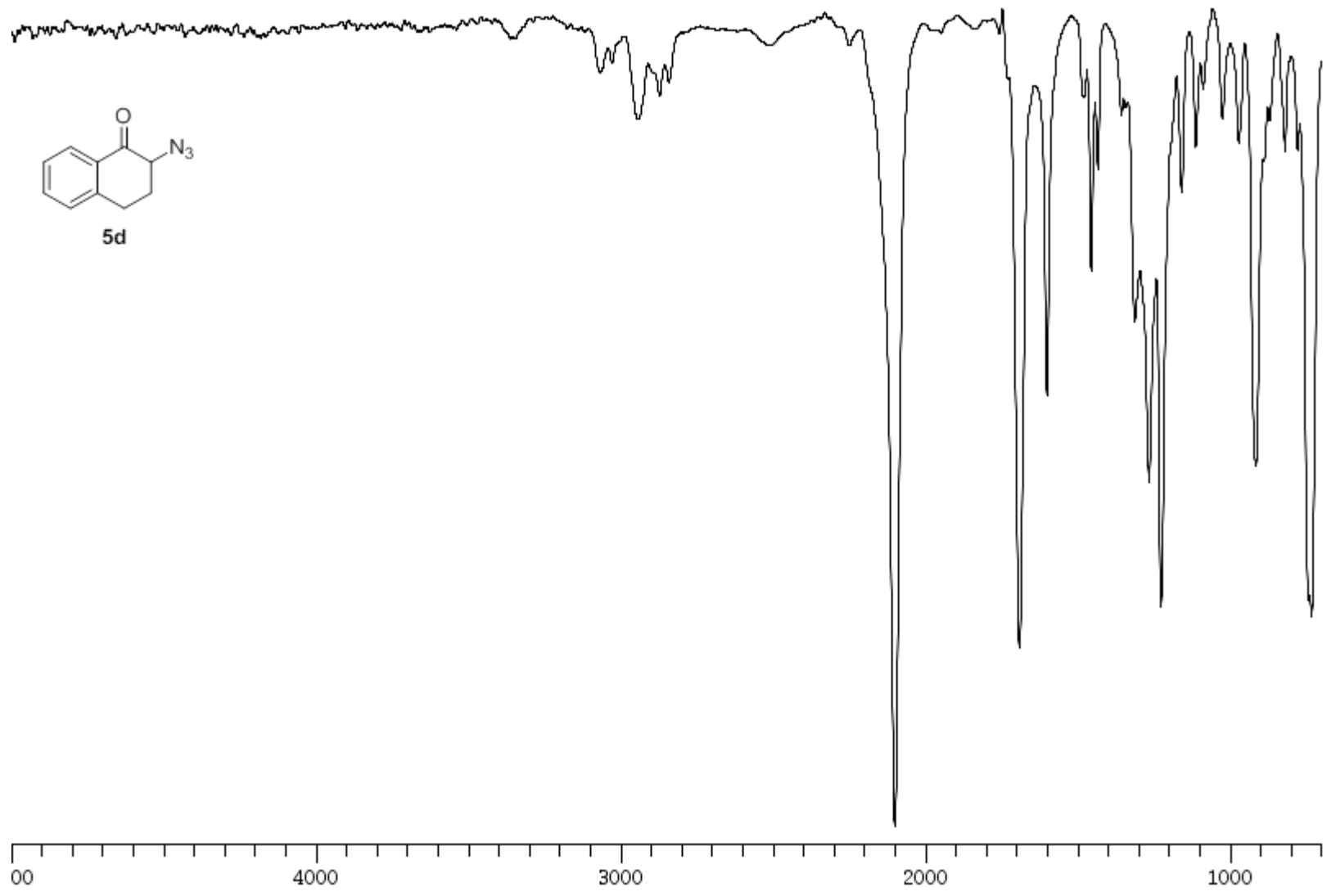125.62
70.19
53.54
38.50

3b

3b

3c

¹H NMR
Solvent: **CDCl₃**
Frequency: 400.08 MHz

195.47

169.37
168.65
166.79

155.13
155.03

129.35
128.15
128.05

117.09
116.85
113.49
113.26

77.40 CDCl3
77.08 CDCl3
76.76 CDCl3

70.32

53.64

38.33

3c

¹³C NMR
Solvent: **CDCl₃**
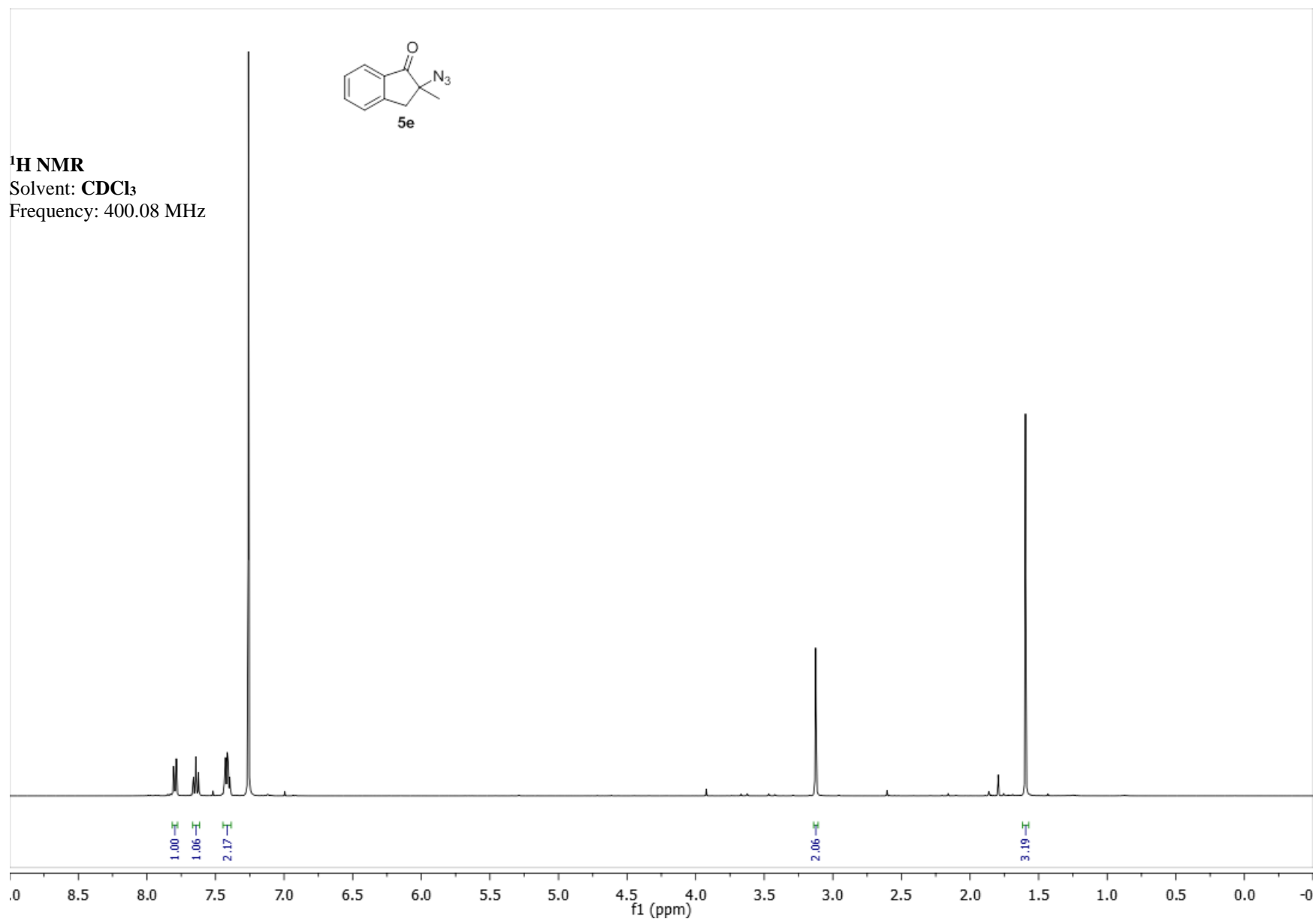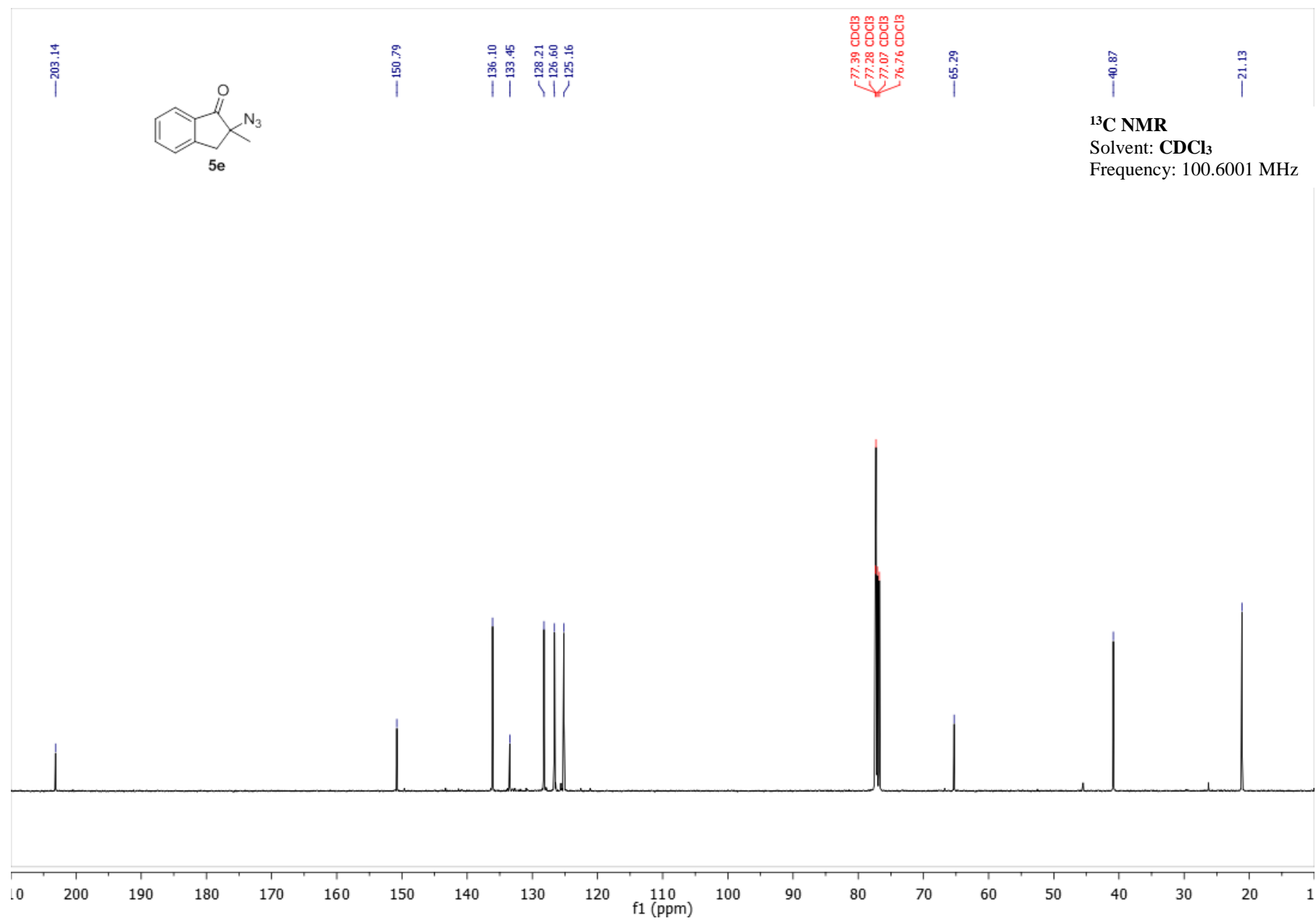Frequency: 100.6001 MHz

f1 (ppm)

