Supporting Information

Synthesis of Tri-substituted, Aliphatic and ^{13}C-Labelled α,β-Unsaturated Carboxylic Acids *via* Wittig CO_2 Utilisation Reactions

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1. General Considerations

Solvents: Reaction solvents toluene and THF were dried over activated 3Å molecular sieves. Molecular sieves (10 weight percent per unit volume of compound to be dried, 20 weight percent was used when drying THF) were activated by flame drying in the storage flask(s) for 5–10 minutes (depending on quantity of sieves to be dried).[1] After flame-drying, the storage flask was immediately connected to a Schlenk line, subjected to vacuum (between 2 and 5×10^{-3} mbar), and allowed to stand until the sieves had cooled. The flask was then subjected to several vacuum/refill cycles to establish a nitrogen atmosphere inside,[2] and the solvent to be dried was then added by cannula transfer directly from a Winchester bottle which was sealed using a rubber septum (sized for a B29 ground glass socket joint). Pre-activated molecular sieves are also available commercially (in bottles sealed under nitrogen) that can be used without flame-drying and are successful in producing solvents with equally low water content; with these, we typically store the molecular sieves under nitrogen in a glove box.

Anhydrous solvents were stored under an atmosphere of nitrogen either in customised Young's flasks with two J. Young's valves (one for connection to the Schlenk manifold, the other for removal of solvent into a syringe) or Schlenk flasks fitted with second stopcocks. When accessing the dry solvent, the angled side-arm was sealed with a rubber septum, and the small volume contained between the septum and the sealed tap of the J. Young's valve was flushed with a stream of nitrogen gas for a minimum of five minutes prior to opening the valve. The solvent required several days after commencing drying to reach maximal dryness (analysis by Karl Fischer titration) but was dry enough for most purposes after one day. Solvents stored in this manner were found to retain water contents of less than 10 ppm for more than one year.

Solvents for chromatography and work-up procedures, except in the case of ethyl acetate and cyclohexane, were used as obtained from commercial sources. Ethyl acetate and cyclohexane were purified by distillation – this was done due to the purity level of these solvents available to us during this project; with ethyl acetate and cyclohexane of sufficient purity, distillation is not necessary. Organic phases in reaction work-up procedures were dried using anhydrous magnesium sulfate.

Starting Materials: Ethyltriphenylphosphonium bromide, dimethyldiphenylphosphonium triflate and diethyldiphenylphosphonium triflate were used as starting phosphonium salts in the reactions. Methyltriphenylphosphonium bromide was obtained commercially and purified by

recrystallization from acetonitrile/ethyl acetate. Ethyltriphenylphosphonium bromide and was obtained using an established literature method.[3] Dimethyldiphenylphosphonium triflate and diethyldiphenylphosphonium triflate were synthesised from methyldiphenylphosphine or ethyldiphenylphosphine and the relevant alkyl triflate in ether (see procedure below). Phosphonium salts were dried in a vacuum dessicator over P_2O_5 and $CaCl_2$ and stored in a desiccator under an atmosphere of nitrogen. Liquid benzaldehydes obtained commercially were purified by distillation and stored in a Young's flask under an atmosphere of nitrogen. Solid benzaldehydes were used as obtained from commercial sources and made into stock solutions in dry toluene or THF to be used in the reactions. Some of the solid benzaldehydes had low solubility in toluene so were instead made as stock solutions in THF. Methyl trifluoromethanesulfonate was stored in a Young's flask under an atmosphere of nitrogen. Ethyl trifluoromethanesulfonate was distilled before use and stored in a Young's flask under an atmosphere of nitrogen.

Base Solutions: KHMDS solutions were obtained commercially as solutions in toluene from Acros or Sigma Aldrich. Base solutions were transferred by cannula under nitrogen to Young's flasks, in which they were stored under an atmosphere of nitrogen. In many instances, the KHMDS solution used in the reactions were titrated by a literature method,[4] however, efforts to find a convenient titration method were being made while simultaneously optimizing the reaction, so in some cases the nominal concentrations from the supplier were used for stoichiometry. In instances in which the KHMDS solution was titrated prior to the reaction, the notation (titr.) will be used after the concentration listed.

Reaction Setup: For reactions carried out under an atmosphere of nitrogen, the inert atmosphere was established inside a Schlenk flask by the standard Schlenk pump and fill technique[2] (three repeats of evacuation and re-fill to < 0.010 mbar as measured by a Pirani gauge), using a nitrogen/vacuum manifold that allowed each of five rubber tubes to each be open either to vacuum or to the nitrogen supply by means of a three-way double oblique bore stopcock. When not in use, the open end of each length of rubber tubing was fitted with a syringe barrel with an attached needle. The needle was inserted through a rubber septum into a small pear-shaped flask containing dry KOH pellets, and the tip was embedded in amongst the pellets. In this manner the tubing was kept free of ambient moisture by the hygroscopic KOH.

Chromatography: Dry column vacuum chromatography (DCVC) was carried out using 60 Å (20-45 μm particle size) silica gel (Fluorochem), following a reported procedure.[5] This DCVC procedure is further explained in full below in section 5, under general work-up procedure C. Flash column chromatography was carried out using 60 Å (35-75 μm particle size) silica gel. TLC was carried out on pre-coated silica gel plates (Merck TLC Silica gel 60 F_{254}). The developed plates were visualised under UV light (wavelength 254 nm).

NMR Spectroscopy: Nuclear Magnetic Resonance (NMR) samples were prepared using deuterated chloroform ($CDCl_3$) or deuterated dimethylsulfoxide (DMSO-d_6) as solvents, as specified below for individual experiments. ^{1}H NMR (600 MHz), ^{1}H-NMR (500 MHz), ^{1}H NMR (400 MHz), and ^{1}H NMR (300 MHz) spectra were recorded on Bruker Avance 600, Bruker Avance 500, Bruker Avance 400, Varian VnmrS 400, JEOL 400, and Bruker Avance 300 NMR spectrometers, respectively, in proton coupled mode using tetramethylsilane (TMS) as the reference standard. ^{13}C NMR (150 MHz), ^{13}C NMR (125 MHz), ^{13}C NMR (100 MHz) and ^{13}C NMR (75 MHz) spectra were recorded on Bruker Avance 600, Bruker Avance 500, Bruker Avance 400 and Bruker Avance 300 NMR spectrometers, respectively, in proton decoupled mode using tetramethylsilane (TMS) as the reference standard. ^{31}P{^{1}H} (162 MHz) and ^{31}P{^{1}H} (121 MHz) spectra were recorded on Bruker Avance 400 and Bruker Avance 300 NMR spectrometers, respectively, in proton decoupled mode. ^{31}P NMR chemical shifts were measured relative to an external orthophosphoric acid standard. ^{19}F {^{1}H} (565 MHz), ^{19}F {^{1}H} (471 MHz), ^{19}F {^{1}H} (376 MHz), ^{19}F {^{1}H} (282 MHz) NMR spectra were recorded on Bruker Avance 600, Bruker Avance 500, Bruker Avance 400 and Bruker Avance 300 NMR spectrometers, respectively, in proton decoupled mode. ^{19}F NMR chemical shifts were measured relative to fluorotrichloromethane (CCl_3F). ^{13}C{^{1}H}, ^{31}P{^{1}H} and ^{19}F {^{1}H} NMR spectra were recorded with broadband decoupling from ^{1}H. Chemical shifts (δ) are expressed as parts per million (ppm), positive shift being downfield from TMS. Chemical shifts (δ_H and δ_C) are reported in parts per million (ppm) relative to tetramethylsilane (TMS) and coupling constants (*J*) are expressed in hertz (Hz). Splitting patterns in ^{1}H NMR spectra are designated as: s (singlet), br s (broad singlet), d (doublet), dd (doublet of doublets), t (triplet), q (quartet), sept. (septet), and m (multiplet).

Mass Spectrometry: Low resolution mass spectra (LRMS) were recorded using electrospray ionisation (ESI) on a Waters Quattro Micro triple quadropole instrument using 50% acetonitrile-water, containing 0.1% formic acid as eluent. Samples were prepared in acetonitrile or methanol at a concentration of *ca*. 1 mg mL^{-1} or 0.1 mg mL^{-1}. High resolution precise mass spectra (HRMS)

were recorded using electrospray ionisation (ESI) on a Waters LCT Premier TOF LC-MS or Agilent-6546-QToF instruments using 50% acetonitrile-water, containing 0.1% formic acid as eluent; samples were made up in acetonitrile or methanol at a concentration of *ca*. 1 mg mL^{-1}. Reported results are all within the range of ± 5ppm of the calculated mass.

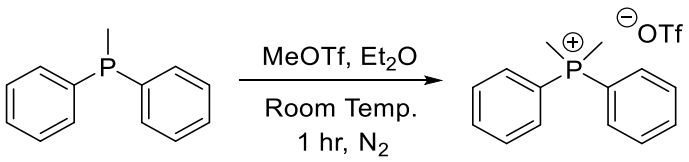
Melting Points: Melting points for solids were measured on an Electrothermal IA9300 instrument and are uncorrected.

IR Spectroscopy: Infrared spectra for novel compounds were measured using a Perkin FTIR UATR2 spectrometer or a Bruker ALPHA platinum ATR instrument.

Note on *E*- and *Z*-alkene isomers: In the Wittig CO_2 utilisation reactions outlined below affording α,β-unsaturated carboxylic acids, formation of the *E*-isomer is strongly favoured in many instances (> 90:10 *E:Z* ratio). In many cases, the isolated product was exclusively *E*-isomer, and in the remaining cases, the *E:Z* isomeric ratio for each isolated product is outlined, along with the observed ^{1}H NMR signals for the *Z*-isomer. For products derived from aliphatic aldehydes, a slightly higher percentage of the *Z*-isomer was generally observed.

2. Preparation of Starting Materials

Dimethyldiphenylphosphonium Trifluoromethanesulfonate [6,7]

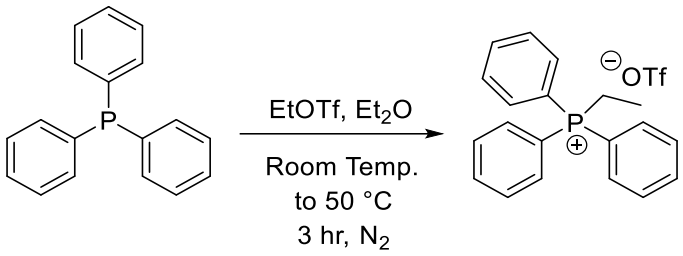


A solution of methyldiphenylphosphine (4.7 mL, 25 mmol, 1.0 equiv.) in dry diethyl ether (25 mL) was prepared in a Schlenk flask under an atmosphere of nitrogen. Methyl trifluoromethanesulfonate (3.0 mL, 27 mmol, 1.1 equiv.) was added to the reaction mixture by syringe, and the reaction was left to stir for 1 hour at room temperature. The solid product that had formed was then filtered and washed with additional ether. The product was purified by recrystallisation from acetonitrile/ethyl acetate, affording the pure product as a white solid in an isolated yield of 8.4 g (92%). The crystals obtained were dried in a vacuum desiccator over P_2O_5 and $CaCl_2$, stored in the desiccator under nitrogen.

m.p. = 122–124 °C; **LRMS:** *m/z* (ESI+): 215 [$(M + H)^+$, 100%]; *m/z* (ESI−): 149 [$(M - H)^-$, 100%]

^{1}H NMR (300 MHz, $CDCl_3$) [6] δ 7.82–7.67 (m, 6H, Phenyl H-3 and Phenyl H-4), 7.66– 7.58 (m, 4H, Phenyl H-2), 2.53 (d, $^{2}J_{PH}$ = 14.0 Hz, 6H, C*H*$_3$); **^{31}P{^{1}H} NMR** (121 MHz, $CDCl_3$) [6] δ 20.7; **^{19}F{^{1}H}** NMR (282 MHz, $CDCl_3$) δ –78.3 (–C*F*$_3$); **^{13}C{^{1}H} NMR** (75 MHz, $CDCl_3$) [6] δ 134.9 (d, $^{4}J_{PC}$ = 3 Hz, Phenyl C-4), 132.0 (d, $^{2}J_{PC}$ = 11 Hz, Phenyl C-2), 130.4 (d, $^{3}J_{PC}$ = 13 Hz, Phenyl C-3), 120.4 (d, $^{1}J_{PC}$ = 88 Hz, Phenyl C-1), 9.5 (d, $^{1}J_{PC}$ = 57 Hz, *C*H$_3$). There was no signal evident for –*C*F$_3$ in the ^{13}C NMR spectrum.

Ethyltriphenylphosphonium Trifluoromethanesulfonate[8,9]

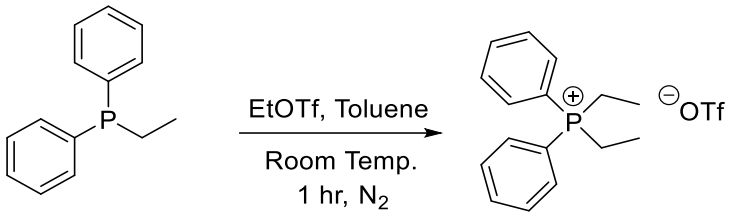


A solution of triphenylphosphine (2.8 g, 10.7 mmol, 1.0 equiv.) in dry diethyl ether (21 mL) was prepared in a Schlenk flask under an atmosphere of nitrogen. Ethyl trifluoromethanesulfonate (1.4 mL, 10.7 mmol, 1.0 equiv.) was added to the reaction mixture by syringe, and the reaction was left to stir for 1 hour at room temperature and then heated to 50 °C and stirred for a further 2 hours. The solid product that had formed was then filtered and washed with additional ether. The product was purified by recrystallisation from acetonitrile/ethyl acetate, affording the pure product as a white solid in an isolated yield of 4.0 g (86%). The crystals obtained were dried in a vacuum desiccator over P_2O_5 and $CaCl_2$, and then stored in the desiccator under nitrogen.

m.p. = 134 – 135 °C (lit.[9] 132 – 134 °C); **HRMS:** *m/z* (ESI-TOF; positive mode) *m/z*: $[M + H]^+$ calcd. for $[C_{20}H_{19}P]^+$: 291.1297; found: 291.1295.

^{1}H NMR (300 MHz, $CDCl_3$)[8] δ 7.81–7.72 (m, 3H, Phenyl H-4), 7.71– 7.61 (m, 12H, Phenyl H-3 and Phenyl H-2), 3.31 (dq, *J* = 12.5 Hz, 7.4 Hz, 2H, C*H*$_2$), 1.32 (dt, *J* = 19.9 Hz, 7.4 Hz, 3H, C*H*$_3$); **^{31}P{^{1}H} NMR** (121 MHz, $CDCl_3$) [8] δ 25.7; **^{19}F{^{1}H}** NMR (376 MHz, $CDCl_3$)[8] δ –78.2 (–C*F*$_3$); **^{13}C{^{1}H} NMR** (101 MHz, $CDCl_3$) [8] δ 135.2 (d, $^{4}J_{PC}$ = 3 Hz, Phenyl C-4), 133.4 (d, $^{2}J_{PC}$ = 10 Hz, Phenyl C-2), 130.6 (d, $^{3}J_{PC}$ = 13 Hz, Phenyl C-3), 120.9 (d, $^{1}J_{FC}$ = 321 Hz, *C*F$_3$), 117.8 (d, $^{1}J_{PC}$ = 86 Hz, Phenyl C-1), 16.2 (d, $^{1}J_{PC}$ = 53 Hz, *C*H$_2$), 6.58 (d, $^{2}J_{PC}$ = 5 Hz, *C*H$_3$).

Diethyldiphenylphosphonium Trifluoromethanesulfonate [3]



A solution of ethyldiphenylphosphine (5.0 g, 23.3 mmol, 1.0 equiv.) in dry toluene (47 mL) was prepared in a Schlenk flask under an atmosphere of nitrogen. Ethyl trifluoromethanesulfonate (3.33 mL, 25.6 mmol, 1.1 equiv.) was added to the reaction mixture by syringe, and the reaction was left to stir for 1 hour at room temperature. The solid product that had formed was then filtered and washed with additional toluene. The product was purified by recrystallisation from acetonitrile/ethyl acetate, affording the pure product as a white solid in an isolated yield of 7.7 g (84%). The crystals obtained were dried in a vacuum desiccator over P_2O_5 and $CaCl_2$, and then stored in the desiccator under nitrogen.

m.p. = 98 – 100 °C; **HRMS:** *m/z* (ESI-TOF; positive mode) *m/z*: $[M + H]^+$ calcd. for $[C_{16}H_{19}P]^+$: 243.1297; found: 243.1297.