3c

3d

¹H NMR
Solvent: **CDCl₃**
Frequency: 400.08 MHz

^{13}C NMR
Solvent: CDCl$_3$
Frequency: 100.6001 MHz

196.26
168.51
150.10
136.50
134.89
134.50
127.67
125.24
77.39 CDCl3
77.27
77.07 CDCl3
76.75 CDCl3
70.57
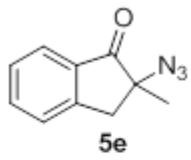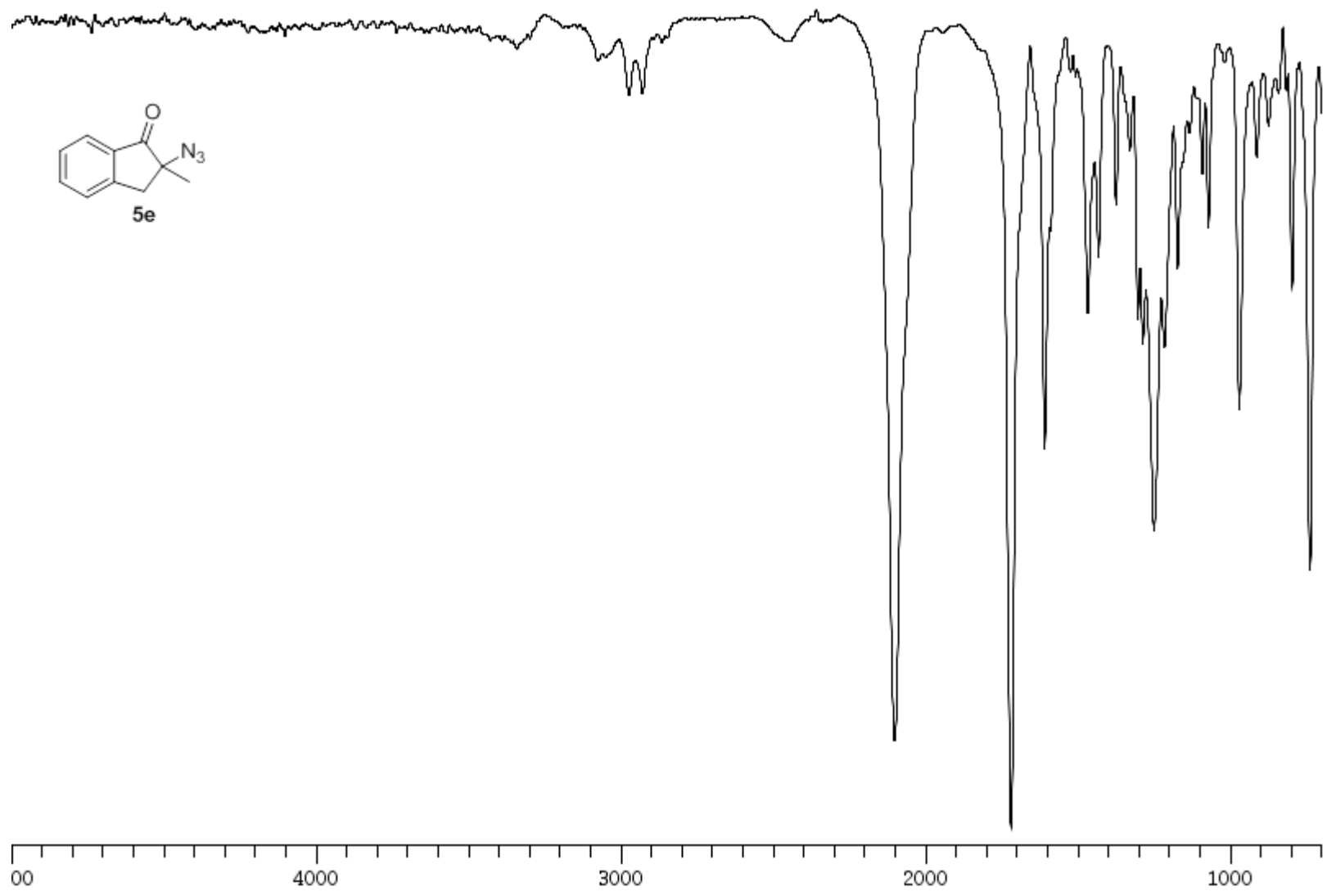53.70
38.14

3d

f1 (ppm)

3d

¹H NMR
Solvent: **CDCl₃**
Frequency: 400.08 MHz

197.98
167.29
152.23
136.27
133.16
128.26
126.36
125.42
84.45
70.47
38.51
27.63

3e

¹³C NMR
Solvent: CDCl₃
Frequency: 100.6001 MHz

3e

3f

¹H NMR
Solvent: **CDCl₃**
Frequency: 400.08 MHz
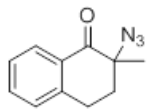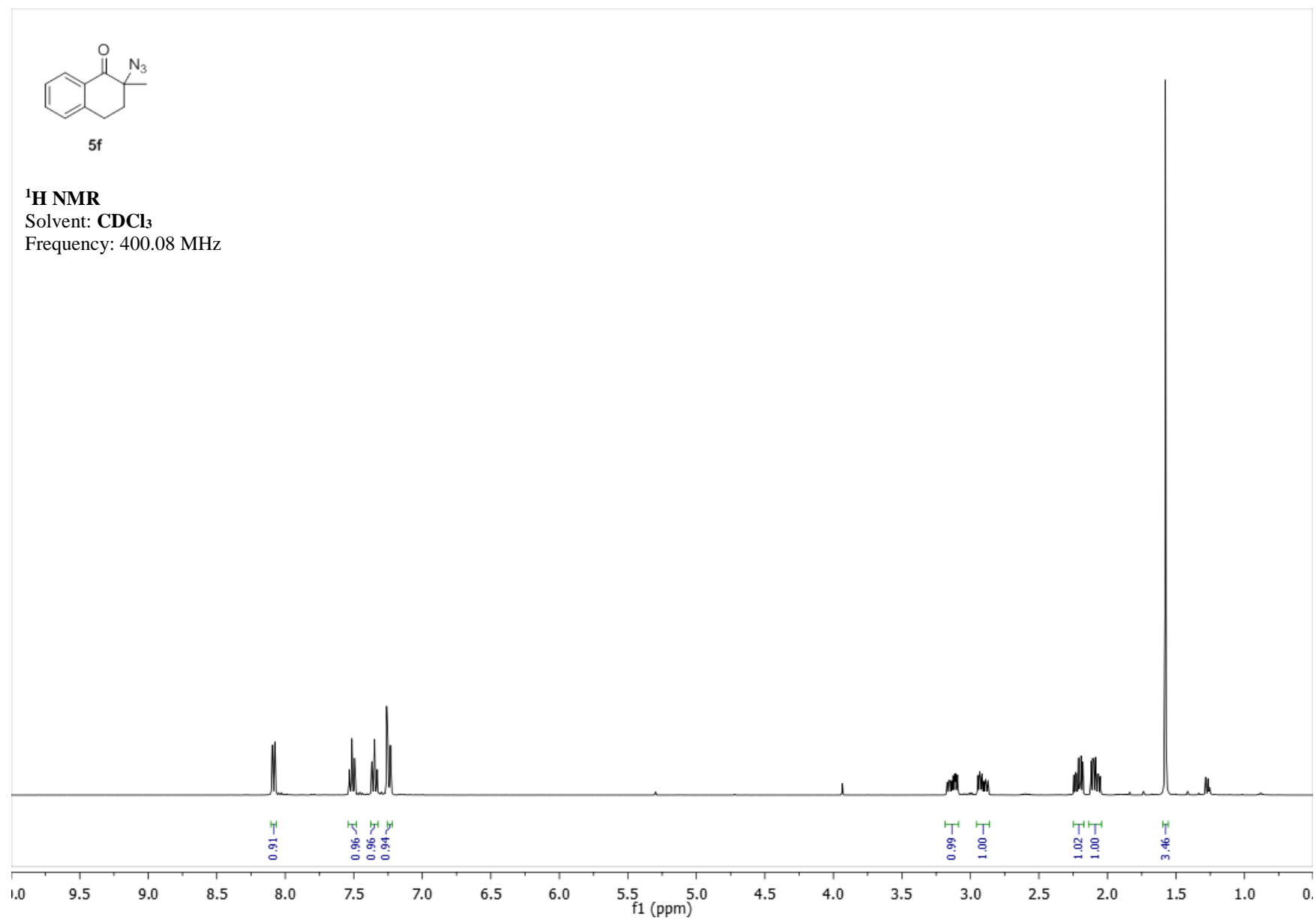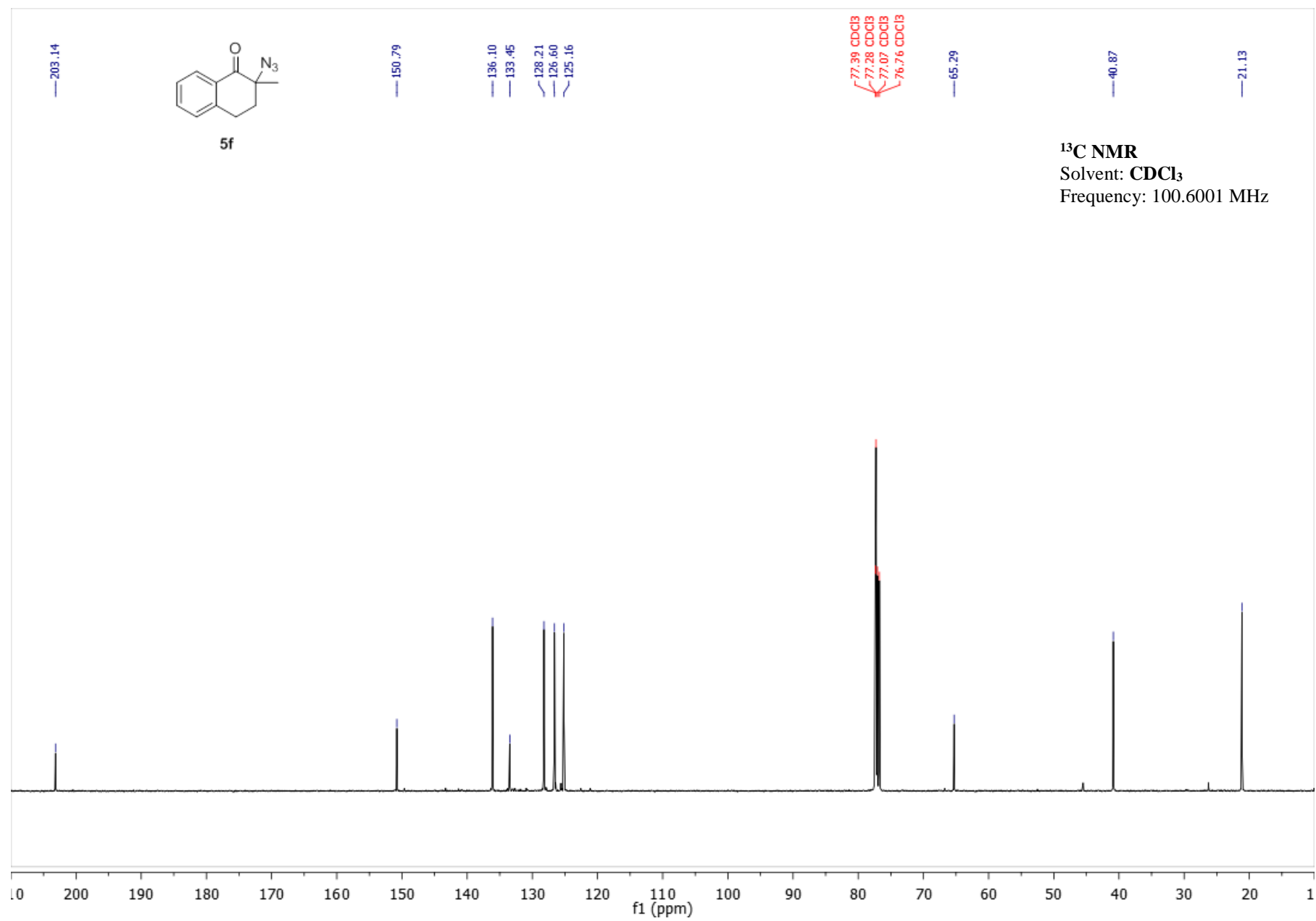
^{13}C NMR
Solvent: CDCl$_3$
Frequency: 100.6001 MHz

198.07
166.92
152.26
136.23
133.22
128.22
126.35
125.39
84.46
77.44 CDCl3
77.33
77.13 CDCl3
76.81 CDCl3
70.46
41.10
38.58
35.93
30.90

3f

f1 (ppm)

3f

3g

¹³C NMR
Solvent: **CDCl₃**
Frequency: 100.6001 MHz

3g

3h

¹H NMR
Solvent: **CDCl₃**
Frequency: 400.08 MHz

1.99   1.00   1.98   2.72   2.77

10.0   9.5   9.0   8.5   8.0   7.5   7.0   6.5   6.0   5.5   5.0   4.5   4.0   3.5   3.0   2.5   2.0   1.5   1.0   0.
f1 (ppm)

^{13}C NMR
Solvent: **CDCl₃**
Frequency: 100.6001 MHz

190.91
170.32
133.76
133.43
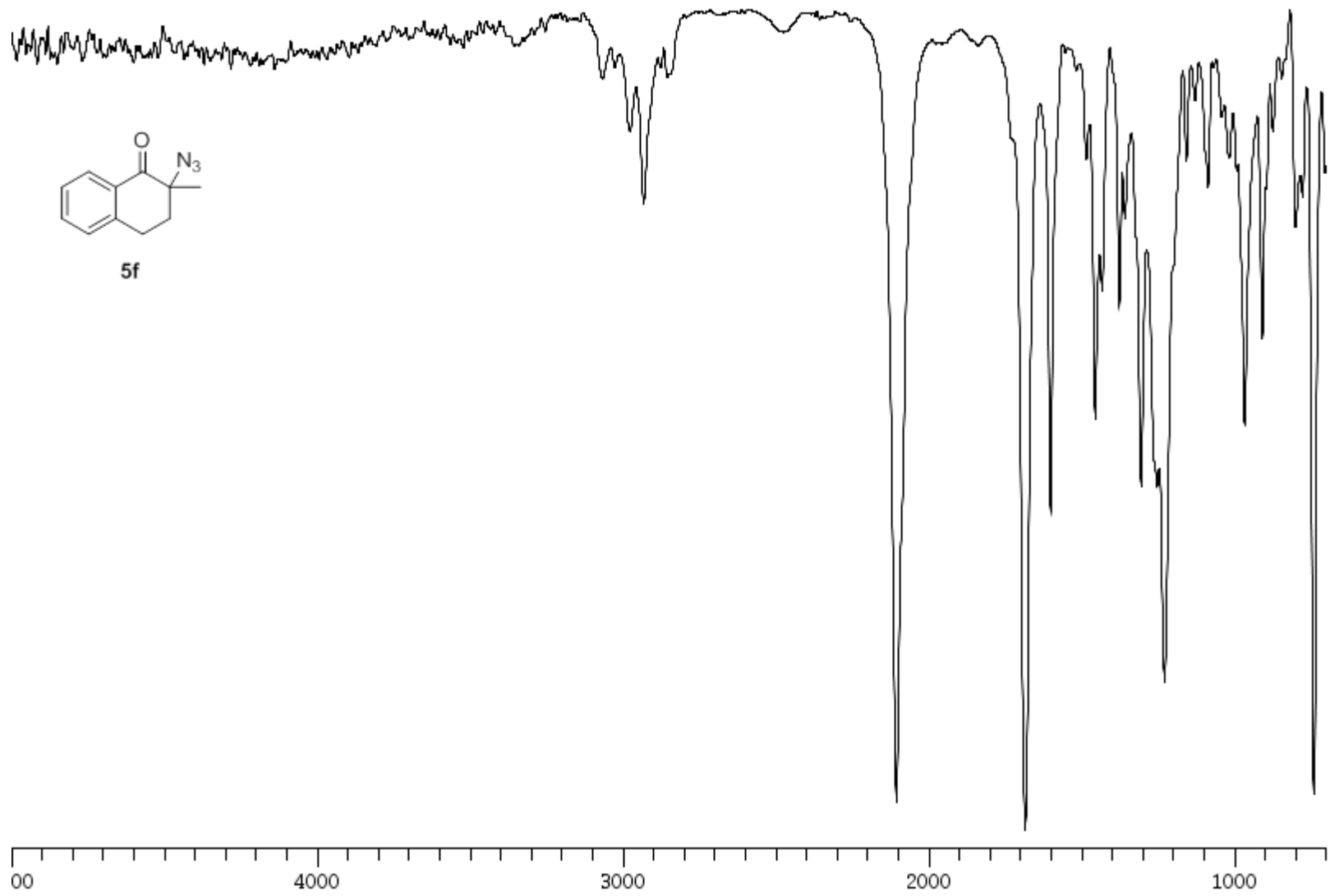129.39
128.70
77.37 CDCl3
77.00 CDCl3
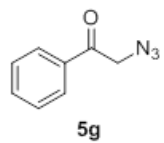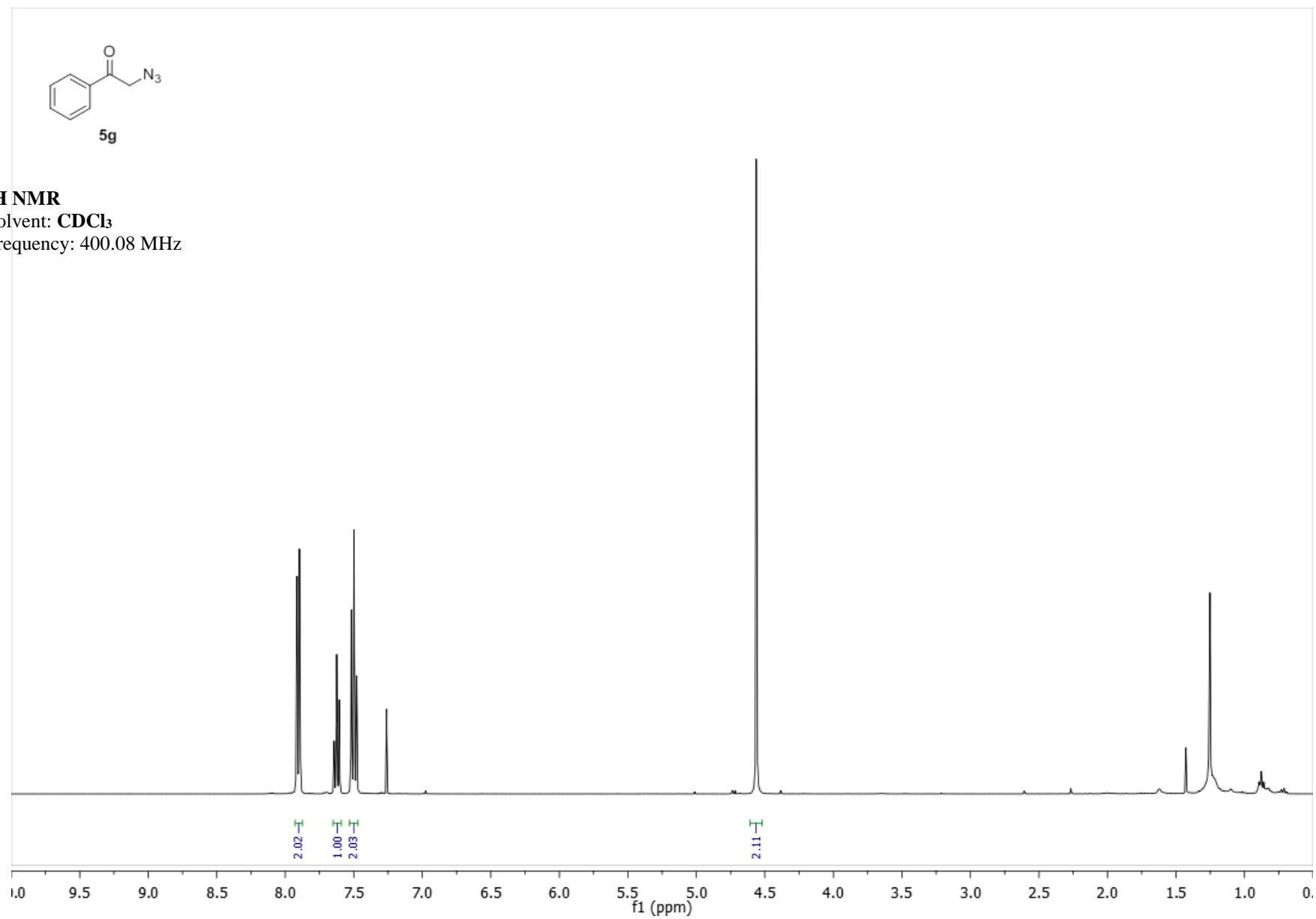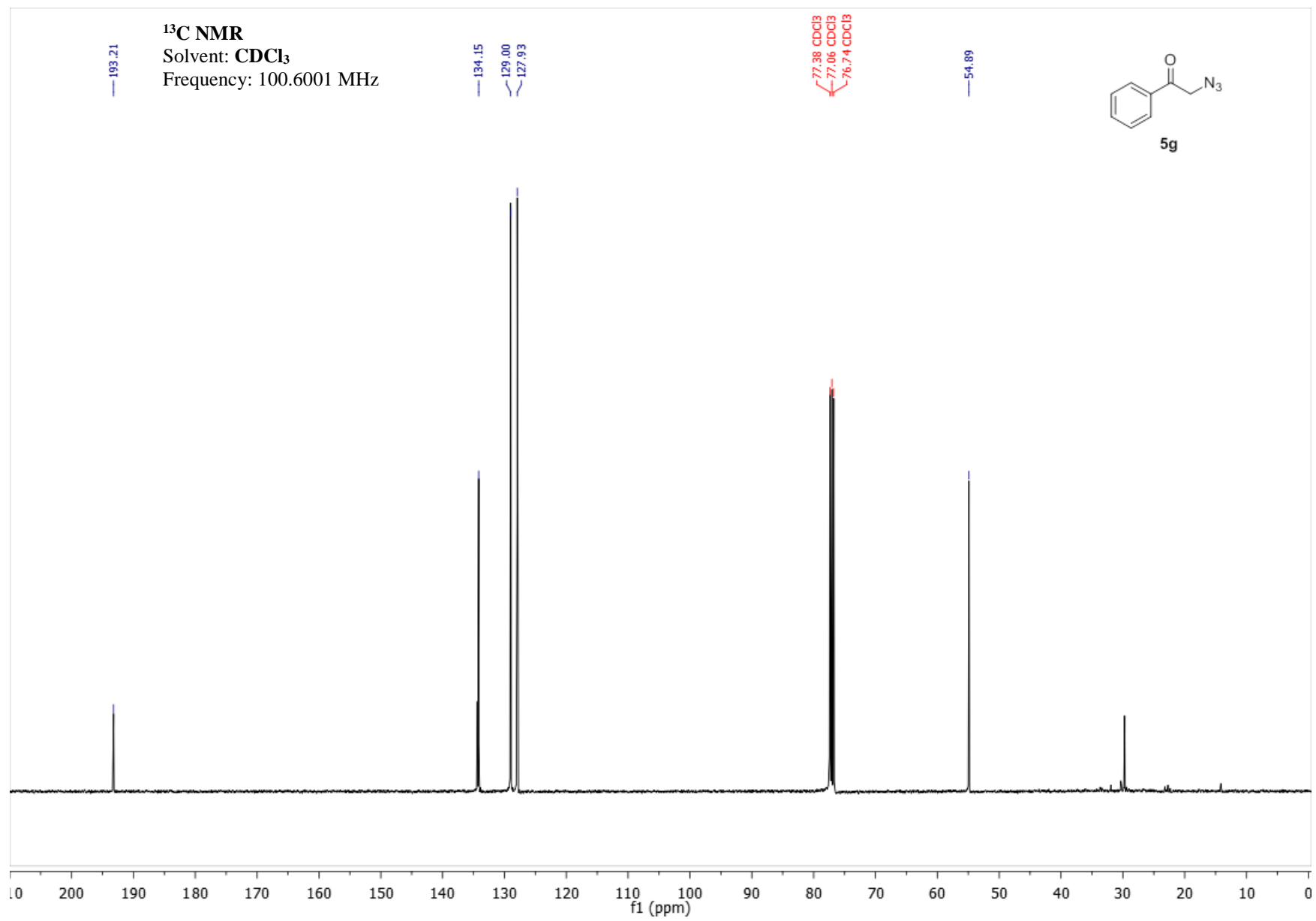76.73 CDCl3
71.11
53.48
20.29

3h

f1 (ppm)