^{1}H NMR (300 MHz, $CDCl_3$) [3] δ 7.80–7.76 (m, 2H, Phenyl H-4), 7.76– 7.70 (m, 4H, Phenyl H-3), 7.70 – 7.62 (m, 4H, Phenyl H-2), 2.93 (dq, *J* = 12.5 Hz, 7.5 Hz, 2H, C*H*$_2$), 1.18 (dt, *J* = 19.6 Hz, 7.5 Hz, 3H, C*H*$_3$); **^{31}P{^{1}H} NMR** (121 MHz, $CDCl_3$) [3] δ 31.4; **^{19}F{^{1}H}** NMR (376 MHz, $CDCl_3$) δ –78.3 (–C*F*$_3$); **^{13}C{^{1}H} NMR** (126 MHz, $CDCl_3$) [3] δ 134.9 (d, $^4J_{PC}$ = 3 Hz, Phenyl C-4), 132.9 (d, $^2J_{PC}$ = 9 Hz, Phenyl C-2), 130.5 (d, $^3J_{PC}$ = 12 Hz, Phenyl C-3), 120.9 (d, $^1J_{FC}$ = 322 Hz, *C*F$_3$), 117.0 (d, $^1J_{PC}$ = 83 Hz, Phenyl C-1), 14.5 (d, $^1J_{PC}$ = 51 Hz, *C*H$_2$), 5.85 (d, $^2J_{PC}$ = 5 Hz, *C*H$_3$).

3. General Reaction Procedure for Wittig CO_2 Utilisation Reactions

For these reactions, Schlenk flasks fitted with a second stopcock were used (see **Section 4** below for a description of the reaction setup and how reagents were added to the reaction flasks). Phosphonium salt starting material (1.0 equiv.) was added to a Schlenk flask under an atmosphere of nitrogen. To this was added KHMDS (3–4 equiv.) as a commercially available solution in toluene. The reaction was left to stir under N_2 for 1 hour at room temperature giving a coloured solution of the ylide. Carbon dioxide was then allowed to flow over the reaction mixture for 1 hour, giving a pale yellow cloudy heterogenous reaction mixture. See below in **Section 4** for a detailed description on how the CO_2 was administered. After this, the nitrogen gas supply to the reaction flask was restored, and then the appropriate aldehyde (1.0–1.5 equiv.) was added by syringe to the Schlenk flask under an atmosphere of nitrogen, through the side-arm of the flask (see **Section 4** below for further details on this process), which was promptly closed thereafter. Once the aldehyde was added, the reaction mixture was heated using an oil bath (temperature for each reaction is given below). The tap on the additional stopcock on the top of the flask was then also closed, thereby leaving the reaction sealed inside the flask under a blanket of nitrogen. Typical reaction temperatures were between 80–100 °C. In order to avoid unsafe pressure in the sealed Schlenk flask upon heating to these temperatures, 50 mL size Schlenk round-bottomed flasks were used with < 10 mL solvent volumes, and only the bottom part of the Schlenk flask (up to the solvent level) was immersed in the oil bath.

After aldehyde addition, the reaction mixture was left to stir for a certain length of time (specified below for each experiment), after which point the flask was opened to air. The reaction was then worked-up and purified by one of the general purification procedures A, B, C, D or E, described in **Section 5** below.

Note on aldehyde addition: Liquid aldehydes were added neat by a nitrogen-flushed syringe. Solid aldehydes were added to the reaction under an atmosphere of nitrogen as stock solutions in dry toluene stored under nitrogen. In some cases, the solid aldehydes were poorly soluble in toluene, so stock solutions in dry THF were prepared instead.

4. General Set-Up for Wittig CO_2 Utilisation Reactions

For carbon dioxide utilisation reactions, 50 mL round-bottomed Schlenk flasks were used. A nitrogen atmosphere was established inside the Schlenk flask (containing a stir-bar) using the standard "pump and fill" technique[2] (as described above in general considerations). An

additional greased ground glass stopcock with a ground glass joint on one side (sealed with a "Schlenk cap" – see Fig. 1a) and a glass tubing connection on the other side (see Fig. 1b) was connected to the Schlenk double manifold. A nitrogen atmosphere was established in the sealed stopcock using the standard Schlenk pump and fill technique.

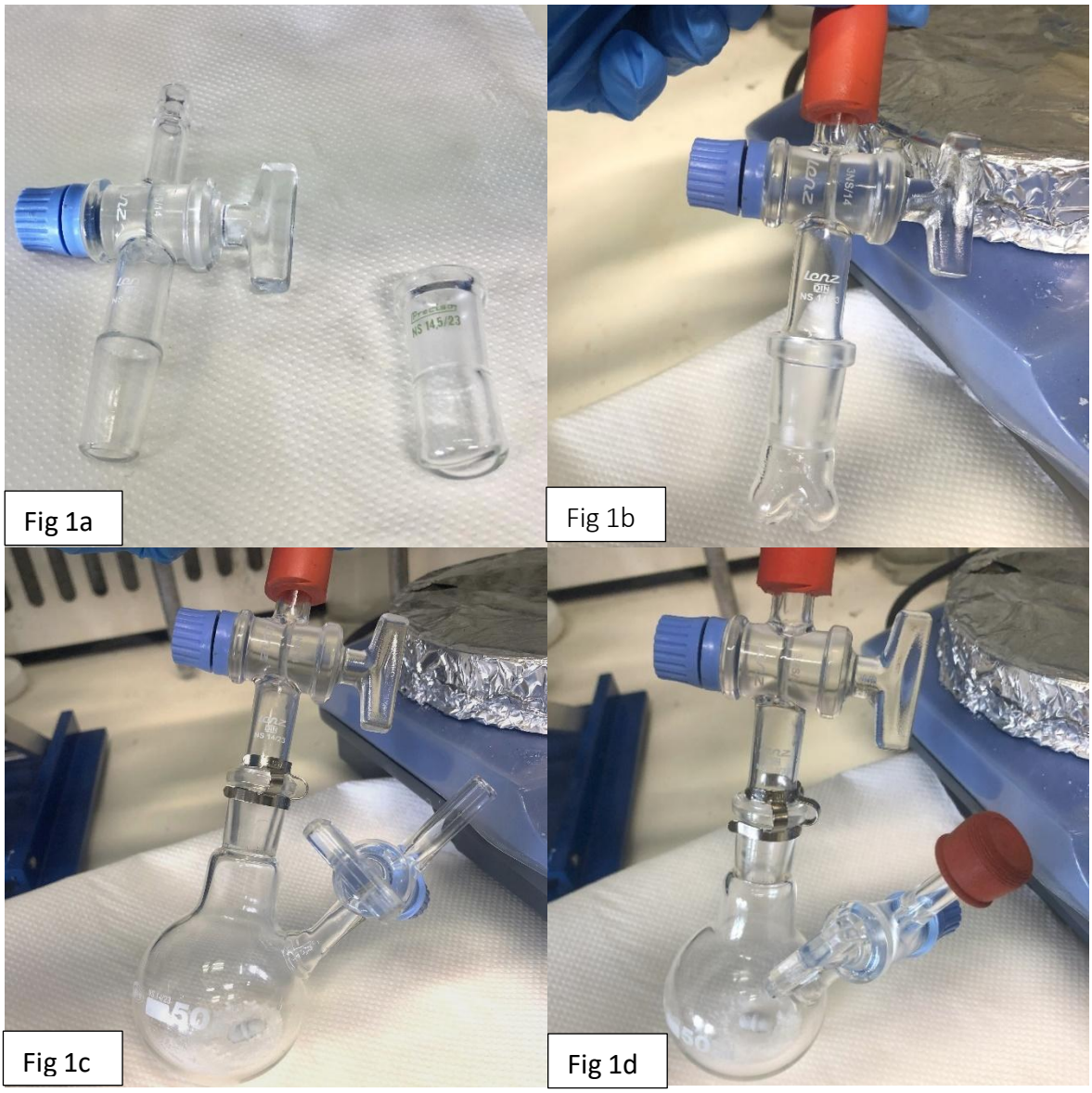


Figure 1. (a) Additional stopcock with ground glass joint (left) and ''Schlenk cap'' (right); **(b)** Stopcock sealed with ''Schlenk cap'', connected to Schlenk line *via* tubing; **(c)** Schlenk flask containing phosphonium salt, after connecting to the additional stopcock and closure of the tap on the side-arm of the flask. **(d)** Schlenk flask with rubber septum on flask side-arm, after flushing the space between the tap and the septum with a nitrogen flush needle. The tap was then opened to allow addition of reagents by syringe through the aperture of the tap.

The phosphonium salt starting material was added to the Schlenk flask against a flow of nitrogen, using a glass vial which is narrower than the neck of the flask. The Schlenk cap was then removed from the additional stopcock and the Schlenk flask and additional stopcock were quickly

attached to each other (with nitrogen gas flowing out from both the flask and the additional stopcock while they were open to the atmosphere) – see Fig. 1c.[2] The stopcock on the side-arm of the Schlenk flask was then closed and the rubber tubing connecting this arm of the flask to the Schlenk manifold was removed.

At this point, the Schlenk flask was connected to the Schlenk manifold only by the additional stopcock at the top of the flask. An appropriately sized rubber septum was then fitted onto the aperture on the side-arm of the flask. The volume contained in the side-arm between the stopcock and the septum was then flushed with a nitrogen flush needle. After flushing for at least 2 minutes, the stopcock was then opened (see Fig. 1d) to allow liquids or solutions to be added into the flask by syringe (by inserting the needle through the aperture of the stopcock in the open position). This allowed for addition of reagents (e.g., KHMDS solution) under an atmosphere of nitrogen while avoiding any momentary exposure of the contents of the flask to the external atmosphere.

For reactions using dry ice to administer carbon dioxide to the reaction flask under inert conditions, a 3-neck flask was used. The 3-neck flask had two greased ground glass stopcocks (each with a ground glass joint on one side and a glass tubing connection on the other side of the stopcock) connected to two of the necks of the flask, and the remaining neck (typically bigger than the other two) was closed via a stopper. Addition of dry ice into the 3-neck flask was typically done *via* this wide ground glass joint. One of the stopcocks connected to the flask was attached to the Schlenk manifold by one of the rubber tubes connected to the manifold, and the other stopcock was connected to the reaction flask side-arm by a separate piece of rubber tubing. Before a nitrogen atmosphere was established in the 3-neck flask, the stopcock on the side-arm of the Schlenk reaction flask was kept closed off from the 3-neck flask The 3-neck flask was put under an atmosphere of nitrogen by the standard pump and fill technique (three repeats of evacuation and re-fill to < 0.010 mbar, then re-fill with nitrogen).[2] A small quantity of dry ice was then added to the 3-neck flask by removing the stopper quickly, with the flask under a high flow of nitrogen (Fig. 2a).

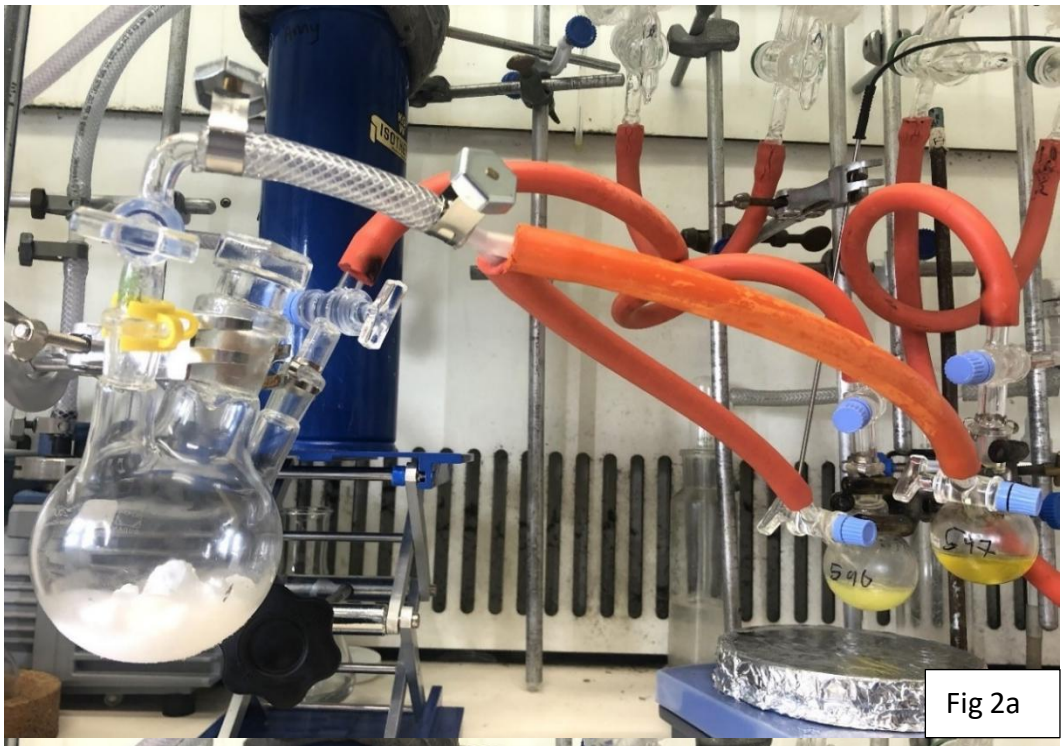


Fig 2a

Fig 2b

Figure 2. (a) During dry ice addition, the tap between the 3-neck flask and the reaction flask is closed. The tap between the Schlenk line and the 3-neck flask is open with a high flow of N_2. During this time, the tap on the side-arm of the reaction flask remains closed; **(b)** CO_2 flow into the reaction flask. In sequence, the tap of 3-neck flask connected to the Schlenk line is closed and the tap connecting to the reaction flask is opened. The tap on the side-arm of the flask is then opened. A cloudy white solution quickly forms.

The tap connecting the 3-neck flask to the Schlenk manifold was then closed and the tap on the side-arm of the Schlenk reaction flask was opened to allow the carbon dioxide to be directed over the surface of the contents of the reaction flask (a solution of phosphonium ylide), which quickly reacts to form a cloudy solution of the carboxylate ylide (Fig 2b). During this time, the gas flowing through the Schlenk line is CO_2 and the flow can be seen increasing through the bubbler when the reaction flasks are opened to the flow of CO_2. **Note:** in practice, CO_2 vapour would typically be administered to two to three reactions simultaneously, using plastic Y-pieces to split tubing connections into each flask.

5. General Work-Up Procedures for Wittig CO_2 Utilisation Reactions

General Work-Up Procedure A: Reaction Work-Up and Yield Determination by NMR Spectroscopy with Internal Standard

When the reaction was complete, the reaction mixture was cooled to room temperature and solvent was removed *in vacuo.* Aqueous acid was then added until the reaction mixture was at pH 2. The mixture was extracted with 3 × 30 mL ethyl acetate washes. The combined organic phases were dried over $MgSO_4$, filtered and concentrated *in vacuo* to give the crude product (also containing phosphine oxide as the by-product). 1,3,5-Trimethoxybenzene (10–15 mol%) was added to the crude reaction mixture, which was dissolved in DMSO-d_6 for NMR spectroscopic analysis.

General Work-Up Procedure B: Isolation of α,β-Unsaturated Carboxylic Acids by DCVC Purification of the Potassium Salt Product

When the reaction was complete, the reaction mixture was cooled to room temperature and loaded onto celite prior to purification by DCVC.[5,10] A cylindrical sintered glass funnel of approximate diameter of 30 mm or 40 mm was used for the column and was packed with silica (60 Å, 20–45 μm) to an approximate height of 5 cm. Wider columns were used for large quantities of material to be separated. The column was connected to vacuum through a three–way tap. Vacuum was applied through use of a Laboport® N96 diaphragm pump. To ensure the silica was packed, a glass stamper was used to press down the silica. The reaction mixture was dry-loaded on celite (see description of the dry-loading process below), and a layer of filter paper was put on top of the silica and the celite was added on top, followed by another layer of filter paper. For each fraction, 20 mL of eluent was prepared, and with each fraction eluted, a 5% increase in polarity was used (the first fraction containing 100% of the less polar solvent). **Note:**

a 5% solvent gradient refers to increasing the percentage of the more polar solvent (acetone or methanol) by 5% for each fraction of solvent eluent prepared. Each eluent mixture was prepared by pre-mixing the solvents in a conical flask while the previous fraction was eluting. Fractions were collected in a small separatory funnel at the bottom of the column, and drained into a test-tube underneath, once vacuum was released through the three-way tap.

To dry load the reaction mixture onto celite, the reaction mixture was transferred to a 100 mL or 250 mL round-bottomed flask (RBF) using solvent such as dichloromethane or methanol. A small spatula full of celite was then added. The solvent was removed *in vacuo* to give the dry reaction mixture loaded onto celite. The material was then transferred from the RBF to the top of the column of silica. Elution of phosphine oxide was performed first, in all instances, using a 5% gradient of dichloromethane/acetone. Then elution of the potassium salt of the α,β-unsaturated carboxylic acids was then performed using a 5% gradient of dichloromethane/methanol. The fractions collected were combined and concentrated *in vacuo* to give the potassium salt of the product. This product was acidified to pH 2 using 1 equiv. of aqueous acid ((+)-CSA or methanesulfonic acid) along with deionised water (10 mL). The resulting acidic solution was extracted three times with ethyl acetate (30 mL per extraction). The organic layers were combined, dried over $MgSO_4$, filtered, and concentrated *in vacuo* to give the isolated α,β-unsaturated carboxylic acid.