S59

3h

¹H NMR
Solvent: CDCl₃
Frequency: 400.08 MHz

¹³C NMR
Solvent: **CDCl₃**
Frequency: 100.6001 MHz

189.98
170.05
136.30
135.31
134.98
134.66
134.33
129.79
127.46
125.72
125.68
125.64
125.60
124.75
122.04
119.33
77.35 CDCl3
77.24 CDCl3
77.03 CDCl3
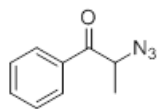76.72 CDCl3
70.97
53.65
19.93

3i

3i

¹H NMR
Solvent: **CDCl₃**
Frequency: 400.08 MHz

3j

3j
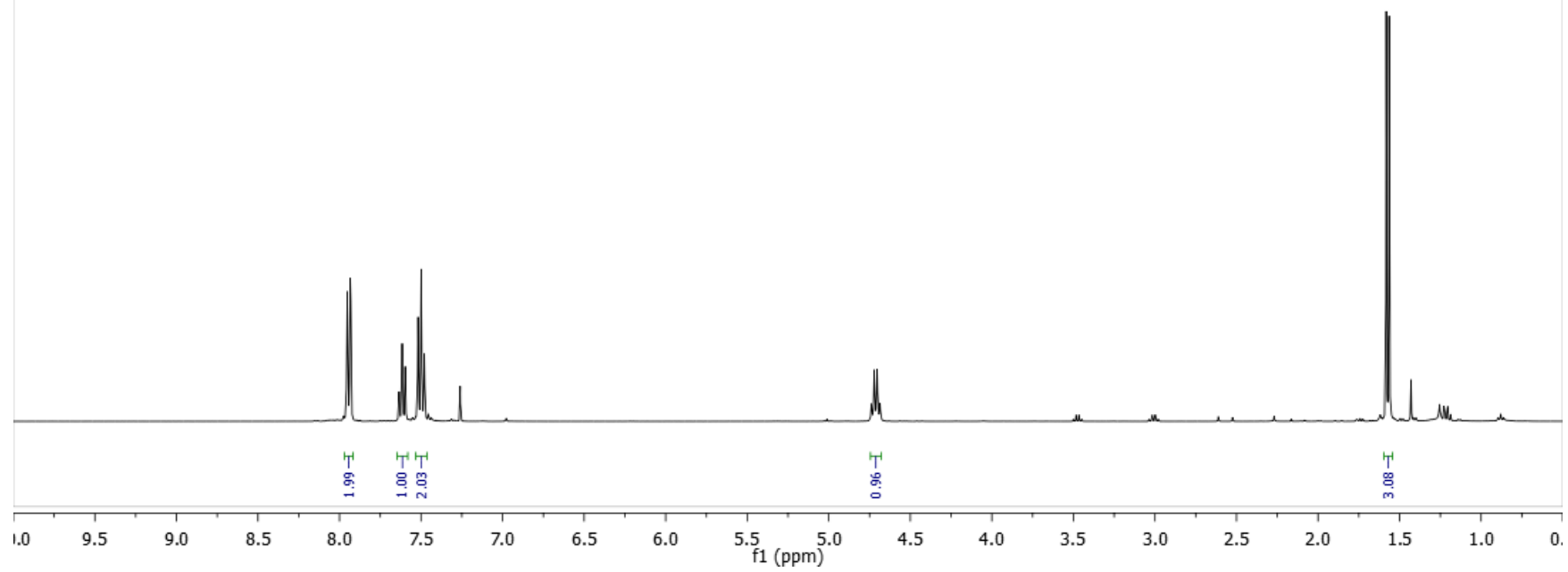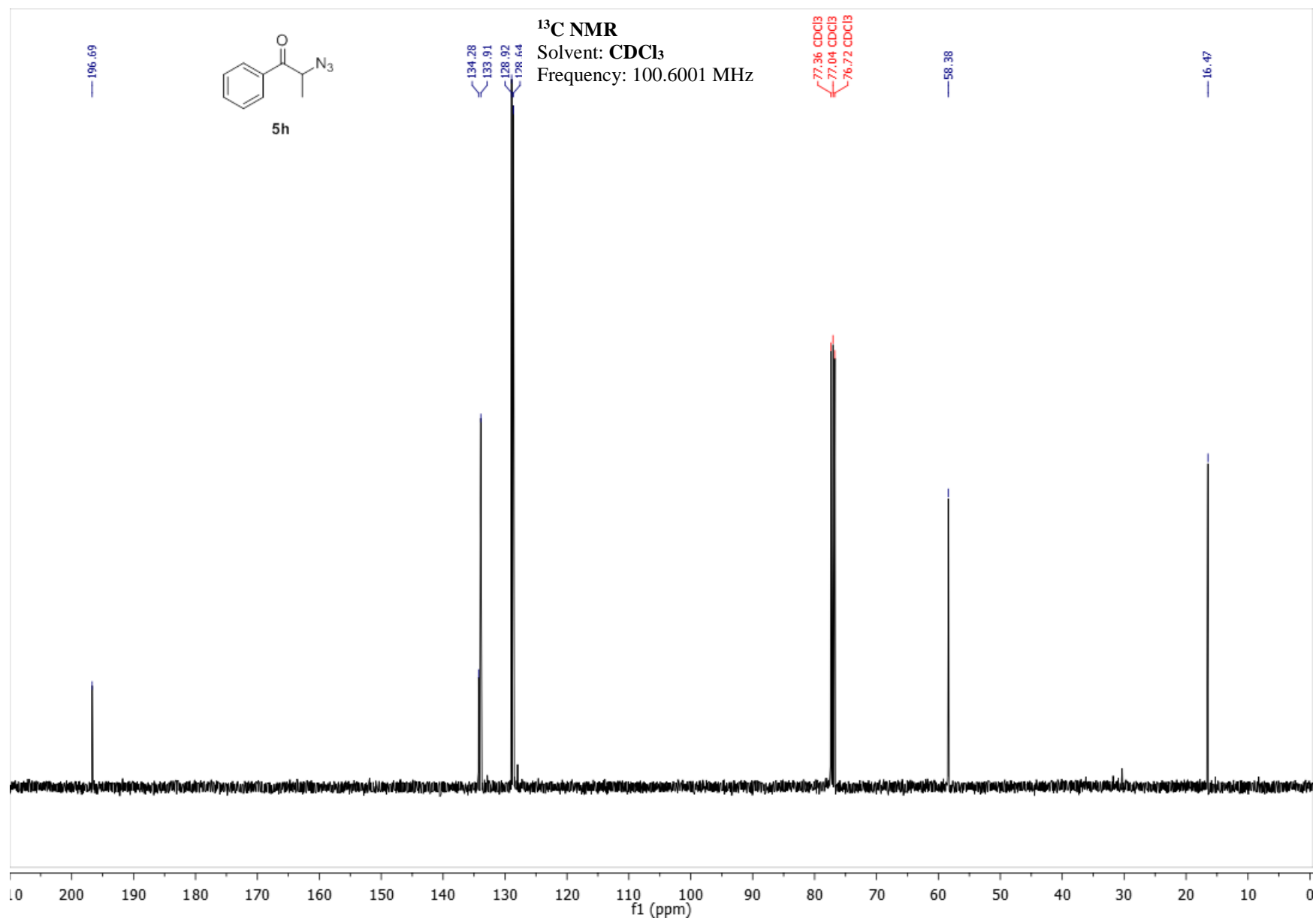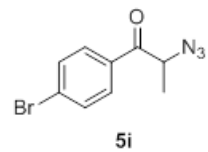
¹H NMR
Solvent: **CDCl₃**
Frequency: 400.08 MHz

¹³C NMR
Solvent: **CDCl₃**
Frequency: 100.6001 MHz

184.50
169.72
139.38
135.44
134.33
128.48
77.38 CDCl3
77.06 CDCl3
76.74 CDCl3
71.87
53.58
20.45

f1 (ppm)

3k

¹H NMR
Solvent: **CDCl₃**
Frequency: 400.08 MHz

¹H NMR
Solvent: **CDCl₃**
Frequency: 400.08 MHz

¹³C NMR
Solvent: **CDCl₃**
Frequency: 100.6001 MHz

148.90, 138.17, 131.14, 126.74, 121.10, 106.05, 77.34 CDCl3, 77.02 CDCl3, 76.71 CDCl3, 11.73, 0.57
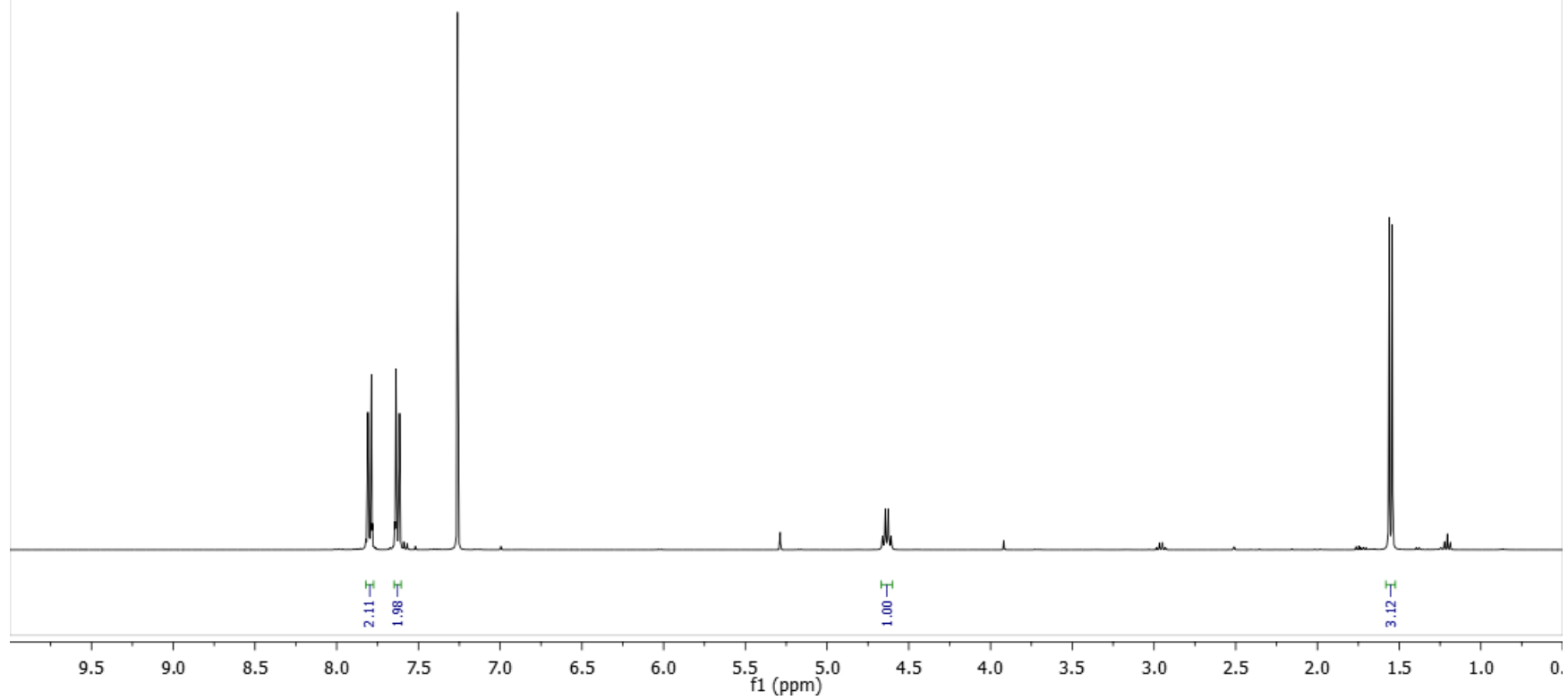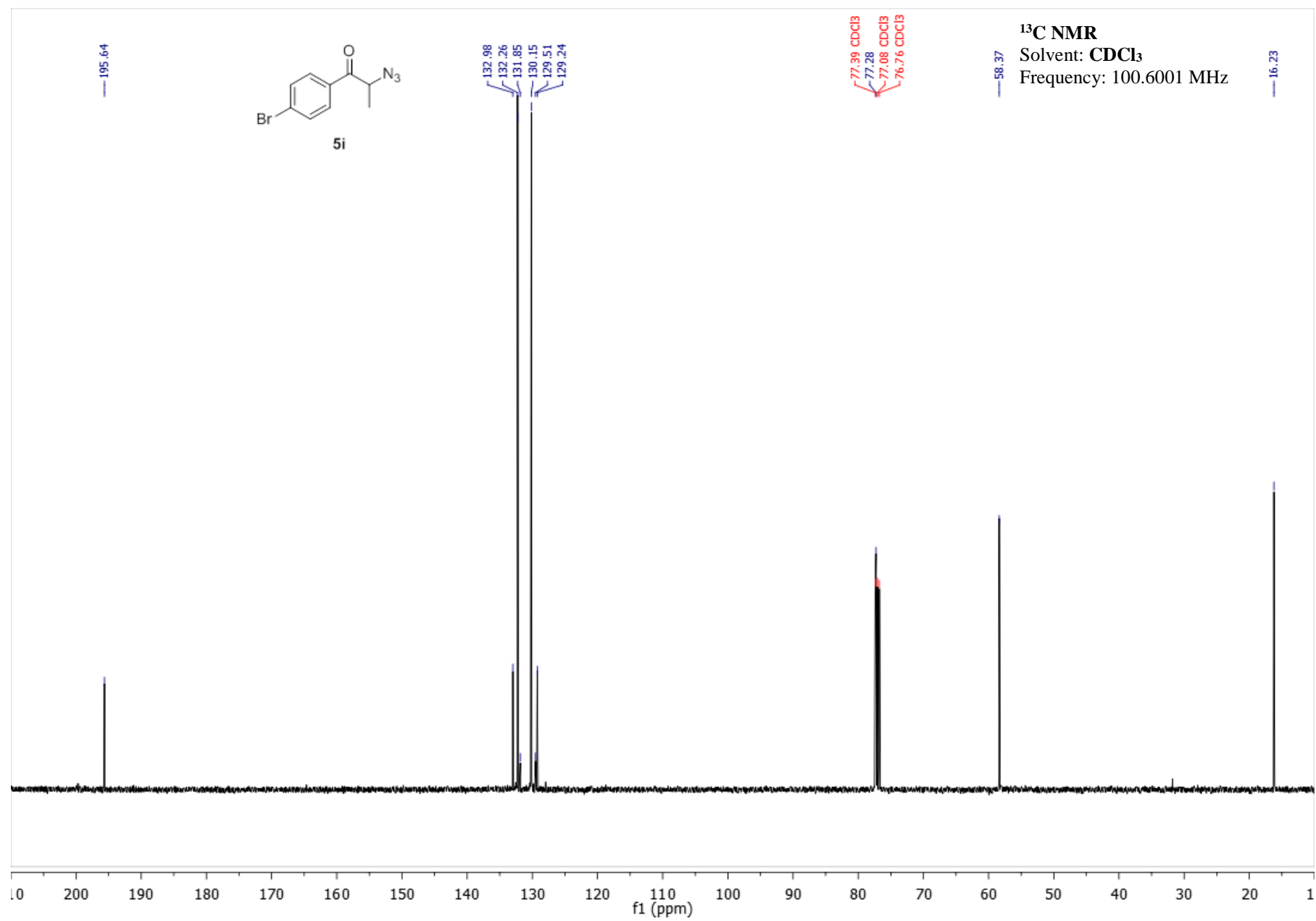
OTMS