General Work-Up Procedure C: Isolation of α,β-Unsaturated Carboxylic Acids by Column Chromatography of the Potassium Salt Product

When the reaction was complete, the reaction mixture was cooled to room temperature, and loaded onto celite prior to purification. This was done by transferring the reaction mixture to a 100 mL or 250 mL round-bottomed flask (RBF) using solvent such as dichloromethane or methanol. A small spatula full of celite was added was then added. The solvent was removed *in vacuo* to give the dry reaction mixture loaded onto celite. The material was then transferred from the RBF to the top of the column of silica. Elution of phosphine oxide was performed first, in all instances, using an 8:2 mixture of dichloromethane/acetone. Then elution of the potassium salts of the α,β-unsaturated carboxylic acids was performed using an elution mixture of 9:1 dichloromethane/methanol. Fractions were combined and concentrated *in vacuo* to give the potassium salt of the product. This product was acidified to pH 2 using 1 equiv. of aqueous acid ((+)-CSA or methanesulfonic acid) along with deionised water (10 mL). The resulting acidic

solution was extracted three times with ethyl acetate (30 mL per extraction). The organic layers were combined, dried over $MgSO_4$, filtered, and concentrated *in vacuo* to give the isolated α,β-unsaturated carboxylic acid.

General Work-Up Procedure D: Isolation of α,β-Unsaturated Carboxylic Acids by Column Chromatography of the Carboxylic Acid Product

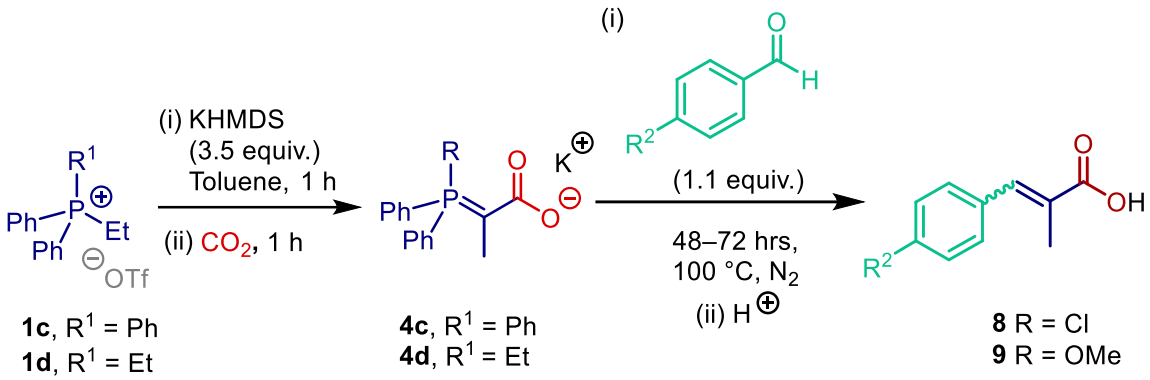
When the reaction was complete, the reaction mixture was cooled to room temperature, and solvent was removed *in vacuo*. The crude product was acidified to pH 2 using an aqueous solution of methanesulfonic acid, along with deionised water (10 mL). The resulting acidic solution was extracted three times with ethyl acetate (30 mL per extraction). The organic layer was dried over $MgSO_4$, filtered, and concentrated *in vacuo* to give the cinnamic acid with phosphine oxide by-product. The product in some instances was loaded onto celite prior to column purification if solubility was low in cyclohexane. In these cases, the dry-loading procedure was followed as described in General Work-Up Procedure D above. A gradient of solvent mixtures from 98:2 → 70:30 cyclohexane/ethyl acetate was used for elution of the cinnamic acid product. 100% ethyl acetate was used to flush the methyldiphenylphosphine oxide by-product from the column.

6. Optimisation of Conditions for Wittig CO_2 Utilisation Reactions

All Experiments below were conducted according to the General Procedure described in sections 3 and 4 above.

6.1. Synthesis of α-Substituted α,β-Unsaturated Carboxylic Acids

Table S1. Optimisation experiments for the synthesis of α,β-unsaturated carboxylic acids containing trisubstituted C=C bonds from *P*-ethyl-containing phosphonium salts.



Entry	Phosphonium Salt	R^2	Time (h)	Yield [a] (%)
1	$[EtPh_3P]OTf$	Cl	48	55
2	$[Et_2Ph_2P]OTf$	Cl	48	60
3	$[Et_2Ph_2P]OTf$	Cl	70	69
4	$[EtPh_3P]OTf$	OMe	48	18
5	$[Et_2Ph_2P]OTf$	OMe	70	64[b]

[a] Isolated yield following column chromatography, [b] Wittig step carried out in an oil bath heated to 105 °C.

Entry 1

Reaction conditions and ^1H NMR spectral data for this entry are outlined in section 8; see details therein for (*E*)-3-(4-(chloro)phenyl)-2-methyl acrylic acid (**8**) starting from ethyltriphenylphosphonium triflate.

Entry 2

From diethyldiphenylphosphonium triflate (0.35 g, 0.90 mmol, 1.0 equiv.), KHMDS in toluene (0.40 mol L^{-1} (titr.), 7.9 mL, 3.2 mmol, 3.5 equiv.), and 4-chlorobenzaldehyde (0.13 g, 0.95 mmol, 1.05 equiv.). After addition of the benzaldehyde, the reaction was left to stir for 48 hours in an oil bath at 100 °C.

The product was purified following general work-up procedure E, using 90:10 → 70:30 cyclohexane/ethyl acetate. For the acidification step of the purification, 2.0 mol L^{-1} aqueous methanesulfonic acid (1.0 equiv.) was employed. The product was isolated as an off-white solid in a yield of 0.11 g (60%, *E*-isomer only).

^{1}H NMR (300 MHz, $CDCl_3$)[11] δ 7.77 (app q, *J* = 1.5 Hz, 1H, C*H*=CH_3COOH), 7.44 – 7.31 (m, 4H, Aryl-H), 2.13 (d, *J* = 1.5 Hz, 3H, CH_3).

Entry 3

Reaction conditions and ^{1}H NMR spectral data for this entry are outlined in section 8; see details therein for (*E*)-3-(4-(chloro)phenyl)-2-methyl acrylic acid (**8**) starting from diethyldiphenylphosphonium triflate.

Entry 4

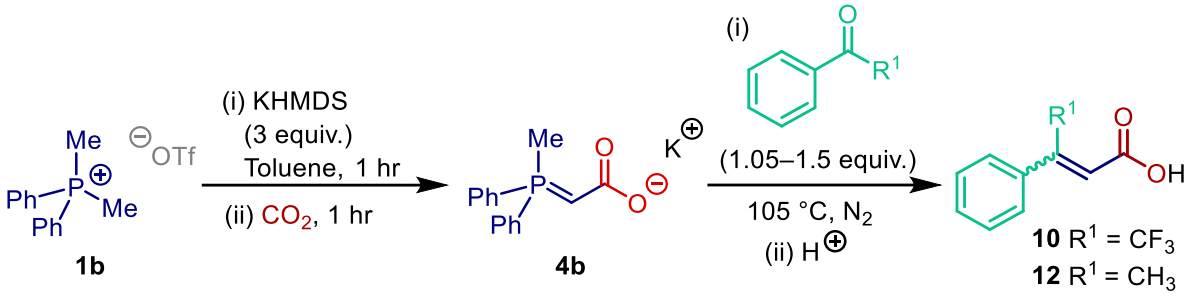
Reaction conditions and ^{1}H NMR spectral data for this entry are outlined in section 8; see details therein for (*E*)-3-(4-(methoxy)phenyl)-2-methyl acrylic acid (**9**) starting from ethyltriphenylphosphonium triflate.

Entry 5

Reaction conditions and ^{1}H NMR spectral data for this entry are outlined in section 8; see details therein for (*E*)-3-(4-(methoxy)phenyl)-2-methyl acrylic acid (**9**) starting from diethyldiphenylphosphonium triflate.

6.2. Synthesis of β-Substituted α,β-Unsaturated Carboxylic Acids.

Table S2. Optimisation reactions for the synthesis of α,β-unsaturated carboxylic acids with trisubstituted C=C bonds using ketones as the carbonyl source.



Entry	Deviation from Standard Conditions	R^2	Ketone Equiv.	Time	Yield (%)
1	/	CF_3	1.05	48 h	83 [a]
2	/	CH_3	1.05	48 h	7 [a]
3	Solvent removal post-CO_2 addition	CH_3	1.5	48 h	40 [b]
4	Solvent removal pre-CO_2 addition	CH_3	1.5	48 h	22 [b]
5	Solvent removal post-CO_2 addition	CH_3	1.5	5 days	44 [a]

[a] Isolated yield following column chromatography, [b] Yields determined by ^{1}H NMR spectroscopy using 1,3,5-trimethoxybenzene as an internal standard.

Entry 1

Reaction conditions and ^{1}H NMR spectral data for this entry are outlined in section 3.10; see details therein for 4,4,4-trifluoro-3-phenylbut-2-enoic acid (**10**).

Entry 2

From dimethyldiphenylphosphonium triflate (0.33 g, 0.91 mmol, 1.0 equiv.), KHMDS in toluene (0.55 mol L^{-1} (titr.), 5.0 mL, 2.7 mmol, 3.0 equiv.), and acetophenone (0.12 g, 0.95 mmol, 1.05

equiv.). After addition of the ketone, the reaction was left to stir for 48 hours in an oil bath at 105 °C.

The product was purified following general work-up procedure E, using 95:5 → 70:30 cyclohexane/ethyl acetate. For the acidification step of the purification, 2.0 mol L^{-1} aqueous methanesulfonic acid (1.0 equiv.) was employed. The product was isolated as a white solid in a yield of 0.010 g (7%).

^{1}H NMR (400 MHz, $CDCl_3$)[12] δ 7.54 – 7.46 (m, 2H, Aryl H-2), 7.42 – 7.37 (m, 3H, Aryl H-3 and H-4), 6.19 (s, 1H, C=C*H*COOH), 2.61 (d, *J* = 1.3 Hz, 3H, CH_3).

Entry 3

From dimethyldiphenylphosphonium triflate (0.14 g, 0.38 mmol, 1.0 equiv.), KHMDS in toluene (0.55 mol L^{-1} (titr.), 2.0 mL, 1.1 mmol, 3.0 equiv.), and acetophenone (0.070 g, 0.56 mmol, 1.5 equiv.). Before the addition of the ketone, a proportion of the solvent was removed by subjecting the flask to a vacuum mediated by the Schlenk line apparatus and collecting the solvent in a liquid nitrogen trap. After concentrating the reaction mixture, the ketone was added, and the reaction was left to stir for 48 hours in an oil bath at 105 °C. Following general work-up procedure A, 1,3,5-trimethoxybenzene (11.7 mg, 0.0696 mmol) was added as a ^{1}H NMR spectroscopy internal standard and a ^{1}H NMR spectrum was obtained.

Assigned to (E)-3-phenylbut-2-enoic acid:[12]

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.42 – 7.37 (m, 3H, Aryl H-3 and H-4), 6.17 (q, *J* = 1.3 Hz, 1H, C=C*H*COOH), 2.61 (d, *J* = 1.3 Hz, 3H, CH_3). The remaining aromatic ^{1}H NMR signals are obscured by the aromatic ^{1}H NMR signals of $MePh_2PO$.

Assigned to (Z)-3-phenylbut-2-enoic acid:[13]

^{1}H NMR (400 MHz, $CDCl_3$) δ 5.94 (q, *J* = 1.4 Hz, 1H, C=C*H*COOH), 2.16 (d, *J* = 1.4 Hz, 3H, CH_3). The remaining aromatic ^{1}H NMR signals are obscured by the aromatic ^{1}H NMR signals of $MePh_2PO$.

Assigned to methydiphenylphosphine oxide:[14]

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.74–7.62 (m, 4H, Aryl H-2), 7.50 – 7.40 (m, 6H, Aryl H-3 and H-4), 2.07 (d, *J* = 13.2 Hz, 3H, CH_3).

Assigned to 1,3,5-trimethoxybenzene internal standard: [15]

^{1}H NMR (400 MHz, $CDCl_3$) δ 6.09 (s, 3H), 3.74 (s, 9H).

NMR Spectral Yield of *E*-isomer: Ratio of *E*-isomer (C*H*COOH) to 1,3,5-trimethoxybenzene (Ar-*H*): 1.84:1. As 0.0696 mmol of 1,3,5-trimethoxybenzene was added, the percentage yield of the *E*-isomer was determined to be 34%.

NMR Spectral Yield of *Z*-isomer: Ratio of *Z*-isomer (C*H*COOH) to 1,3,5-trimethoxybenzene (Ar-*H*): 0.294:1. As 0.0696 mmol of 1,3,5-trimethoxybenzene was added, the percentage yield of the *Z*-isomer was determined to be 6%.

Combined NMR Spectral Yield: 40%

Entry 4

From dimethyldiphenylphosphonium triflate (0.13 g, 0.36 mmol, 1.0 equiv.), KHMDS in toluene (0.55 mol L^{-1} (titr.), 2.0 mL, 1.1 mmol, 3.0 equiv.), and acetophenone (0.0.070 g, 0.54 mmol, 1.5 equiv.). Before the administration of CO_2, a proportion of the solvent was removed by subjecting the flask to a vacuum mediated by the Schlenk line apparatus and collecting the solvent in a liquid nitrogen trap. After addition of the ketone, the reaction was left to stir for 48 hours in an oil bath at 105 °C. Following general work-up procedure A, 1,3,5-trimethoxybenzene (11.6 mg, 0.0690 mmol) was added as a ^{1}H NMR spectroscopy internal standard and a ^{1}H NMR spectrum was obtained.

NMR spectral data as above in entry 3.

NMR Spectral Yield of *E*-isomer: Ratio of *E*-isomer (C*H*COOH) to 1,3,5-trimethoxybenzene (Ar-*H*): 0.982:1. As 0.0690 mmol of 1,3,5-trimethoxybenzene was added, the percentage yield of the *E*-isomer was determined to be 19%.

NMR Spectral Yield of *Z*-isomer: Ratio of *Z*-isomer (C*H*COOH) to 1,3,5-trimethoxybenzene (Ar-*H*): 0.148:1. As 0.0690 mmol of 1,3,5-trimethoxybenzene was added, the percentage yield of the *Z*-isomer was determined to be 3%.

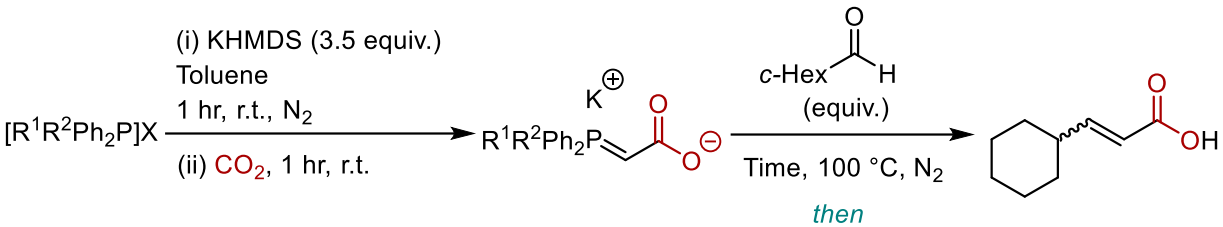
Combined NMR Spectral Yield: 22%

Entry 5

Reaction conditions and ^{1}H NMR spectral data for this entry are outlined in section 8; see details therein for 3-phenylbut-2-enoic acid (**12**).

6.2. Experiments to Determine Optimal Conditions for Reactions of Aliphatic Aldehydes

Table S3. Investigation of Optimal Conditions for Reactions of Aliphatic Aldehydes



1a, R^1 = Me, R^2 = Ph
1b, R^1 = R^2 = Me

4a, R^1 = Me, R^2 = Ph
4b, R^1 = R^2 = Me

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Entry	Phosphonium salt	Aldehyde addition method	Aldehyde (equiv.)	Time (hr)	Yield (%) (*E:Z*)
1	[Ph_3PMe]Br	0.2 M in toluene; added all at once	1.2	26	34 [a] (*82:18*)
2	[Ph_2Me_2P]OTf	0.2 M in toluene; added all at once	1.2	26	59 [a] (*87:13*)
3	[Ph_2Me_2P]OTf	0.2 M in toluene; syringe pump addition for 4 hrs at 100 °C, then reaction stirred at 100 °C for 22 hrs	1.2	26	31 [a] (*81:19*)
4	[Ph_2Me_2P]OTf	Neat aldehyde; added all at once	1.5	48	77 [b] (*85:15*)

[a] Yields were determined by ^{1}H NMR analysis of the alkenyl protons of the product from the ^{1}H NMR spectrum of the crude product with 1,3,5-trimethoxybenzene used as internal standard. [b] Isolated yield after acidification and flash column chromatography.

Entry 1

From methyltriphenylphosphonium bromide (0.15 g, 0.41 mmol, 1.0 equiv.), KHMDS in toluene (0.47 mol L^{-1} (titr.), 3.0 mL, 1.4 mmol, 3.5 equiv.), cyclohexanecarboxaldehyde (0.2 mol L^{-1} in toluene, 2.5 mL, 0.49 mmol, 1.2 equiv.), using the General Procedure described in sections 3 and 4. After the addition of the aldehyde, the reaction was left to stir for 26 hours in an oil bath

at 100 °C. General Work-Up Procedure A was then followed using 2 mol L^{-1} aqueous methanesulfonic acid (~4 mL) to bring the reaction mixture to pH 2. An orange oil resulted containing the product and phosphine oxide by-product.

Assigned to 3-(cyclohexyl)acrylic acid product:[16–18]

^{1}H NMR (300 MHz, DMSO-d_6) δ 6.77 (dd, *J* = 15.8, 6.8 Hz, 1H, *c*-Hex-C*H*=C, *E*-isomer), 6.01 (dd, *J* = 11.5, 9.8 Hz, 1H, *c*-Hex-C*H*=C, *Z*-isomer), 5.70 (d, *J* = 15.8 Hz, 1H, C*H*COOH, *E*-isomer), 5.61 (d, *J* = 11.5 Hz, 1H, C*H*COOH, *Z*-isomer), 2.19–2.03 (m, 1H, *c*-Hex-H, *E*-isomer), 1.75–1.56 (m, 5H, *c*-Hex-H, *E*- and *Z*-isomer overlapping), 1.30–1.02 (m, 5H, *c*-Hex-H, *E*- and *Z*-isomer overlapping). There was no signal evident for COO*H* proton. Remaining ^{1}H multiplet at approximately 3.3 ppm for *c*-Hex-H of the *Z*-isomer is obscured by the water peak in DMSO-d_6.

Assigned to triphenylphosphine oxide:[19]

^{1}H NMR (300 MHz, DMSO-d_6) δ 7.68–7.50 (m, 15H).

^{31}P{^{1}H} NMR (121 MHz, DMSO-d_6) δ 25.6.

Assigned to 1,3,5-trimethoxybenzene internal standard: [15]

^{1}H NMR (300 MHz, DMSO-d_6) δ 6.09 (s, 3H), 3.70 (s, 9H).

NMR spectral yield: Ratio of *E*-isomer (alkene proton signal) and Z-isomer (alkene proton signal) to internal standard (3H signal): 0.93:0.21:1. The amount of internal standard added was 7.1 mg and therefore the percentage yield was determined to be 34%.

Entry 2

From dimethyldiphenylphosphonium triflate (0.14 g, 0.38 mmol, 1.0 equiv.), KHMDS in toluene (0.47 mol L^{-1} (titr.), 2.9 mL, 1.3 mmol, 3.5 equiv.), cyclohexanecarboxaldehyde (0.2 mol L^{-1} in toluene, 2.3 mL, 0.46 mmol, 1.2 equiv.), using the General Procedure described in sections 3 and 4. After the addition of the aldehyde, the reaction was left to stir for 26 hours in an oil bath at 100 °C. General Work-Up Procedure A was then followed using 2 mol L^{-1} aqueous methanesulfonic acid (~4 mL) to bring the reaction mixture to pH 2. An orange oil resulted containing the product and phosphine oxide by-product.

Assigned to 3-(cyclohexyl)acrylic acid product:[16–18]

^{1}H NMR (300 MHz, DMSO) δ 6.77 (dd, *J* = 15.8, 6.8 Hz, 1H, *c*-Hex-C*H*=C, *E*-isomer), 6.01 (dd, *J* = 11.5, 9.8 Hz, 1H, *c*-Hex-C*H*=C, *Z*-isomer), 5.69 (dd, *J* = 15.8, 1.4 Hz, 1H, C*H*COOH, *E*-isomer), 5.61 (dd, *J* = 11.5, 0.9 Hz, 1H, C*H*COOH, *Z*-isomer), 2.19–2.08 (m, 1H, *c*-Hex-H, *E*-isomer), 1.74–1.54

(m, 5H, *c*-Hex-H, *E*- and *Z*-isomer overlapping), 1.32–0.98 (m, 5H, *c*-Hex-H, *E*- and *Z*-isomer overlapping). There was no signal evident for COO*H* proton. Remaining ^{1}H *c*-Hex-H multiplet of the *Z*-isomer at approximately 3.3 ppm is obscured by the water peak in DMSO-d_6.

Assigned to methyldiphenylphosphine oxide:[20]

^{1}H NMR (300 MHz, DMSO-d_6) δ 7.81–7.71 (m, 4H), 7.57–7.46 (m, 6H), 2.03 (d, J = 13.4 Hz, 3H).

^{31}P{^{1}H} NMR (121 MHz, DMSO-d_6) δ 28.0.

Assigned to 1,3,5-trimethoxybenzene internal standard: [15]

^{1}H NMR (300 MHz, DMSO-d_6) δ 6.09 (s, 3H), 3.70 (s, 9H).

NMR spectral yield: Ratio of *E*-isomer (alkene proton signal) and Z-isomer (alkene proton signal) to internal standard (3H signal): 1.62 : 0.25 : 1. The amount of internal standard added was 6.8 mg and therefore the percentage yield was determined to be 59%.

Entry 3

From dimethyldiphenylphosphonium triflate (0.14 g, 0.40 mmol, 1.0 equiv.), KHMDS in toluene (0.47 mol L^{-1} (titr.), 3.0 mL, 1.4 mmol, 3.5 equiv.), cyclohexanecarboxaldehyde (0.2 mol L^{-1} in toluene, 2.4 mL, 0.48 mmol, 1.2 equiv.), using the General Procedure described in sections 3 and 4. **Exception: the aldehyde was added *via* syringe pump at a rate of 0.01 mL min^{-1} (2.4 mL added over 4 hours). The syringe and attached plastic tubing used for the addition was flushed three times with nitrogen prior to use. During the syringe pump addition, the reaction flask was placed in an oil bath at 100 °C.** After the addition of the aldehyde, the reaction was left to stir for 22 hours in an oil bath at 100 °C.

General Work-Up Procedure A was then followed using 2 mol L^{-1} aqueous methanesulfonic acid (~4 mL) to bring the reaction mixture to pH 2. An orange oil resulted containing the product and phosphine oxide by-product. Spectral data as above in entry 2.

NMR spectral yield: Ratio of *E*-isomer (alkene proton signal) to internal standard (3H signal): 0.90:0.21:1. The amount of internal standard added was 6.2 mg and therefore the percentage yield was determined to be 31%.

Entry 4

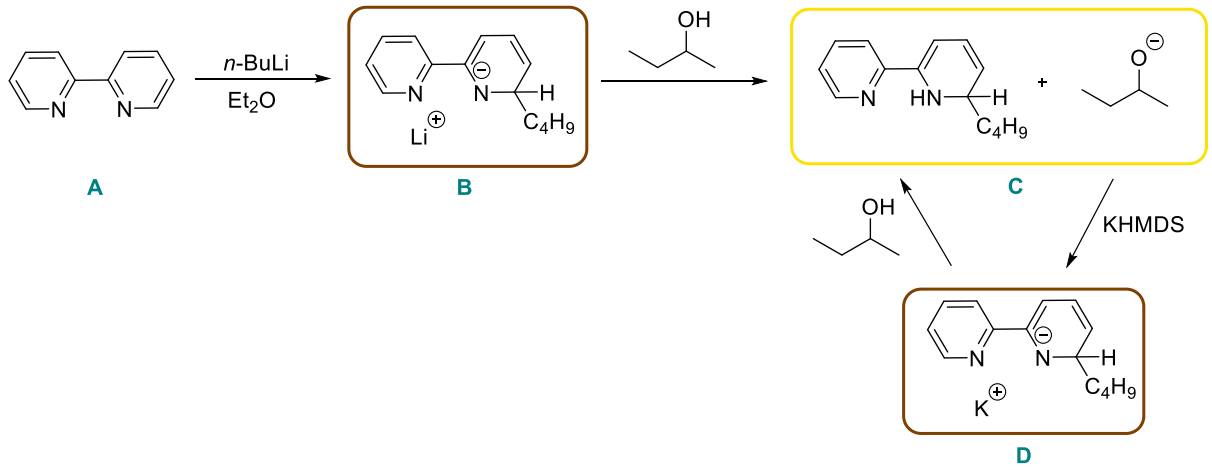
Reaction conditions and ^{1}H NMR spectral data for this entry are outlined in the substrate scope section; see details therein for 3-(cyclohexyl)acrylic acid.

7. Potassium bis(trimethylsilyl)amide (KHMDS) Titrations

To accurately know the concentration of the KHMDS sources used throughout this work, titrations were carried out periodically on the bottles of commercial KHMDS being used. The method followed was that developed by Ireland and Meissner (outlined in Table S4).[4]

The indicator was prepared by the treatment of 2,2,-bipyridine (**A**) with *n*-butyllithium, forming a lithium salt **B** (red/brown) that was quenched with 2-butanol to form the yellow dihydro derivative **C**. The titration method is based on the ability of KHMDS to deprotonate the yellow dihydro indicator, forming the red/brown potassium salt mixture **D**. Based on the quantity of 2-butanol required to re-generate the yellow dihydro indicator solution, the concentration of KHMDS can be determined.

Table S4 Results of KHMDS Titrations



Entry	Source	Volume KHMDS Solution (mL)	Volume 2-Butanol Solution [a] (Average, mL)	KHMDS Concentration (mol L^{-1})
1	**Bottle 1** (Acros)	0.40	0.16	0.40
2	**Bottle 2** (Acros)	0.40	0.23	0.58
3	**Bottle 2** 3 months later	0.40	0.22	0.55
4	**Bottle 3** (Sigma Alrich)	0.40	0.20	0.50
5	Solution of Solid KHMDS in toluene [b]	0.40	0.20	0.50

[a] 1 mol L^{-1} solution in toluene; [b] 0.5 mmol KHMDS in 1 mL toluene (0.50 mol L^{-1}).

Entry 1

The KHMDS solution from **Bottle 1** (0.40 mL) was added to the indicator solution, **C**. A permanent deep red colour was observed. A 1.0 mol L^{-1} solution of 2-butanol (0.16 mL) was added dropwise giving a permanent colour change from deep red to yellow. The titration was repeated 3 times and an average titre of two butanol added was obtained. As the molarity of the 2-butanol solution was 1.0 mol L^{-1}, the quotient of the volume of 2-butanol added and the volume of KHMDS added will give the molarity of the KHMDS solution. Therefore, the concentration of KHMDS was determined to be 0.40 mol L^{-1}.

Entry 2

The KHMDS solution **Bottle 2** (0.40 mL) was added to the indicator solution, **C**. A permanent deep red colour was observed. A 1.0 mol L^{-1} solution of 2-butanol (0.23 mL) was added dropwise giving a permanent colour change from deep red to yellow. The titration was repeated 3 times and an average titre of two butanol added was obtained. The concentration of KHMDS was determined to be 0.58 mol L^{-1}.

Entry 3

The KHMDS solution from **Bottle 2** after 3 months of use from Entry 2 (0.40 mL) was added to the indicator solution, **C**. A permanent deep red colour was observed. A 1.0 mol L^{-1} solution of 2-butanol (0.22 mL) was added dropwise giving a permanent colour change from deep red to yellow. The titration was repeated 3 times and an average titre of two butanol added was obtained. The concentration of KHMDS was determined to be 0.55 mol L^{-1}.

Entry 4

The KHMDS solution from **Bottle 3** (0.40 mL) was added to the indicator solution, **C**. A permanent deep red colour was observed. A 1.0 mol L^{-1} solution of 2-butanol (0.20 mL) was added dropwise giving a permanent colour change from deep red to yellow. The titration was repeated 3 times and an average titre of two butanol added was obtained. The concentration of KHMDS was determined to be 0.50 mol L^{-1}.

Entry 5

A 0.50 mol L^{-1} solution of KHMDS (0.10 g, 0.50 mmol) in toluene (1.0 mL) was prepared in a Schlenk flask under an atmosphere of nitrogen. The KHMDS solution (0.40 mL) was added to the indicator solution, **C**. A permanent deep red colour was observed. A 1.0 mol L^{-1} solution of 2-

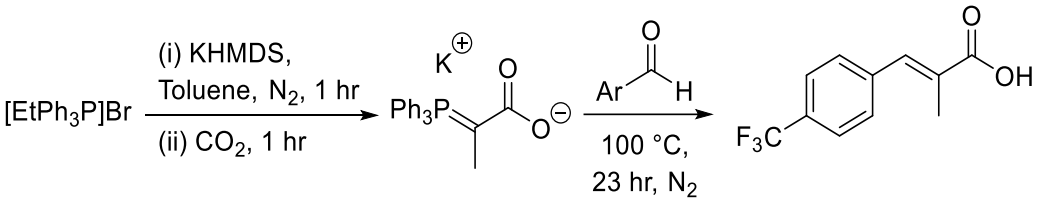
butanol (0.20 mL) was added dropwise giving a permanent colour change from deep red to yellow. The titration was repeated 3 times and an average titre of two butanol added was obtained. The concentration of KHMDS was determined to be 0.50 mol L^{-1}.

8. Substrate Scope of α,β-Unsaturated Carboxylic Acids

All Experiments below were conducted according to the General Procedure described in sections 3 and 4 above.

(*E*)-2-Methyl-3-(4-(trifluoromethyl)phenyl)acrylic Acid (6)

(a) From Ethyltriphenylphosphonium Bromide



Ar = *p*-(F_3C)C_6H_4

From ethyltriphenylphosphonium bromide (0.37 g, 0.99 mmol, 1.0 equiv.), KHMDS in toluene (0.7 mol L^{-1}, 5.0 mL, 3.5 mmol, 3.5 equiv.), and 4-(trifluoromethyl)benzaldehyde (0.18 g, 1.0 mmol, 1.0 equiv.). After addition of the benzaldehyde, the reaction was left to stir for 24 hours in an oil bath at 100 °C.

The product was purified by DCVC as per general work-up procedure B. The DCVC step of the purification yielded a pale yellow solid (0.17 g). For the acidification step of the purification, 2.0 mol L^{-1} aqueous methanesulfonic acid (1.0 equiv.) was employed. The product was isolated as a pale yellow solid in a yield of 0.084 g (37%, *E*-isomer only).

m.p. = 153–155 °C (lit. for *E*-isomer:[21] 155–157 °C).

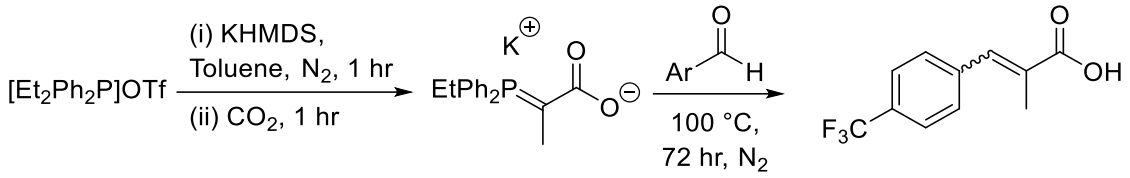
HRMS (ESI-TOF; negative mode) *m/z*: $[M - H]^-$ calcd. for $[C_{11}H_8F_3O_2]^-$: 229.0485; found: 229.0482.

^{1}H NMR (600 MHz, DMSO-d_6)[11] δ 12.72 (br s, 1H, COO*H*), 7.77 (d, *J* = 8.2 Hz, 2H, Aryl H-3), 7.67 (d, *J* = 8.2 Hz, 2H, Aryl H-2), 7.63 (s, 1H, ArC*H*=C), 2.02 (s, 3H, CH_3–C=C).

^{19}F{^{1}H} NMR (282 MHz, DMSO-d_6)[11] δ –61.2 (s, 3F, –CF_3).

^{13}C{^{1}H} NMR (151 MHz, DMSO-d_6)[11] δ 169.1 (*C*OOH), 139.8 (Aryl C-1), 136.0 (Ar*C*=C), 131.3 (C=*C*–COOH*)*, 130.2 (Aryl C-2), 128.4 (q, $^2J_{CF}$ = 32 Hz, Aryl C-4), 125.3 (q, $^3J_{CF}$ = 4 Hz, Aryl C-3), 124.2 (q, $^1J_{CF}$ = 272 Hz, – *C*F_3), 14.0 (*C*H_3-C=C).

(b) From Diethyldiphenylphosphonium triflate



Ar = *p*-(F_3C)C_6H_4

From diethyldiphenylphosphonium triflate (0.35 g, 0.90 mmol, 1.0 equiv.), KHMDS in toluene (0.40 mol L^{-1} (titr.), 7.9 mL, 3.2 mmol, 3.5 equiv.), and 4-(trifluoromethyl)benzaldehyde (0.17 g, 0.95 mmol, 1.05 equiv.). After addition of the benzaldehyde, the reaction was left to stir for 72 hours in an oil bath at 100 °C.

The product was purified following general work-up procedure D, using 95:5 → 70:30 cyclohexane/ethyl acetate. For the acidification step of the purification, 2.0 mol L^{-1} aqueous methanesulfonic acid (1.0 equiv.) was employed. The product was isolated as an off-white solid in a yield of 0.17 g (82%, *E*:*Z* ratio = 92:8).

HRMS (ESI-TOF; negative mode) *m/z*: $[M - H]^-$ calcd. for $[C_{11}H_8F_3O_2]^-$: 229.0485; found: 229.0482.