Br

4i

4000 3000 2000 1000

¹H NMR
Solvent: **CDCl₃**
Frequency: 400.08 MHz

¹³C NMR
Solvent: **CDCl₃**
Frequency: 100.6001 MHz

148.71
142.60
129.31
128.98
128.66
128.29
125.60
125.18
125.11
125.07
125.03
124.99
122.89
107.69
77.32 CDCl3
77.20
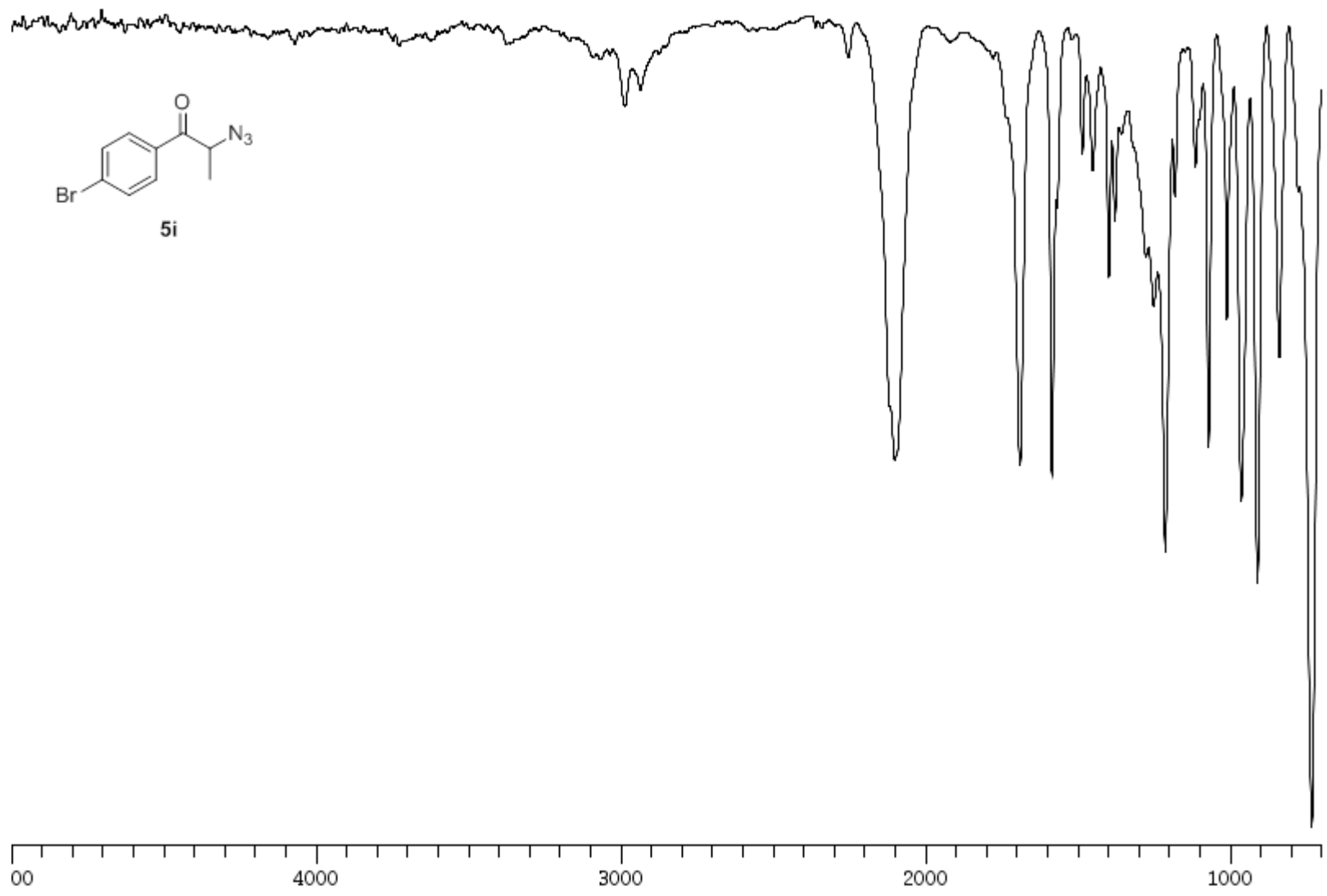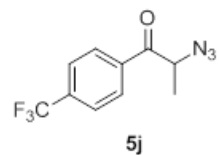77.00 CDCl3
76.68 CDCl3
11.80
0.83
0.54
0.24

4j

f1 (ppm)

OTMS

F₃C

4j

1H NMR
Solvent: **CDCl₃**

Frequency: 400.08 MHz

4k

13C NMR
Solvent: CDCl₃
Frequency: 100.6001 MHz

4k

144.25
143.04
126.42
122.98
122.02
104.16
76.74 CDCl3
76.42 CDCl3
76.11 CDCl3
10.98
0.00

f1 (ppm)