Assigned to *E*-isomer:

^{1}H NMR (300 MHz, DMSO-d_6)[11] δ 12.72 (br s, 1H, COO*H*), 7.78 (d, *J* = 8.2 Hz, 2H, Aryl H-3), 7.67 (d, *J* = 8.2 Hz, 2H, Aryl H-2), 7.63 (s, 1H, ArC*H*=C), 2.02 (s, 3H, CH_3–C=C).

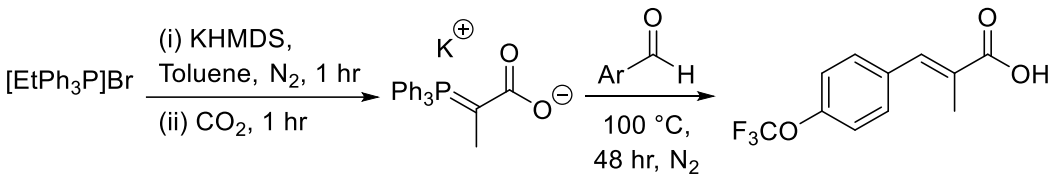
Assigned to *Z*-isomer:

^{1}H NMR (300 MHz, DMSO-d_6) δ 7.49 (d, *J* = 8.2 Hz, 2H, Aryl H-2).*

* Remaining *Z*-isomer proton signals are overlapping with the *E*-isomer proton signals in the ^{1}H NMR spectrum of the isolated product reported.

(*E*)-2-Methyl-3-(4-(trifluoromethoxy)phenyl)acrylic Acid (7)

(a) From Methyltriphenylphosphonium Bromide



Ar = *p*-(F_3CO)C_6H_4

From ethyltriphenylphosphonium bromide (0.34 g, 0.92 mmol, 1.0 equiv.), KHMDS in toluene (0.48 mol L^{-1} (titr.), 8.0 mL, 3.9 mmol, 4.2 equiv.), and 4-trifluoromethoxybenzaldehyde (0.17 g, 0.90 mmol, 1.0 equiv.). After addition of the benzaldehyde, the reaction was left to stir for 48 hours in an oil bath at 100 °C.

The product was purified by DCVC as per general work-up procedure B. The DCVC step of the purification yielded an off-white solid (0.23 g). For the acidification step of the purification, 2.0 mol L^{-1} aqueous methanesulfonic acid (1.0 equiv.) was employed. The product was isolated as an off-white solid in a yield of 0.10 g (46%, *E*-isomer only).

m.p. = 101–102 °C**.**

HRMS (ESI-TOF; negative mode) *m/z*: $[M - H]^-$ calcd. for $[C_{11}H_8F_3O_3]^-$: 245.0431; found: 245.0427.

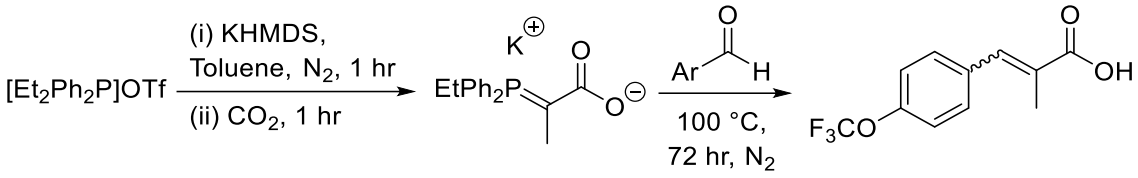
IR $\tilde{\nu}_{max}$ (ATR): 2967–2844 (broad, O—H stretch), 1666 (C=O stretch), 1508 (C=C aromatic stretch), 1453, 1428, 1267, 1207, 1162 (C—F and C—O ether stretches), 1033 cm^{-1}.

^{1}H NMR (400 MHz, DMSO-d_6) δ 12.66 (br s, 1H, COO*H*), 7.59 (app d, app *J* = 8.4 Hz, 3H; overlapping signals; Aryl H, and ArC*H*=C), 7.40 (app d, app *J* = 8.3 Hz, 2H, Aryl H), 2.01 (s, 3H, CH_3–C=C).

^{19}F{^{1}H} NMR (376 MHz, DMSO-d_6) δ –56.8 (s, 3F, –OCF_3).

^{13}C{^{1}H} NMR (101 MHz, DMSO-d_6) δ 169.2 (*C*OOH), 148.0 (d, $^3J_{CF}$ = 2 Hz, Aryl C-4), 136.1 (Ar*C*=C), 134.9 (Aryl C-1), 131.6 (2 × Aryl C), 129.8 (C=*C*–COOH), 121.0 (2 × Aryl C), 120.1 (q, $^1J_{CF}$ = 257 Hz, –O*C*F_3), 13.9 (s, *C*H_3–C=C).

(b) From Diethyldiphenylphosphonium triflate



Ar = *p*-(F_3OC)C_6H_4

From diethyldiphenylphosphonium triflate (0.36 g, 0.91 mmol, 1.0 equiv.), KHMDS in toluene (0.58 mol L^{-1} (titr.), 5.5 mL, 3.2 mmol, 3.5 equiv.), and 4-(trifluoromethoxy)benzaldehyde (0.18 g, 0.96 mmol, 1.05 equiv.). After addition of the benzaldehyde, the reaction was left to stir for 72 hours in an oil bath at 100 °C.

The product was purified following general work-up procedure D, using 95:5 → 70:30 cyclohexane/ethyl acetate. For the acidification step of the purification, 2.0 mol L^{-1} aqueous methanesulfonic acid (1.0 equiv.) was employed. The product was isolated as an off-white solid in a yield of 0.15 g (68%, *E*:*Z* ratio = 91:9).

m.p. = 95–97 °C**.**

HRMS (ESI-TOF; negative mode) *m/z*: $[M - H]^-$ calcd. for $[C_{11}H_8F_3O_3]^-$: 245.0431; found: 245.0427.

IR $\tilde{\nu}_{max}$ (ATR): 2921 (broad, O—H stretch), 1668 (C=O stretch), 1508 (C=C aromatic stretch), 1452, 1427, 1260, 1208, 1163 (C—F and C—O ether stretches), 914 cm^{-1}.

Assigned to *E*-isomer:

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.78 (s, 1H, ArC*H*=C), 7.45 (d, *J* = 8.6 Hz, 2H Aryl H), 7.25 (d, *J* = 8.2 Hz, 2H, Aryl H), 2.13 (s, 3H, CH_3–C=C).

Assigned to *Z*-isomer:

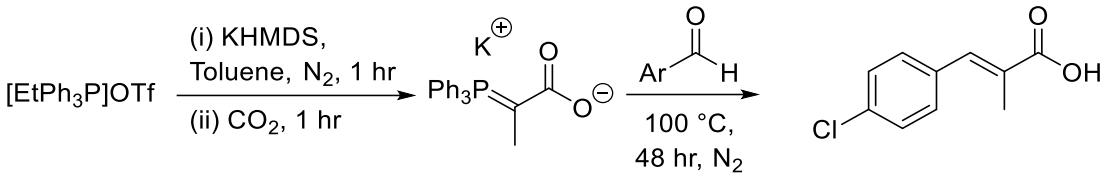
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.35 (d, *J* = 8.6 Hz, 2H Aryl H), 7.14 (d, *J* = 8.2 Hz, 2H, Aryl H), 6.81 (s, 1H, ArC*H*=C).

^{19}F{^{1}H} NMR (282 MHz, $CDCl_3$) δ –57.8 (s, 3F, –OCF_3).

^{13}C{^{1}H} NMR (101 MHz, DMSO-d_6) δ 172.8 (*C*OOH), 148.2 (d, $^3J_{CF}$ = 2 Hz, Aryl C-4), 138.5 (Ar*C*=C), 133.1 (Aryl C-1), 130.3 (2 × Aryl C), 128.9 (C=*C*–COOH), 120.4 (2 × Aryl C), 119.8 (–O*C*F_3), 12.6 (s, *C*H_3–C=C).

(*E*)-3-(4-(Chloro)phenyl)-2-(methyl) Acrylic Acid (8)

(a) From Ethyltriphenylphosphonium Triflate



Ar = *p*-(Cl)C_6H_4

From ethyltriphenylphosphonium triflate (0.40 g, 0.91 mmol, 1.0 equiv.), KHMDS in toluene (0.40 mol L^{-1} (titr.), 8.0 mL, 3.2 mmol, 3.5 equiv.), and 4-chlorobenzaldehyde (0.14 g, 0.96 mmol, 1.05 equiv.). After addition of the benzaldehyde, the reaction was left to stir for 48 hours in an oil bath at 100 °C.

The product was purified by column chromatography in CH_2Cl_2/MeOH 98:2 → 9:1 following purification procedure C. For the acidification step of the purification, 2.0 mol L^{-1} aqueous methanesulfonic acid (1.0 equiv.) was employed. The product was isolated as an off-white solid in a yield of 0.099 g (55%, *E*-isomer only).

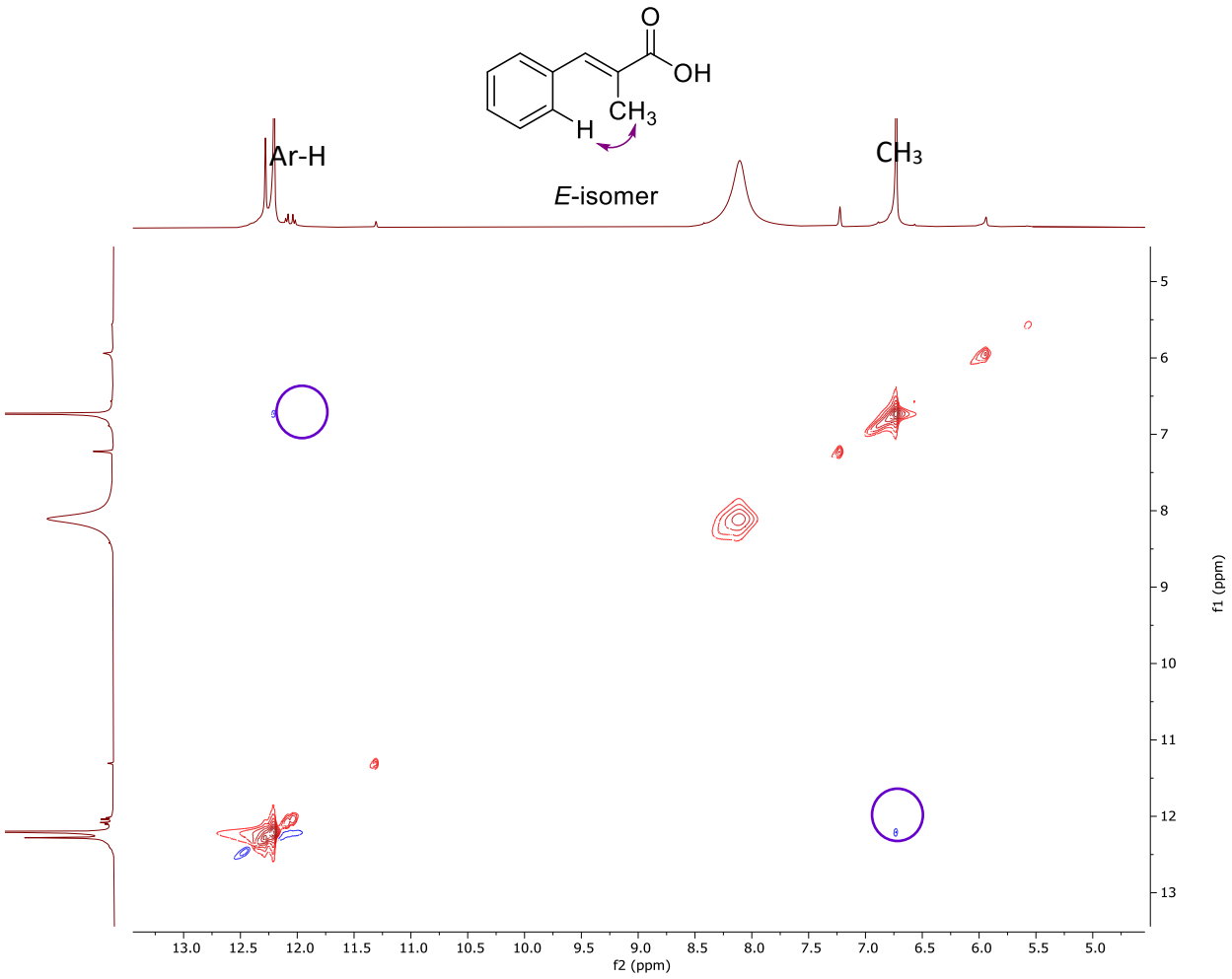
m.p. = 165–166 °C (lit. for *E*-isomer: [11] 166–167 °C)

HRMS (ESI-TOF; negative mode) *m/z*: $[M - H]^-$ calcd. for $[C_{10}H_8ClO_2]^-$: 195.0218; found: 195.0215.

^{1}H NMR (300 MHz, DMSO-d_6)[11] δ 7.57 (q, *J* = 1.5 Hz, 1H, C*H*=CH_3COOH), 7.49 (s, 4H, Aryl-H), 2.02 (d, *J* = 1.5 Hz, 3H, CH_3).

^{13}C{^{1}H} NMR (126 MHz, DMSO-d_6)[11] δ 169.6 (*C*OOH), 136.7 (*C*H=CCH_3), 134.9 (Aryl C-1), 133.4 (Aryl C-4), 131.8 (Aryl C-2), 130.0 (C=*C*–COOH), 129.0 (Aryl C-3), 14.4 (*C*H_3).

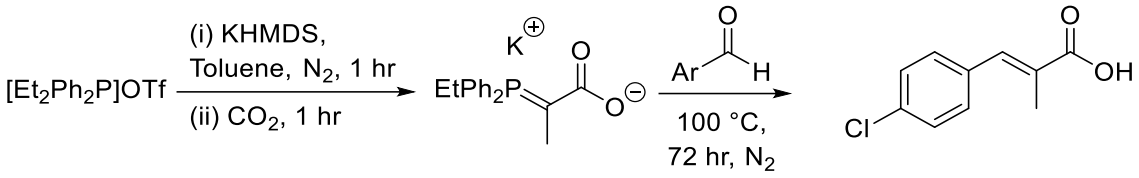
To further confirm the stereochemistry of (*E*)-3-(4-(chloro)phenyl)-2-methyl acrylic acid (**8**), a 2D-NOESY experiment was carried out on a JEOL 400 NMR spectrometer. A through space interaction between the α-methyl substituent and the aromatic protons would confirm *E*-stereochemistry of the alkene bond. The *Z*-isomer would have no through space interaction between the α-methyl substituent and the aromatic protons.



The 2D-NOESY spectrum shows a cross peak between the aromatic protons (7.48 ppm, s, 4H) and the methyl group protons (2.00 ppm, *J* = 1.6 Hz, 3H, C*H*$_3$), confirming the through space interaction between these protons, and subsequent *E*-stereochemistry. *

* Isomerisation of the *E*-alkene to the *Z*-isomer over time was observed due to the presence of the Z-isomer in the 2D-NOESY spectrum which was obtained months after synthesising compound 44.

(b) From Diethyldiphenylphosphonium Triflate



Ar = *p*-(Cl)C_6H_4

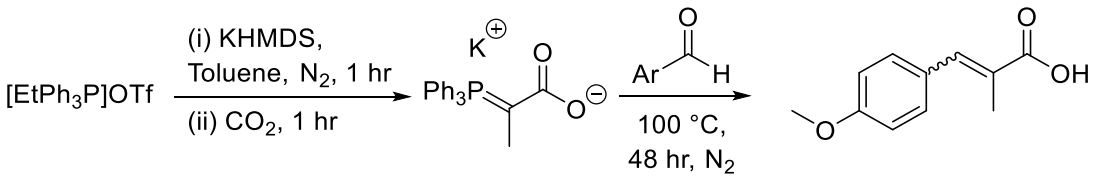
From diethyldiphenylphosphonium triflate (0.35 g, 0.88 mmol, 1.0 equiv.), KHMDS in toluene (0.40 mol L^{-1} (titr.), 7.7 mL, 3.1 mmol, 3.5 equiv.), and 4-chlorobenzaldehyde (0.13 g, 0.93 mmol, 1.05 equiv.). After addition of the benzaldehyde, the reaction was left to stir for 72 hours in an oil bath at 100 °C.

The product was purified following general work-up procedure D, using 95:5 → 70:30 cyclohexane/ethyl acetate. For the acidification step of the purification, 2.0 mol L^{-1} aqueous methanesulfonic acid (1.0 equiv.) was employed. The product was isolated as an off-white solid in a yield of 0.12 g (69%, *E*-isomer only).

^{1}H NMR (300 MHz, $CDCl_3$)[11] δ 7.77 (br d, *J* = 1.1 Hz, 1H, C*H*=CH_3COOH), 7.42 – 7.34 (m, 4H, Aryl-H), 2.13 (d, *J* = 1.3 Hz, 3H, CH_3).

(*E*)-3-(4-(Methoxy)phenyl)-2-methyl Acrylic Acid (9)

(a) From Ethyltriphenylphosphonium Triflate



Ar = *p*-(OMe)C_6H_4

From ethyltriphenylphosphonium triflate (0.41 g, 0.92 mmol, 1.0 equiv.), KHMDS in toluene (0.40 mol L^{-1} (titr.), 8.1 mL, 3.2 mmol, 3.5 equiv.), and 4-methoxybenzaldehyde (0.13 g, 0.97 mmol, 1.05 equiv.). After addition of the benzaldehyde, the reaction was left to stir for 48 hours in an oil bath at 100 °C.

The product was purified by column chromatography in CH_2Cl_2/MeOH 98:2 → 9:1 following purification procedure C. For the acidification step of the purification, 2.0 mol L^{-1} aqueous methanesulfonic acid (1.0 equiv.) was employed. The product was isolated as an off-white solid in a yield of 0.033 g (18%, *E*:Z ratio = 95:5).

m.p. = 150–153 °C (lit. for *E*-isomer: [11] 153–154 °C)

HRMS (ESI-TOF; negative mode) *m/z*: $[M - H]^-$ calcd. for $[C_{11}H_{11}O_2]^-$: 191.0714; found: 191.0716.

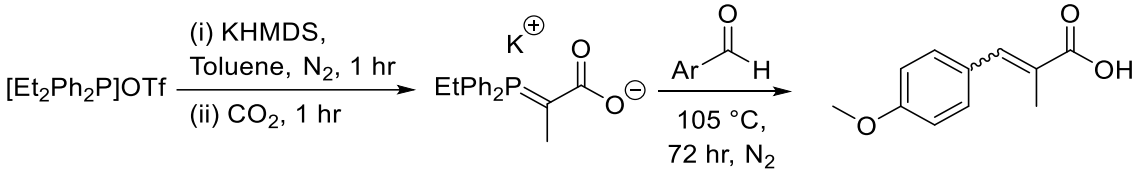
Assigned to *E*-isomer:

^{1}H NMR (300 MHz, DMSO-d_6)[11] δ 7.55 (s, 1H C*H*=CH_3COOH), 7.45 (d, J = 8.7 Hz, 2H, Aryl-H), 6.99 (d, J = 8.7 Hz, 2H, Aryl-H), 3.79 (s, 3H, OCH_3), 2.03 (d, J = 1.1 Hz, 3H, CH_3).

Assigned to *Z*-isomer:

^{1}H NMR (300 MHz, DMSO-d_6) δ 7.28 (d, *J* = 8.7 Hz, 2H, Aryl-H), 6.87 (d, *J* = 8.7 Hz, 2H, Aryl-H), 3.74 (s, 3H, OCH_3), 1.98 (d, *J* = 1.3 Hz, 3H, CH_3).

(b) From Diethyldiphenylphosphonium Triflate



Ar = *p*-(OMe)C_6H_4

From diethyldiphenylphosphonium triflate (0.35 g, 0.88 mmol, 1.0 equiv.), KHMDS in toluene (0.40 mol L^{-1} (titr.), 7.7 mL, 3.1 mmol, 3.5 equiv.), and 4-methoxybenzaldehyde (0.13 g, 0.92 mmol, 1.05 equiv.). After addition of the benzaldehyde, the reaction was left to stir for 72 hours in an oil bath at 100 °C.

The product was purified following general work-up procedure D, using 95:5 → 70:30 cyclohexane/ethyl acetate. For the acidification step of the purification, 2.0 mol L^{-1} aqueous methanesulfonic acid (1.0 equiv.) was employed. The product was isolated as an off-white solid in a yield of 0.11 g (64%, *E*:Z ratio = 94:6).

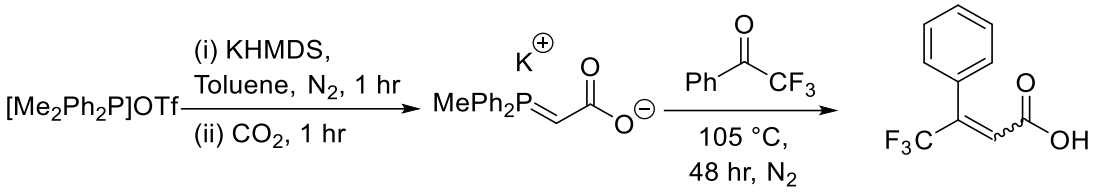
Assigned to *E*-isomer:

^{1}H NMR (300 MHz, DMSO-d_6)[11] δ 7.55 (s, 1H C*H*=CH_3COOH), 7.45 (d, J = 8.7 Hz, 2H, Aryl-H), 6.99 (d, J = 8.7 Hz, 2H, Aryl-H), 3.79 (s, 3H, OCH_3), 2.03 (d, J = 1.1 Hz, 3H, CH_3).

Assigned to *Z*-isomer:

^{1}H NMR (300 MHz, DMSO-d_6) δ 7.28 (d, J = 8.7 Hz, 2H, Aryl-H), 6.87 (d, J = 8.7 Hz, 2H, Aryl-H), 3.74 (s, 3H, OCH_3), 1.98 (d, J = 1.1 Hz, 3H, CH_3).

4,4,4-Trifluoro-3-phenylbut-2-enoic Acid (10)



From dimethyldiphenylphosphonium triflate (0.33 g, 0.89 mmol, 1.0 equiv.), KHMDS in toluene (0.55 mol L^{-1} (titr.), 4.9 mL, 2.7 mmol, 3.0 equiv.), and 2-trifluoroacetophenone (0.16 g, 0.94 mmol, 1.05 equiv.). After addition of the ketone, the reaction was left to stir for 48 hours in an oil bath at 105 °C.

The product was purified following general work-up procedure D, using 95:5 → 70:30 cyclohexane/ethyl acetate. For the acidification step of the purification, 2.0 mol L^{-1} aqueous methanesulfonic acid (1.0 equiv.) was employed. The product was isolated as a pale-yellow solid in a yield of 0.16 g (83%, *E*:Z ratio = 62:38).

Assigned to *E*-isomer:

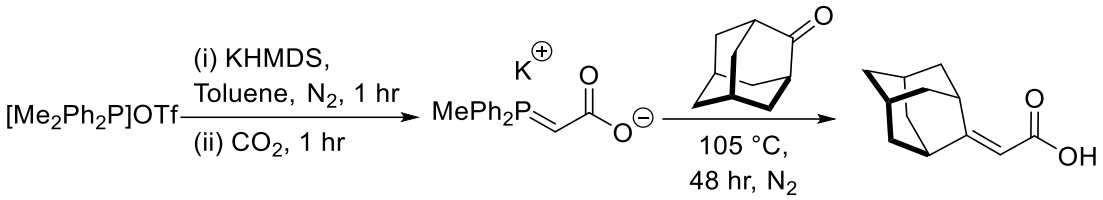
^{1}H NMR (300 MHz, $CDCl_3$)[11] δ 7.47 – 7.36 (m, 5H, Aryl H), 6.60 (s, 1H, C*H*COOH); **^{13}C{^{1}H} NMR** (101 MHz, $CDCl_3$) δ 169.6 (*C*OOH), 144.9 (q, *J* = 31.1 Hz), 130.0 (Aryl C-1), 129.8 (Aryl C-4), 128.9 (Aryl C-2), 128.5 (Aryl C-3), 127.9 (*C*HCOOH), 122.2 (q, *J* = 275 Hz, *C*F_3); **^{19}F NMR** (376 MHz, $CDCl_3$) δ –59.9.

Assigned to *Z*-isomer:

^{1}H NMR (300 MHz, $CDCl_3$)[22] δ 7.47 – 7.36 (m, 3 H, Aryl H-3 , H-4), 7.29 (d, *J* = 7.1 Hz, 2H, Aryl H-2), 6.33 (s, 1H, C*H*COOH); **^{13}C{^{1}H} NMR** (101 MHz, $CDCl_3$) δ 170.14, 140.0 (d, *J* = 32.3 Hz), 128.7 (*C*HCOOH), 122.5 (q, *J* = 275 Hz, *C*F_3). **^{19}F NMR** (376 MHz, $CDCl_3$) δ –67.7.*

* The phenyl ring carbon signals of the *Z*-isomer are overlapping with the *E*-isomer signals in the $^{13}C\{^{1}H\}$ NMR spectrum.

(2-Carboxyl-1-enyl)-adamantane (11)

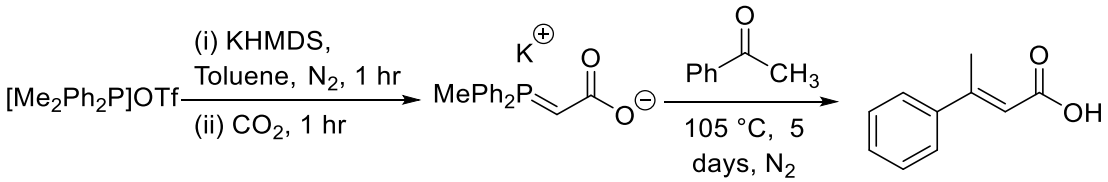


From dimethyldiphenylphosphonium triflate (0.28 g, 0.77 mmol, 1.0 equiv.), KHMDS in toluene (0.55 mol L^{-1} (titr.), 4.2 mL, 2.3 mmol, 3.0 equiv.), and 1.0 mol L^{-1} solution of 2-adamantanone (1.15 mL, 0.17 g, 1.15 mmol, 1.5 equiv.) in THF. After addition of the ketone, the reaction was left to stir for 48 hours in an oil bath at 105 °C.

The product was purified following general work-up procedure D, using 95:5 → 70:30 cyclohexane/ethyl acetate. For the acidification step of the purification, 2.0 mol L^{-1} aqueous methanesulfonic acid (1.0 equiv.) was employed. The product was isolated as a white solid in a yield of 0.11 g (74%).

^{1}H NMR (400 MHz, DMSO-*d*$_6$)[23] δ 11.80 (br s, 1H, COOH), 5.52 (s, 1H, *CHC*=C), 4.00 (s, 1H, C*H*), 2.42 (s, 1H, C*H*), 1.99 – 1.65 (m, 12H); **^{13}C{^{1}H} NMR** (101 MHz, DMSO-*d*$_6$)[23] δ 170.3 (*C*OOH), 167.6 (*C*=CH), 109.4 (*C*HCOOH), 40.3 (1C), 39.5 (overlap with DMSO-*d*$_6$, 2C), 38.6 (2C), 36.2 (1C), 31.9 (1C), 27.3 (2C).

(*E*)-3-Phenylbut-2-enoic Acid (12)



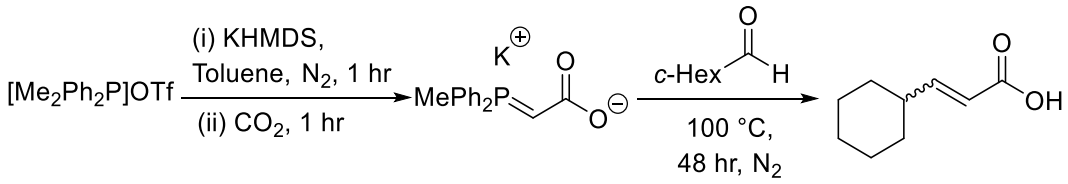
From dimethyldiphenylphosphonium triflate (0.14 g, 0.38 mmol, 1.0 equiv.), KHMDS in toluene (0.55 mol L^{-1} (titr.), 2.0 mL, 1.1 mmol, 3.0 equiv.), and acetophenone (0.070 g, 0.56 mmol, 1.5 equiv.). Before the addition of the ketone, a proportion of the solvent was removed by subjecting the flask to a vacuum mediated by the Schlenk line apparatus and collecting the solvent in a liquid nitrogen trap. After concentrating the reaction mixture, the ketone was added, and the reaction was left to stir for 48 hours in an oil bath at 105 °C.

The product was purified following general work-up procedure D, using 95:5 → 70:30 cyclohexane/ethyl acetate. For the acidification step of the purification, 2.0 mol L^{-1} aqueous

methanesulfonic acid (1.0 equiv.) was employed. The product was isolated as a white solid in a yield of 0.06 g (44%, *E*-isomer only).

^{1}H NMR (400 MHz, $CDCl_3$)[12] δ 7.53 – 7.47 (m, 2H, Aryl H-2), 7.42 – 7.36 (m, 3H, Aryl H-3 and H-4), 6.19 (q, *J* = 1.3 Hz, 1H, C=C*H*COOH), 2.61 (d, *J* = 1.3 Hz, 3H, CH_3); **^{13}C NMR** (101 MHz, $CDCl_3$)[12] δ 172.0 (*C*OOH), 158.6 (CH_3*C*=CH), 142.1 (Aryl C-1), 129.4 (Aryl C-3), 128.7 (Aryl C-4), 126.5 (Aryl C-2), 116.5 (*C*HCOOH), 18.4 (*C*H_3).

3-(Cyclohexyl)acrylic Acid (13)[23,25]



From dimethyldiphenylphosphonium triflate (0.36 g, 0.98 mmol, 1.0 equiv.), KHMDS in toluene (0.40 mol L^{-1} (titr.), 8.6 mL, 3.4 mmol, 3.5 equiv.), and cyclohexanecarboxaldehyde (0.17 g, 1.5 mmol, 1.5 equiv.). After addition of the aldehyde, the reaction was left to stir for 48 hours in an oil bath at 100 °C.

The product was purified following general work-up procedure D, using 95:5 → 70:30 cyclohexane/ethyl acetate. This afforded the isolated product as a mixture of *E*- and *Z*- isomers as a white solid (on standing) in a total yield of 0.12 g (77%, *E:Z* ratio = 85:15). The *Z*-isomer eluted off the column first affording 3.6 mg (2.4% yield) of the *Z*-isomer, followed by a mixture of the *E*- and *Z*- isomers (47 mg, 31% yield, *E:Z* ratio = 78:22), and then the remaining *E*-isomer eluted off the column with a small amount of Z-isomer present (66 mg, 44% yield, *E:Z* ratio = 95:5).

Assigned to fraction 1 (Z-isomer):

^{1}H NMR (300 MHz, $CDCl_3$)[23] δ 6.15 (dd, *J* = 11.5, 10.0 Hz, 1H, *c*-Hex-C*H*=C), 5.68 (d, *J* = 11.5 Hz, 1H, C*H*COOH), 3.44–3.11 (m, 1H, *c*-Hex-H), 1.78–1.66 (m, 5H, *c*-Hex-H), 1.44– 1.01 (m, 5H, *c*-Hex-H). There was no signal evident for COO*H* proton.

Assigned to fraction 2 (*E:Z* ratio = 78:22):

^{1}H NMR (300 MHz, $CDCl_3$)[23,24] δ 10.42 (br s, 1H, COO*H*), 7.03 (dd, *J* = 15.8, 6.8 Hz, 1H, *c*-Hex-C*H*=C, *E*-isomer), 6.14 (dd, *J* = 11.6, 10.0 Hz, 1H, *c*-Hex-C*H*=C, *Z*-isomer), 5.77 (dd, *J* = 15.8, 1.4 Hz, 1H, C*H*COOH, *E*-isomer), 5.67 (dd, *J* = 11.6, 1.0 Hz, 1H, C*H*COOH, *Z*-isomer), 3.35–3.20 (m, 1H, *c*-Hex-

H, *Z*-isomer), 2.24–2.09 (m, 1H, *c*-Hex-H, *E*-isomer), 1.84–1.62 (m, 5H, *c*-Hex-H, *E*- and *Z*-isomer overlapping), 1.40–0.99 (m, 5H, *c*-Hex-H, *E*- and *Z*-isomer overlapping).

$^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$) [23,24] δ 172.8 (*C*OOH, *E*-isomer), 172.3 (*C*OOH, *Z*-isomer), 158.3 (*c*-Hex-*C*=C, *Z*-isomer), 157.3 (*c*-Hex-*C*=C, *E*-isomer), 118.5 (C=*C*–COOH, *E*-isomer), 117.3 (C=*C*–COOH, *Z*-isomer), 40.7 (*c*-Hex *C*H, *E*-isomer), 37.6 (*c*-Hex *C*H, *Z*-isomer), 32.4 (*c*-Hex, *C*H_2, *Z*-isomer), 31.7 (*c*-Hex, *C*H_2, *E*-isomer), 26.0 (*c*-Hex, *C*H_2, *E*- and *Z*- isomer overlapping), 25.8 (*c*-Hex, *C*H_2, *E*-isomer), 25.5 (*c*-Hex, *C*H_2, *Z*-isomer).

Assigned to fraction 3 (*E:Z* ratio = 95:5*):*

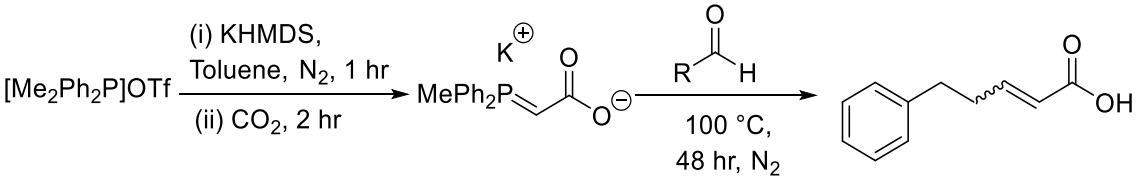
m.p. = 51–53 °C (lit. for *E*-isomer: 56–57 °C[25]).