4k

¹H NMR
Solvent: CDCl₃
Frequency: 400.08 MHz

5a

201.79

151.21

136.09
134.21

128.26
126.62
124.68

77.40 CDCl3
77.08 CDCl3
76.76 CDCl3

62.02

33.02

5a

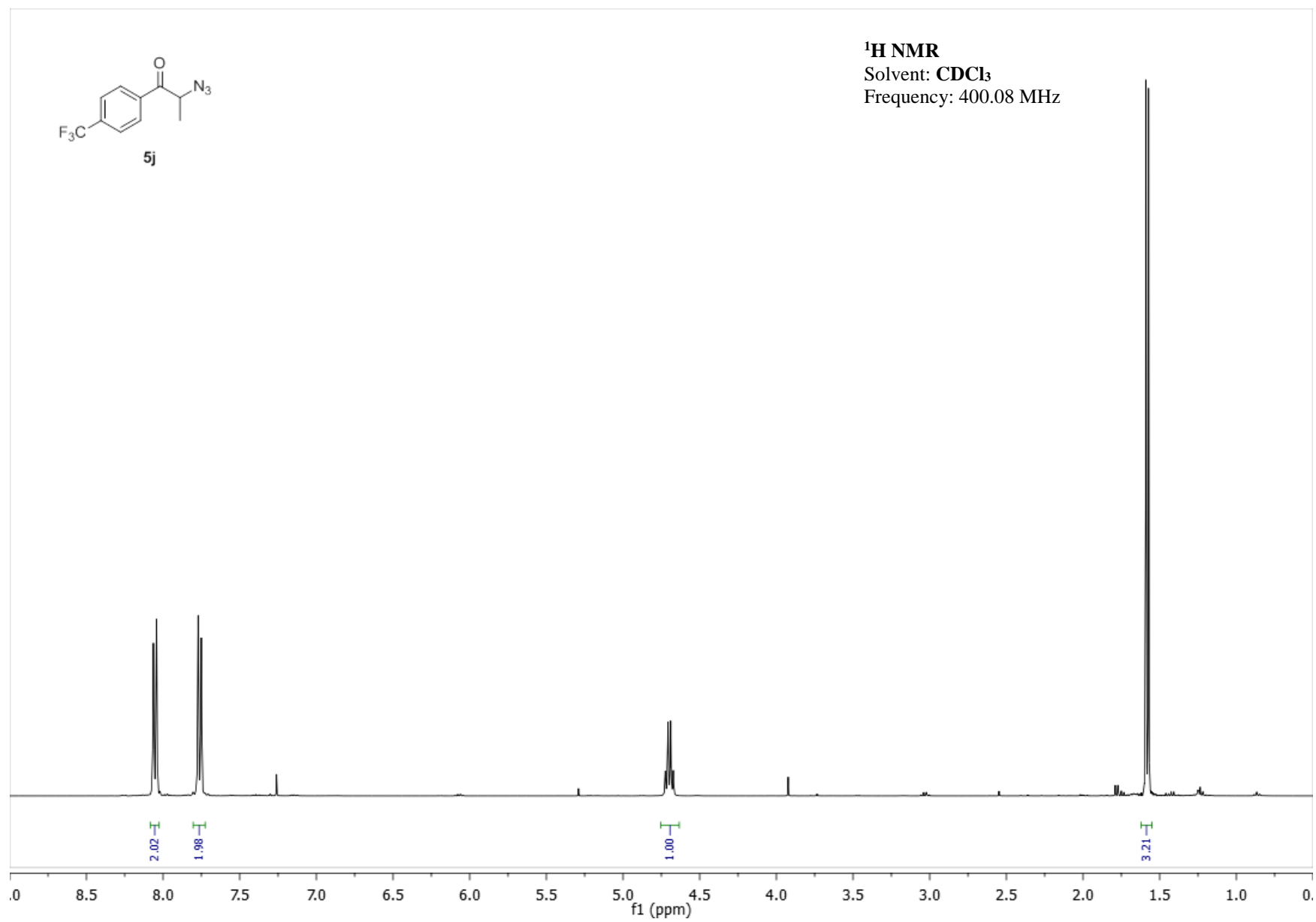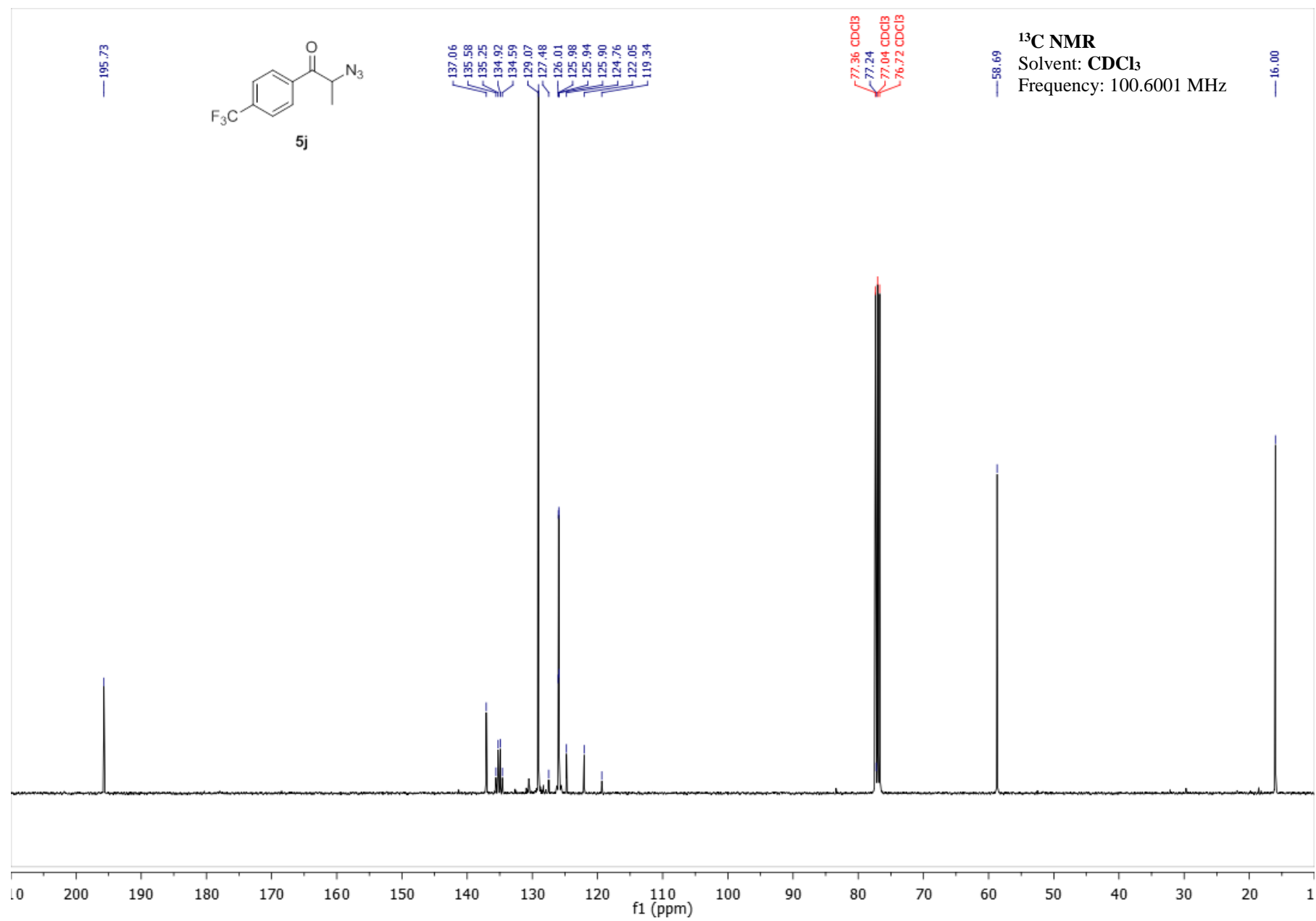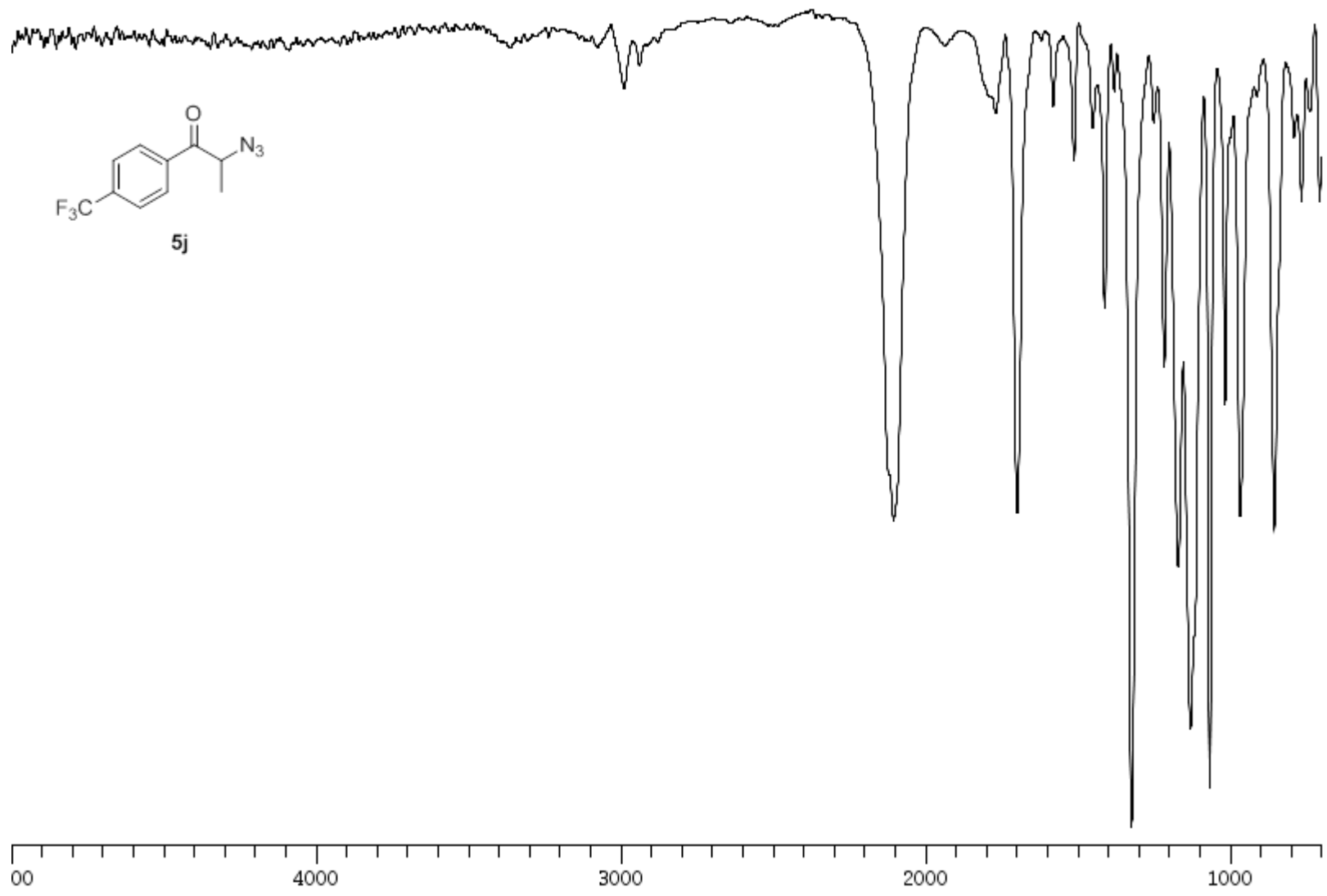**¹³C NMR**
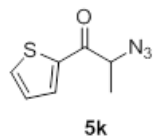Solvent: **CDCl₃**
Frequency: 100.6001 MHz
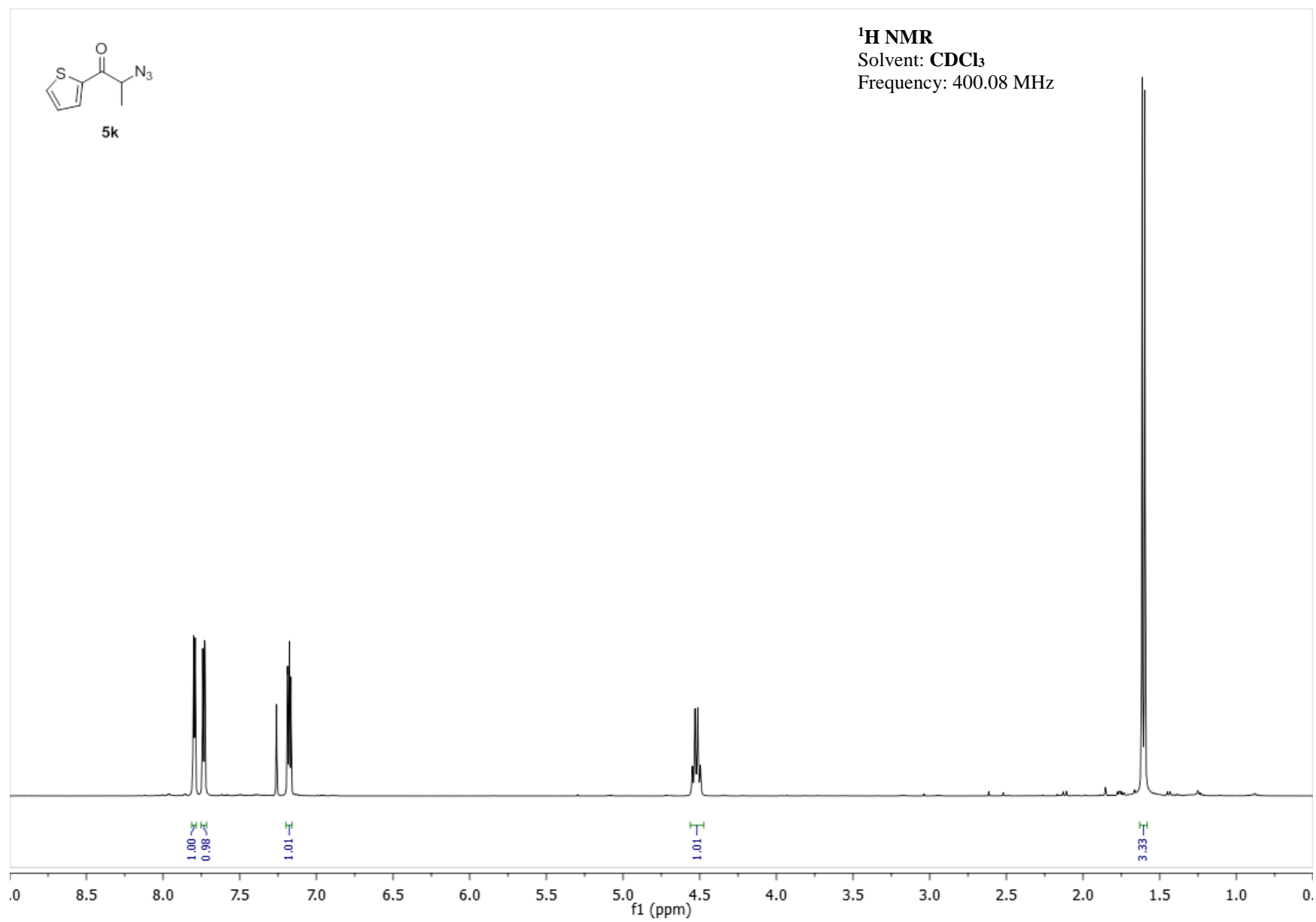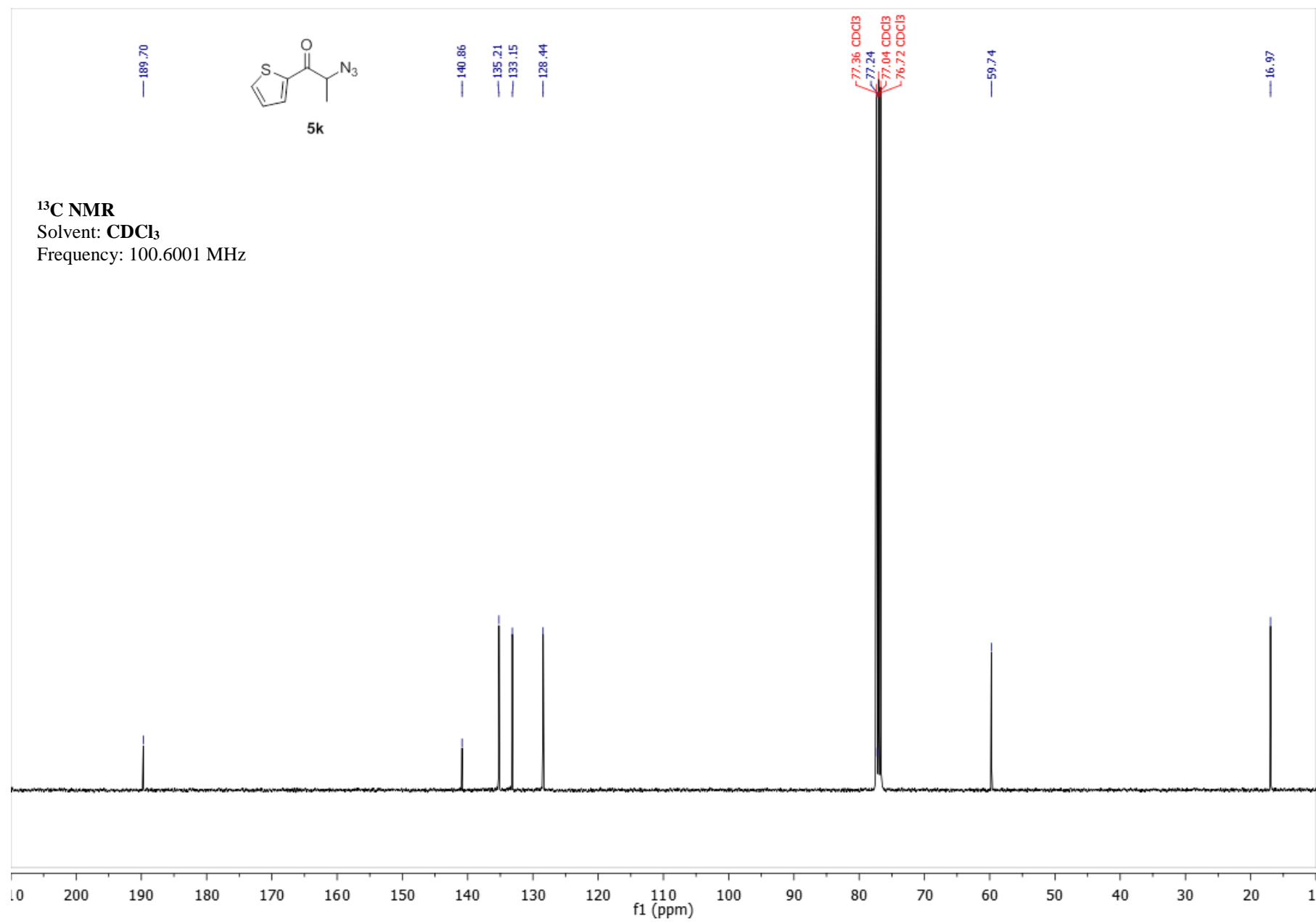
f1 (ppm)