HRMS (ESI-TOF; negative mode) *m/z*: $[M - H]^-$ calcd. for $[C_9H_{13}O_2]^-$: 153.0921; found: 153.0915.

NMR spectral data for *E*-isomer: **^{1}H NMR** (300 MHz, $CDCl_3$)[24] δ 10.33 (br s, 1H, COO*H*), 7.03 (dd, *J* = 15.8, 6.7 Hz, 1H, *c*-Hex-C*H*=C), 5.77 (d, *J* = 15.8 Hz, 1H, C*H*COOH), 2.22–2.13 (m, 1H, *c*-Hex-H), 1.83–1.64 (m, 5H, *c*-Hex-H), 1.40–1.02 (m, 5H, *c*-Hex-H); **$^{13}C\{^1H\}$ NMR** (75 MHz, $CDCl_3$) [24] δ 172.8 (*C*OOH), 157.3 (*c*-Hex-*C*=C), 118.5 (C=*C*–COOH), 40.7 (*c*-Hex *C*H), 31.7 (*c*-Hex, *C*H_2), 26.0 (*c*-Hex, *C*H_2), 25.8 (*c*-Hex, *C*H_2).

NMR spectral data for *Z*-isomer: **^{1}H NMR** (300 MHz, $CDCl_3$) δ 6.14 (app t, app *J* = 10.7 Hz, 1H, *c*-Hex-C*H*=C), 5.66 (app d, app *J* = 11.6 Hz, 1H, C*H*COOH), 3.39–3.17 (m, 1H, *c*-Hex-H).*

5-(Phenyl)pentenoic Acid (14) [24]



R = $(C_6H_5)CH_2CH_2$

From dimethyldiphenylphosphonium triflate (0.33 g, 0.90 mmol, 1.0 equiv.), KHMDS in toluene (0.40 mol L^{-1} (titr.), 7.9 mL, 3.1 mmol, 3.5 equiv.), and 3-phenylpropanal (0.18 g, 1.4 mmol, 1.5 equiv.). After addition of the aldehyde, the reaction was left to stir for 48 hours in an oil bath at 100 °C.

* Only 5% *Z*-isomer present in this fraction so only alkenyl proton signals and *c*-Hex-H signals are evident in the ^{1}H NMR spectrum as reported here. The remaining two 5H *c*-Hex-H signals are overlapping with the corresponding proton signals for the *E*-isomer.

The product was purified following general work-up procedure D, using 95:5 → 70:30 cyclohexane/ethyl acetate. This afforded the isolated product as a colourless oil in a total yield of 0.099 g (63%, *E*:*Z* ratio = 94:6).

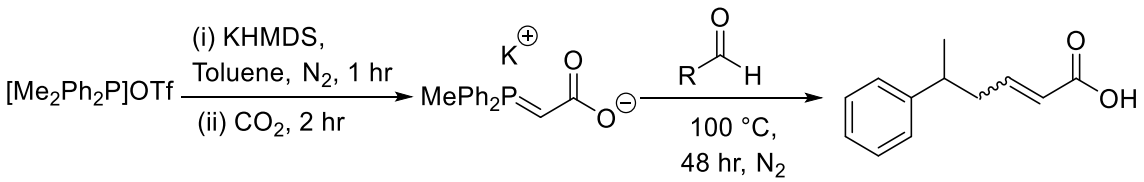
HRMS (ESI-TOF; negative mode) *m/z*: $[M - H]^-$ calcd. for $[C_{11}H_{12}O_2]^-$: 175.0765; found: 175.0767.

Assigned to both *E*-isomer and *Z*-isomer: **^{1}H NMR** (400 MHz, $CDCl_3$)[24] δ 7.44–6.83 (m, 12 H, Phenyl-H and CH_2CH=CH), 5.77 (dt, *J* = 15.6, 1.5 Hz, 2H, C*H*COOH); **^{13}C{^{1}H} NMR** (101 MHz, $CDCl_3$) [24] δ 171.9 (*C*OOH), 151.0 (CH_2*C*H=CH), 140.6 (Aryl *C*-1), 128.5 (2Aryl *C*-2 or 2Aryl *C*-3), 128.3 (2Aryl *C*-3 or 2Aryl *C*-2), 126.3 (Aryl *C*-4), 121.3 (*C*HCOOH), 34.2 (*C*H_2CH=CH), 34.0 (Ph*C*H_2).

Assigned to *E*-isomer: **^{1}H NMR** (400 MHz, $CDCl_3$) δ 2.72 (t, *J* = 7.7 Hz, 2H, CH_2CH=CH), 2.56–2.41 (m, 2H, PhCH_2).

Assigned to *Z*-isomer: **^{1}H NMR** (400 MHz, $CDCl_3$) δ 2.89 (t, *J* = 7.7 Hz, 2H, CH_2CH=CH), 2.61 (t, *J* = 7.7 Hz, 2H, PhCH_2).

5-Phenyl-2-hexenoic Acid (15) [25]



R = CH_2CHCH_3Ph

From dimethyldiphenylphosphonium triflate (0.32 g, 0.88 mmol, 1.0 equiv.), KHMDS in toluene (0.40 mol L^{-1} (titr.), 7.7 mL, 3.1 mmol, 3.5 equiv.), and 3-phenylbutryaldehyde (0.19 g, 1.3 mmol, 1.5 equiv.). After addition of the aldehyde, the reaction was left to stir for 48 hours in an oil bath at 100 °C.

The product was purified following general work-up procedure D, using 95:5 → 70:30 cyclohexane/ethyl acetate. This afforded the isolated product as a colourless oil in a total yield of 0.12 g (73%, *E*:*Z* ratio = 90:10).

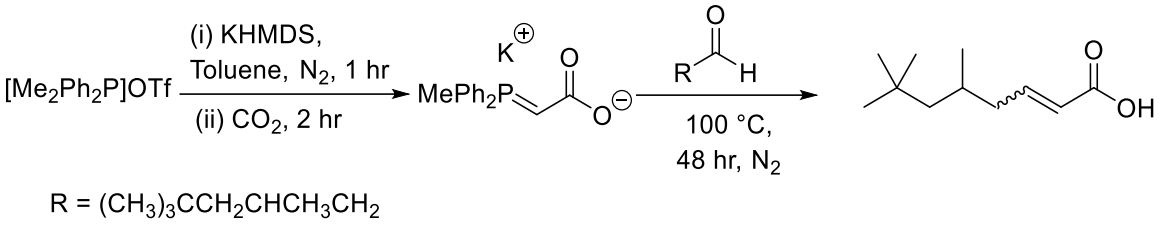
HRMS (ESI-TOF; negative mode) *m/z*: $[M - H]^-$ calcd. for $[C_{12}H_{14}O_2]^-$: 189.0921; found: 189.0929.

Assigned to *E*-isomer: **^{1}H NMR** (400 MHz, $CDCl_3$)[25] δ 7.43–7.17 (m, 5H, Phenyl-H), 7.13–6.96 (m, 1H, CH_2CH=CH), 5.84 (app d, *J* = 16.0 Hz, 1H, CHCOOH), 3.04–2.89 (m, 1H, CH_2CHCH_3), 2.69–2.43 (m, 2H, CH_2), 1.35 (app d, *J* = 7.0 Hz, 3H, CH_3); **^{13}C{^{1}H} NMR** (101 MHz, $CDCl_3$)[25] δ 171.8 (*C*OOH),

150.3 (CH_2CH=CH), 145.8 (Aryl *C*-1), 128.6 (2Aryl *C*-2 or 2Aryl *C*-3), 126.8 (2Aryl *C*-3 or 2Aryl *C*-2), 126.4 (Aryl *C*-4), 122.1 (*C*HCOOH), 40.99 (CH_2), 39.12 (*C*H), 21.67 (CH_3).

Assigned to *Z*-isomer: **^{1}H NMR** (400 MHz, $CDCl_3$) δ 6.35–6.25 (m, 1H, CH_2CH=CH).*

5,5,7-(Trimethyl)octenoic Acid (16)



R = $(CH_3)_3CCH_2CHCH_3CH_2$

From dimethyldiphenylphosphonium triflate (0.23 g, 0.62 mmol, 1.0 equiv.), KHMDS in toluene (0.40 mol L^{-1} (titr.), 5.4 mL, 2.2 mmol, 3.5 equiv.), and 3,5,5-trimethylhexanal (0.13 g, 0.93 mmol, 1.5 equiv.). After addition of the aldehyde, the reaction was left to stir for 48 hours in an oil bath at 100 °C.

The product was purified following general work-up procedure D, using 95:5 → 70:30 cyclohexane/ethyl acetate. This afforded the isolated product as a colourless oil in a total yield of 0.062 g (55%, *E*:*Z* ratio = 76:24).

HRMS (ESI-TOF; negative mode) *m/z*: $[M - H]^-$ calcd. for $[C_{11}H_{20}O_2]^-$: 183.1390; found: 183.1396.

IR $\tilde{\nu}_{max}$ (ATR): 2960 (=C—H stretch), 2678 (O—H stretch), 1695 (C=O stretch), 1652 (C=C stretch) cm^{-1}.

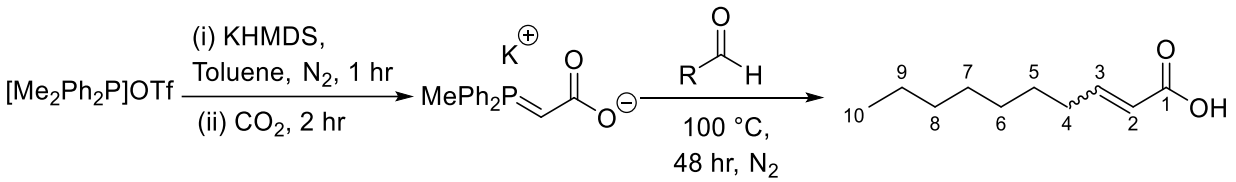
Assigned to both *E*-isomer and *Z*-isomer: **^{1}H NMR** (400 MHz, $CDCl_3$) δ 5.82 (overlapping d, app *J* = 15.3, 11.6 Hz, 2 H, CHCOOH), 1.79–1.61 (m, 2H, C*H*), 1.32–1.03 (m, 4H, $(CH_3)_3CH_2CH$), 0.95 (overlapping d, app *J* = 6.6, 4.5 Hz, $CH_2CHCH_3CH_2$), 0.90 (s, 18 H, $(CH_3)_3$); **^{13}C{^{1}H} NMR** (101 MHz, $CDCl_3$) δ 172.1 (*C*OOH), 152.5 (*C*H=CHCOOH, *Z*-isomer), 151.3 (*C*H=CHCOOH, *E*-isomer), 121.9 (CHCOOH, *E*-isomer), 119.9 (CHCOOH, *Z*-isomer), 50.6 ($(CH_3)_3CH_2CH$, *Z*-isomer), 50.5 ($(CH_3)_3CH_2CH$, *E*-isomer), 42.0 (CH_2CH=CH, *E*-isomer), 38.4 (CH_2CH=CH, *Z*-isomer), 31.1 ($(CH_3)_3C$) *E*-isomer), 31.05 ($(CH_3)_3C$) *Z*-isomer), 30.0 ($(CH_3)_3C$, *Z*-isomer), 29.9 ($(CH_3)_3C$, *E*-isomer), 29.7 ($CH_2CHCH_3CH_2$, *Z*-isomer), 29.0 ($CH_2CHCH_3CH_2$, *E*-isomer), 22.5 ($CHCH_3CH_2$, *E*-isomer), 22.5 ($CHCH_3CH_2$, *Z*-isomer).

* Only alkenyl proton evident in ^{1}H NMR spectrum, the remaining *Z*-isomer proton signals are overlapping with the *E*-isomer proton signals in the ^{1}H NMR spectrum.

Assigned to *E*-isomer: **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.06 (dt, *J* = 15.3, 7.5 Hz, 1H, CH_2CH=CH), 2.31–1.99 (m, 2H, CH_2CH=CH)

Assigned to *Z*-isomer: **^{1}H NMR** (400 MHz, $CDCl_3$) δ 6.36 (dt, *J* = 11.6, 7.5 Hz, 1H, CH_2CH=CH), 2.72–2.48 (m, 2H, CH_2CH=CH)

2-Decenoic Acid (17) [26,27]



R = *n*-heptyl

From dimethyldiphenylphosphonium triflate (0.32 g, 0.87 mmol, 1.0 equiv.), KHMDS in toluene (0.40 mol L^{-1} (titr.), 7.7 mL, 3.1 mmol, 3.5 equiv.), and octanal (0.17 g, 1.3 mmol, 1.5 equiv.). After addition of the aldehyde, the reaction was left to stir for 48 hours in an oil bath at 100 °C. The product was purified following general work-up procedure D, using 95:5 → 70:30 cyclohexane/ethyl acetate. This afforded the isolated product as a colourless oil in a total yield of 0.081 g (54%, *E*:*Z* ratio = 96:4).

HRMS (ESI-TOF; negative mode) *m/z*: $[M - H]^-$ calcd. for $[C_{10}H_{18}O_2]^-$: 169.1234; found: 169.1236.

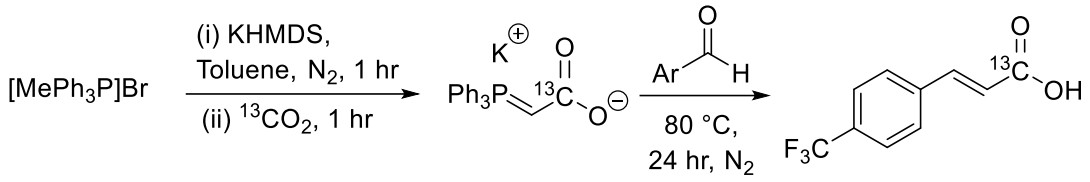
Assigned to 2-decenoic acid (E-isomer and Z-isomer): **^{1}H NMR** (300 MHz, $CDCl_3$)[26] δ 10.67 (br s, 2H, COOH), 5.87–5.75 (two overlapping dt, 2H, C*H*=CHCOOH),* 1.49–1.15 (m, 16H, CH_2), 0.89 (t, 6H, CH_3); **^{13}C{^{1}H} NMR** (101 MHz, $CDCl_3$) [26] δ 172.3 (C-1), 152.5 (C-3), 120.7 (C-2), 31.7 (C-4), 32.3 (C-5), 29.1, 29.0, 27.9 (C6 – C-8), 22.6 (C-9), 14.0 (C-10).

Assigned to (E)-2-decenoic acid: **^{1}H NMR** (300 MHz, $CDCl_3$)[26] δ 7.09 (dt, *J* = 15.5, 7.0 Hz, 1H, CH=C*H*COOH), 2.22 (q, 1H, CH_2CH=CH), 1.54–1.40 (m, 2H, CH_2CH_2CH=CH).

Assigned to (Z)-2-decenoic acid: **^{1}H NMR** (300 MHz, $CDCl_3$)[27] δ 6.35 (dt, *J* = 11.6, 7.6 Hz, 1H, CH=C*H*COOH), 2.65 (q, 1H, CH_2CH=CH), 2.35 (t, 1H, CH_2CH=CH).

* The *J* values could not be discerned due to the overlapping nature of the dt signals in the ^{1}H NMR spectrum.

^{13}C-Labelled 4-(trifluoromethyl)cinnamic Acid (18)



Ar = *p*-$(CF_3)C_6H_4$

From methyltriphenylphosphonium triflate (0.33 g, 0.91 mmol, 1.0 equiv.), KHMDS in toluene (0.40 mol L^{-1} (titr.), 8.0 mL, 3.2 mmol, 3.5 equiv.), $^{13}CO_2$ gas (99.0 atom % ^{13}C (Sigma Aldrich)), and 4-(trifluoromethyl)benzaldehyde (0.17 g, 1.0 mmol, 1.1 equiv.).

Note: To expose the reaction flask to an atmosphere of $^{13}CO_2$ (1 atm), a brief vacuum was applied to the flask. A 1 L lecture bottle of $^{13}CO_2$ was connected to the side arm of the Schlenk flask, an oil bubbler, and a pressure gauge via rubber tubing and a three-way-oblique tap. The Schlenk flask was closed off to the Schlenk manifold, and $^{13}CO_2$ was used to refill the flask under reduced pressure to atmospheric pressure (monitored by a pressure gauge). This technique estabilished a static atmosphere of $^{13}CO_2$.

After addition of the benzaldehyde, the reaction was left to stir for 24 hours in an oil bath at 80 °C.

The product was purified by column chromatography in CH_2Cl_2/MeOH 98:2 → 90:10 following purification procedure C. For the acidification step of the purification, 2.0 mol L^{-1} aqueous methanesulfonic acid (1.0 equiv.) was employed. The product was isolated as an off-white solid in a yield of 0.14 g (70%, *E*-isomer only).