S81

5a

5d

¹H NMR
Solvent: **CDCl₃**
Frequency: 400.08 MHz

13C NMR
Solvent: CDCl₃
Frequency: 100.6001 MHz

5d

5d

¹H NMR
Solvent: **CDCl₃**
Frequency: 400.08 MHz

5e

203.14

150.79

136.10
133.45
128.21
126.60
125.16

77.39 CDCl3
77.28 CDCl3
77.07 CDCl3
76.76 CDCl3

65.29

40.87

21.13

5e

¹³C NMR
Solvent: **CDCl₃**
Frequency: 100.6001 MHz

f1 (ppm)

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

5e

5f

¹H NMR
Solvent: **CDCl₃**
Frequency: 400.08 MHz

203.14

150.79

136.10
133.45

128.21
126.60
125.16

77.39 CDCl3
77.28 CDCl3
77.07 CDCl3
76.76 CDCl3

65.29

40.87

21.13

5f

¹³C NMR
Solvent: **CDCl₃**
Frequency: 100.6001 MHz

5f

1H NMR
Solvent: **CDCl₃**
Frequency: 400.08 MHz

^{13}C NMR
Solvent: CDCl$_3$
Frequency: 100.6001 MHz

193.21

134.15
129.00
127.93

77.38 CDCl3
77.06 CDCl3
76.74 CDCl3

54.89

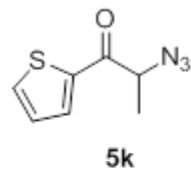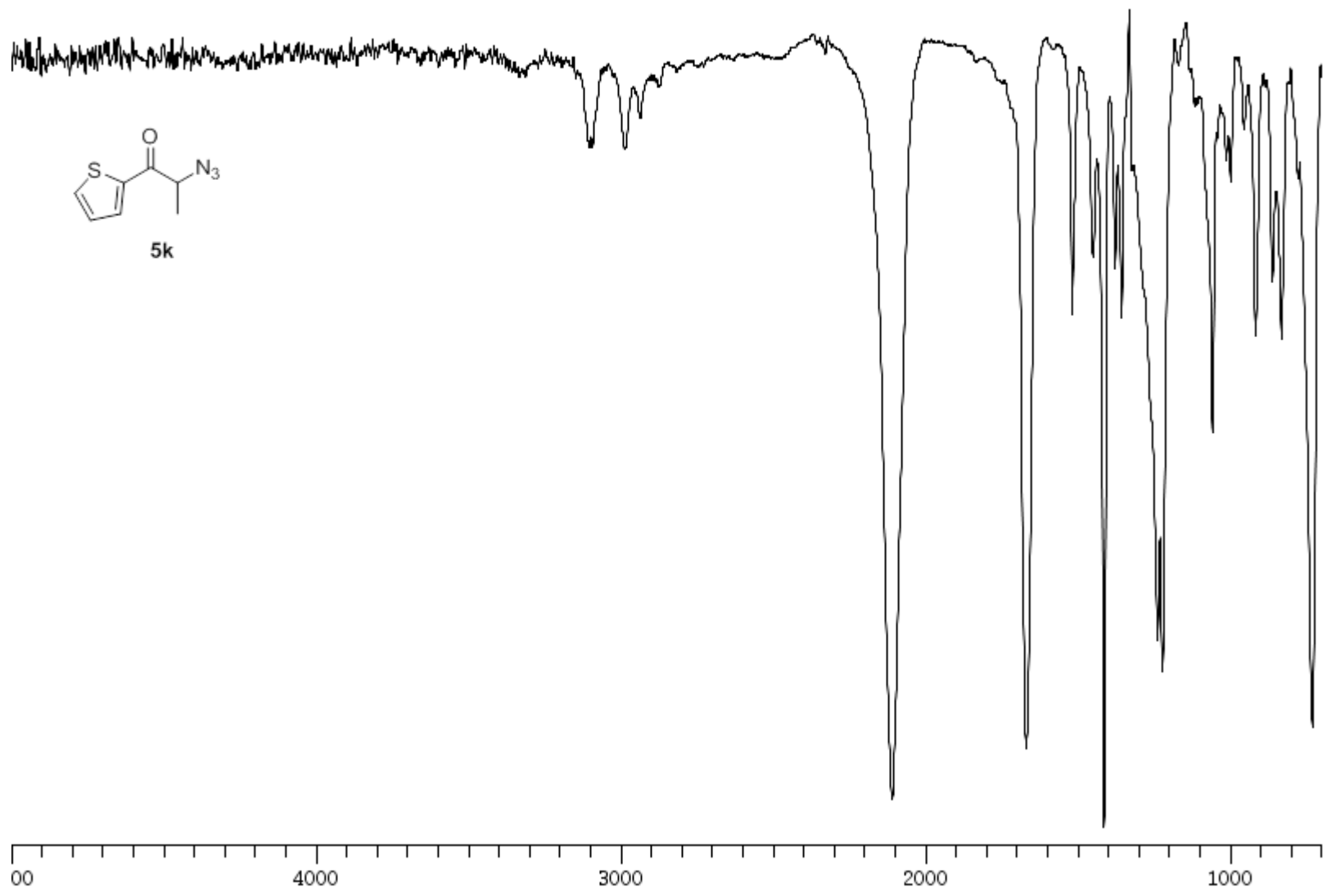**5g**

f1 (ppm)

¹H NMR
Solvent: **CDCl₃**
Frequency: 400.08 MHz

5h

13C NMR
Solvent: CDCl₃
Frequency: 100.6001 MHz

196.69   134.28 133.91 128.92 128.64   77.36 CDCl3 77.04 CDCl3 76.72 CDCl3   58.38   16.47
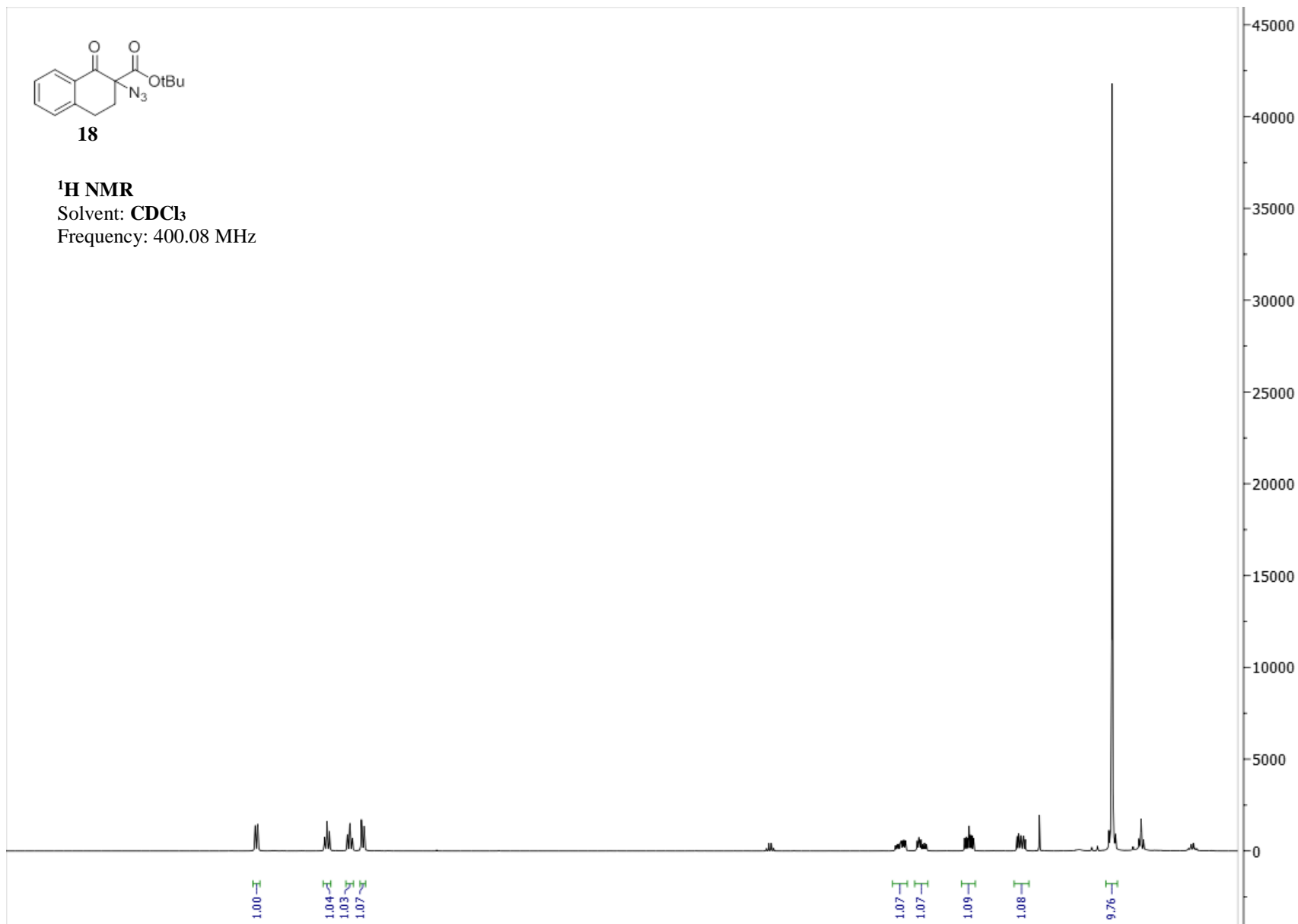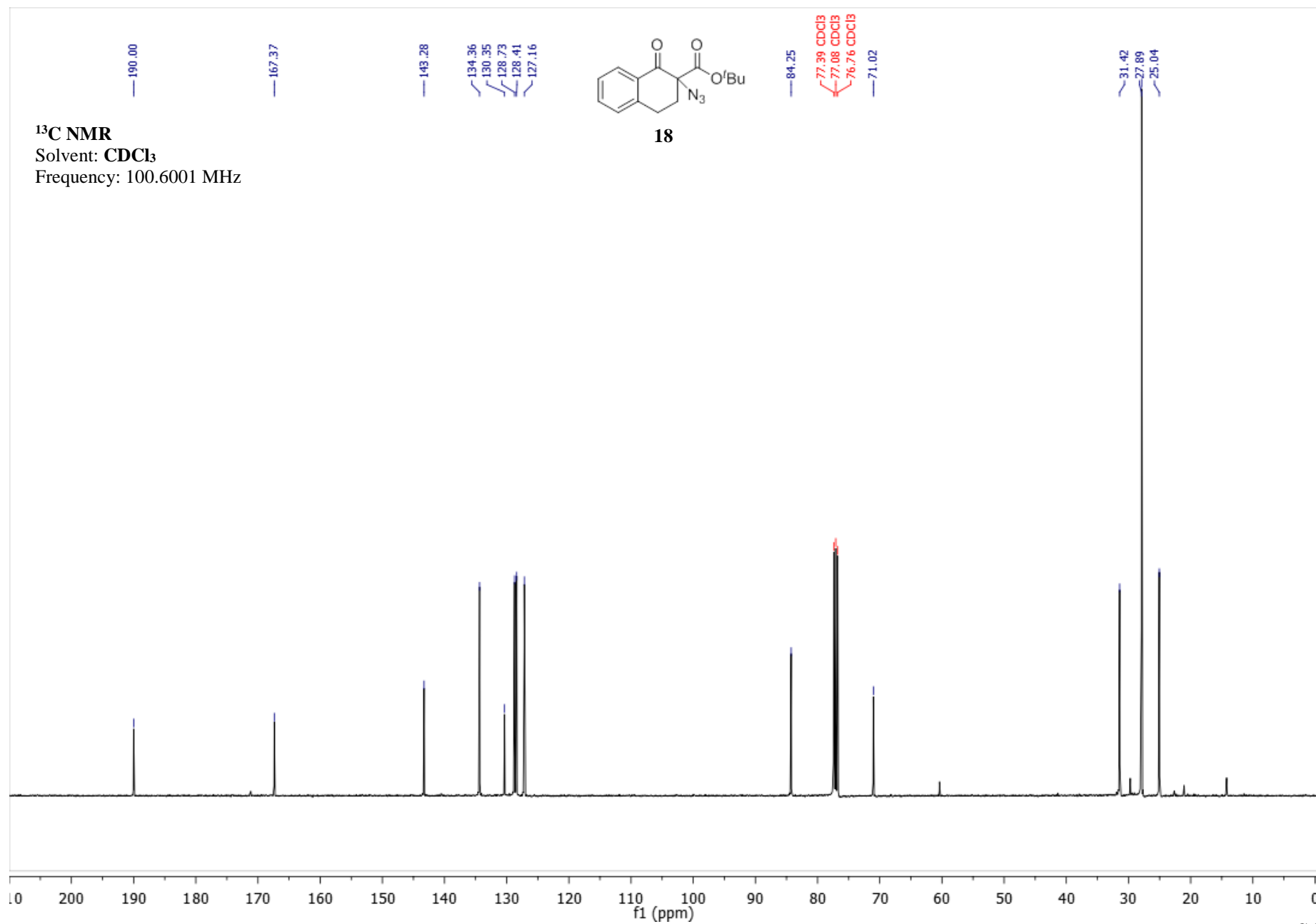
5h

f1 (ppm)

¹H NMR
Solvent: **CDCl₃**
Frequency: 400.08 MHz

5i

2.11 1.98 1.00 3.12

9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.
f1 (ppm)

5i

¹H NMR
Solvent: **CDCl₃**
Frequency: 400.08 MHz

5j

2.02 1.98 1.00 3.21

9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.
f1 (ppm)

^{13}C NMR
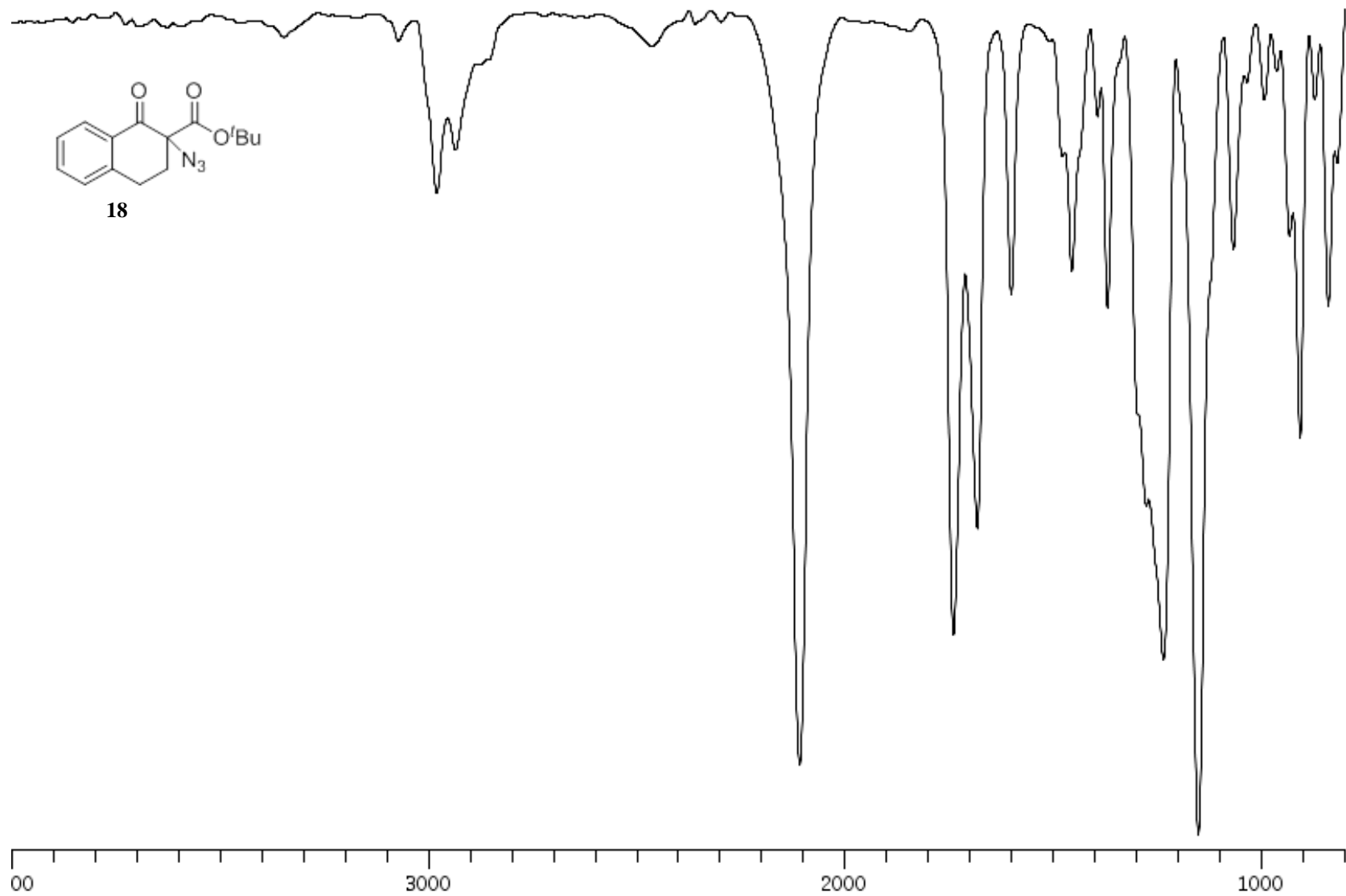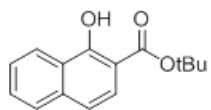Solvent: **CDCl₃**
Frequency: 100.6001 MHz

5j

¹H NMR
Solvent: **CDCl₃**
Frequency: 400.08 MHz

5k

¹³C NMR
Solvent: **CDCl₃**
Frequency: 100.6001 MHz

5k

18

¹H NMR
Solvent: **CDCl₃**
Frequency: 400.08 MHz

¹³C NMR
Solvent: **CDCl₃**
Frequency: 100.6001 MHz

19

¹H NMR
Solvent: **CDCl₃**
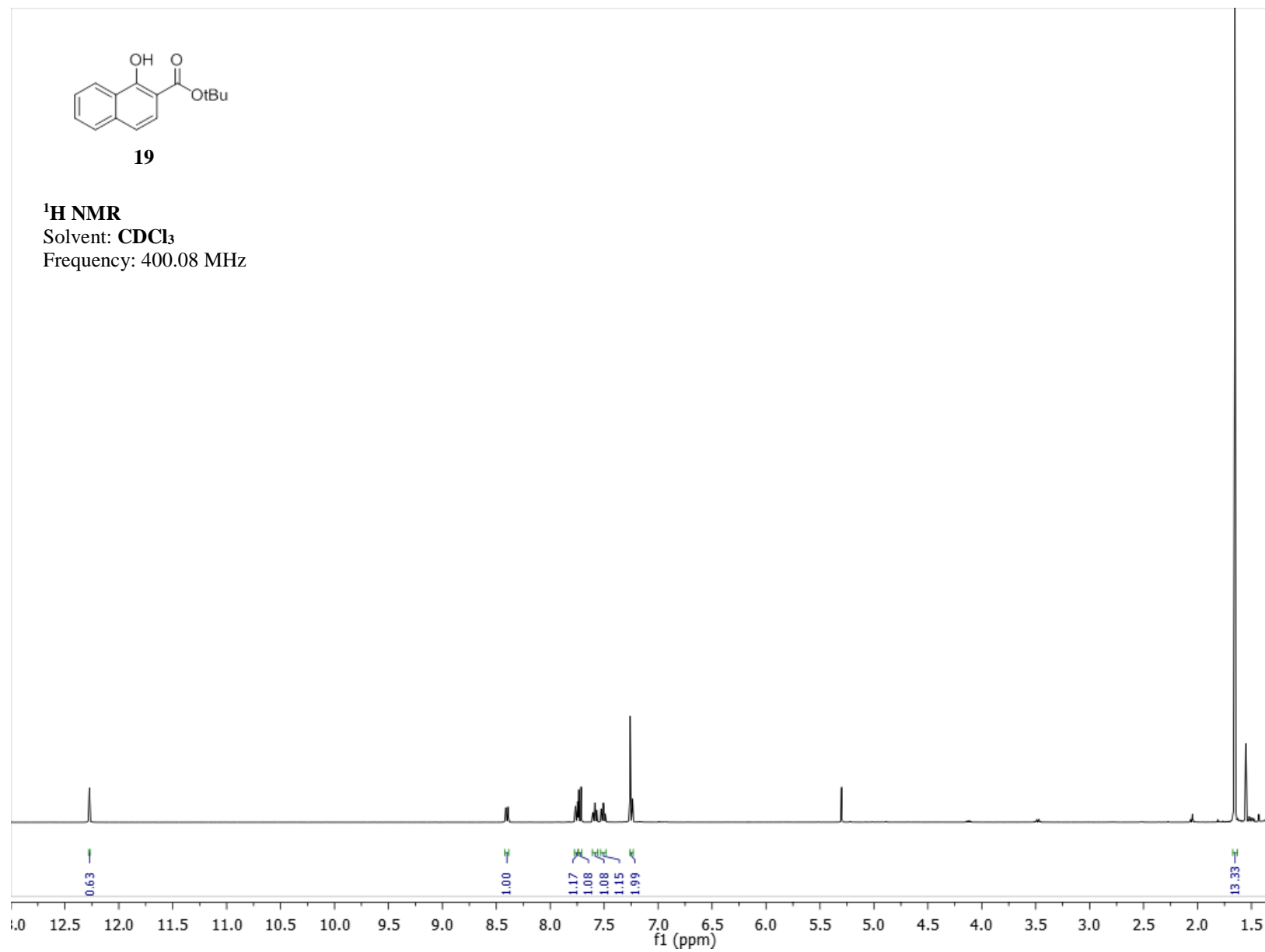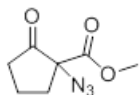Frequency: 400.08 MHz

20

¹H NMR
Solvent: **CDCl₃**
Frequency: 400.08 MHz

^{13}C NMR
Solvent: **CDCl₃**
Frequency: 100.6001 MHz

20

S111