^{1}H NMR (400 MHz, DMSO-d_6) [28] δ 12.60 (br s, 1H, COO*H*), 7.92 (d, *J* = 8.1 Hz, 2H, Phenyl H-2), 7.77 (d, *J* = 8.2 Hz, 2H, Aryl H-3), 7.67 (dd, *J* = 16.1, 6.8 Hz, 1H, ArC*H*=CH) 6.68 (dd, *J* = 16.1, 2.5 Hz, 1H, C*H*^{13}COOH); **^{13}C{^{1}H} NMR** (126 MHz, DMSO-d_6) [28] δ 167.6 (*C*OOH), 142.5 (Ar*C*=C), 138.8 (d, *J* = 6.9 Hz, Aryl C-1), 130.30 (q, $^3J_{CF}$ = 31.9 Hz, Aryl C-4), 129.27 (Aryl C-2), 126.12 (q, $^3J_{CF}$ = 3.7 Hz, Aryl C-3), 124.48 (d, $^1J_{CF}$ = 272.1 Hz, *C*F_3), 122.62 (d, *J* = 72.0 Hz, C=*C*HCOOH).

9. Supporting Information References

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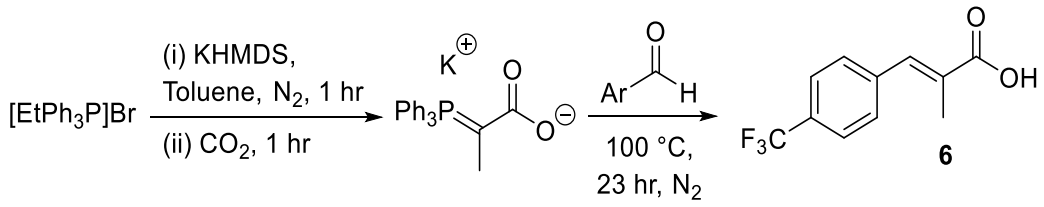
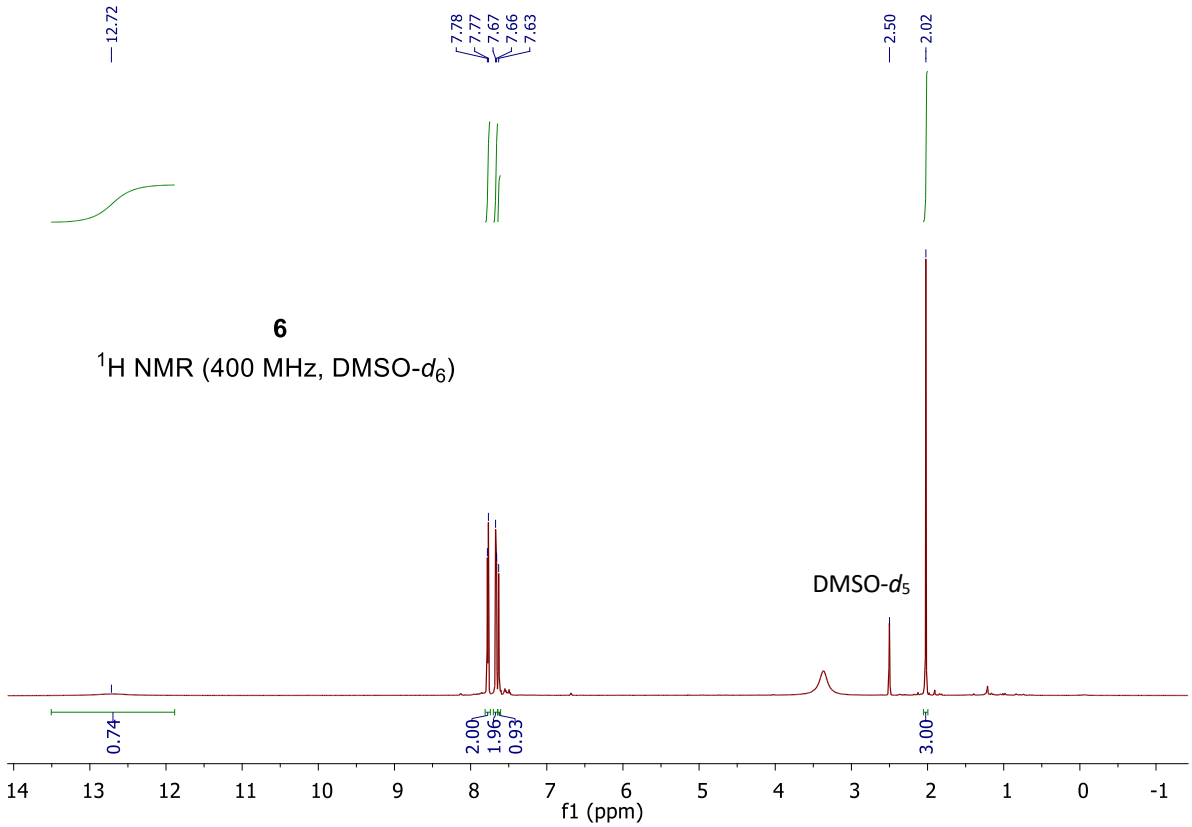
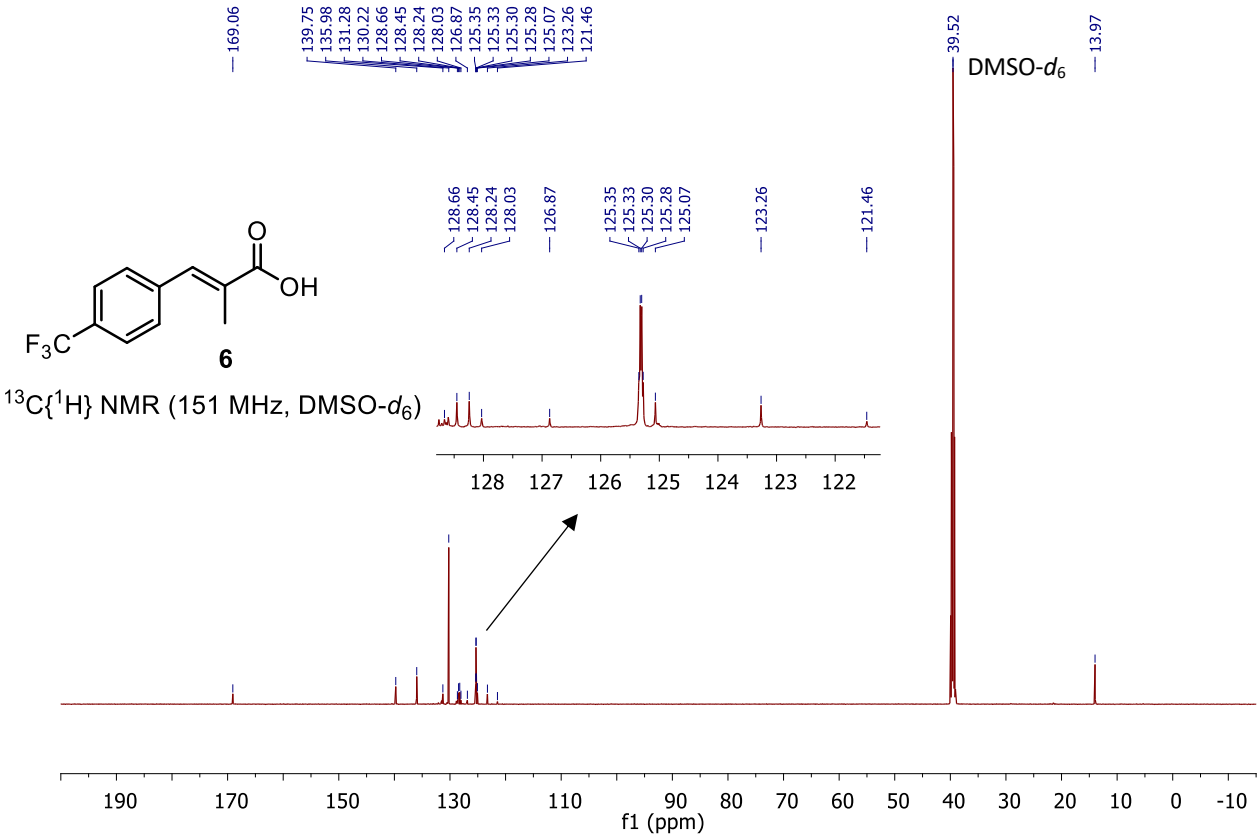
10. NMR Spectra



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131.28
130.22
128.66
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128.03
126.87
125.35
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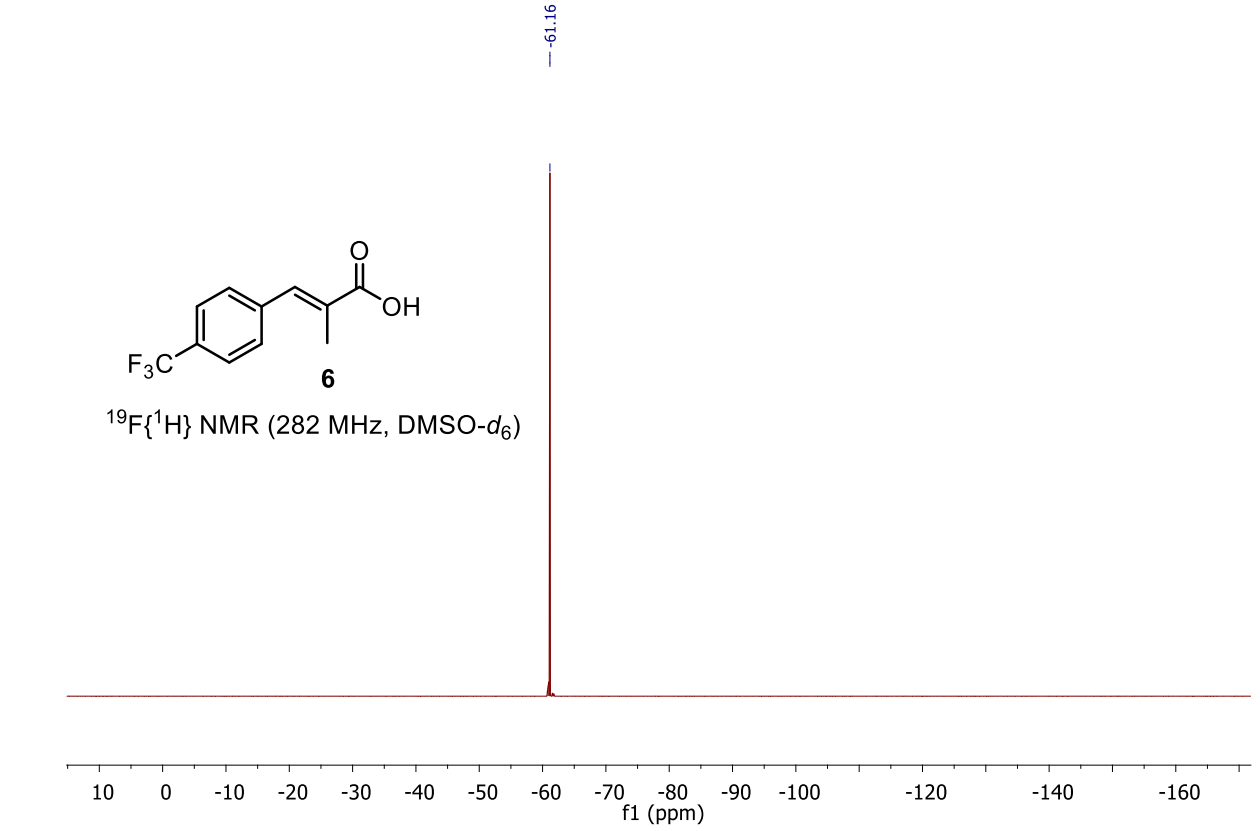
125.30
125.28
125.07
123.26
121.46
39.52
DMSO-d_6
13.97
O
OH
F_3C
6
$^{13}C\{^1H\}$ NMR (151 MHz, DMSO-d_6)
f1 (ppm)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O
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F_3C
6
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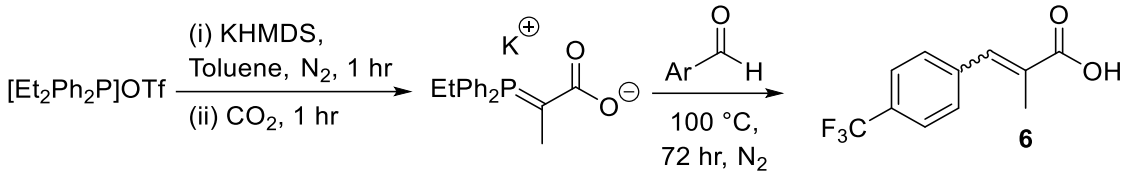
f1 (ppm)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72 hr, N2
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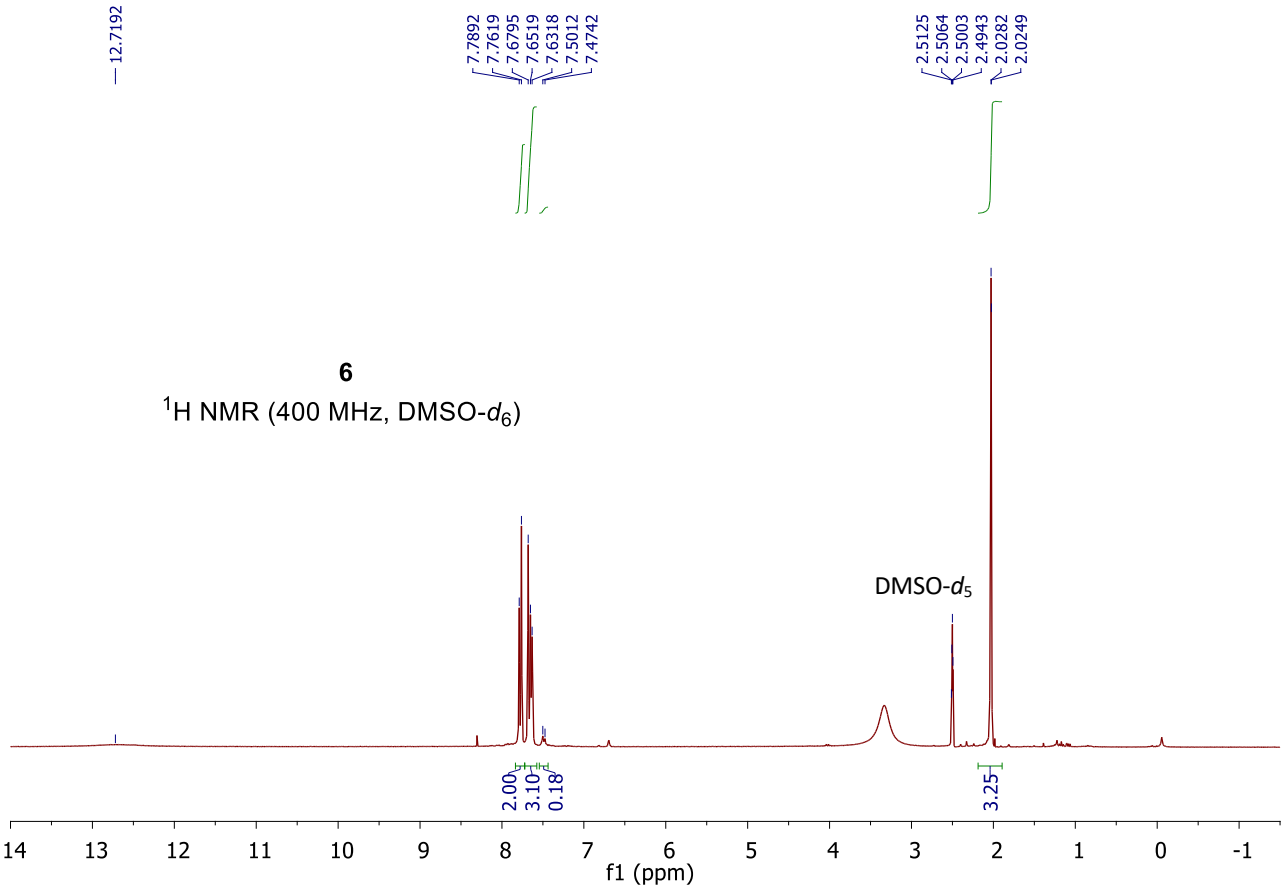
O
OH
6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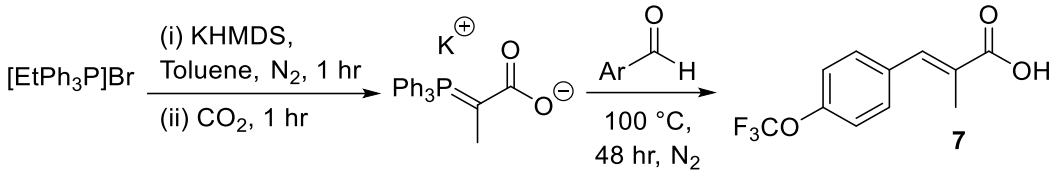
7.7619
7.6795
7.6519
7.6318
7.5012
7.4742
2.5125
2.5064
2.5003
2.4943
2.0282
2.0249
6
1H NMR (400 MHz, DMSO-d6)
DMSO-d5
2.00
3.10
0.18
3.25
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
f1 (ppm)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Ar
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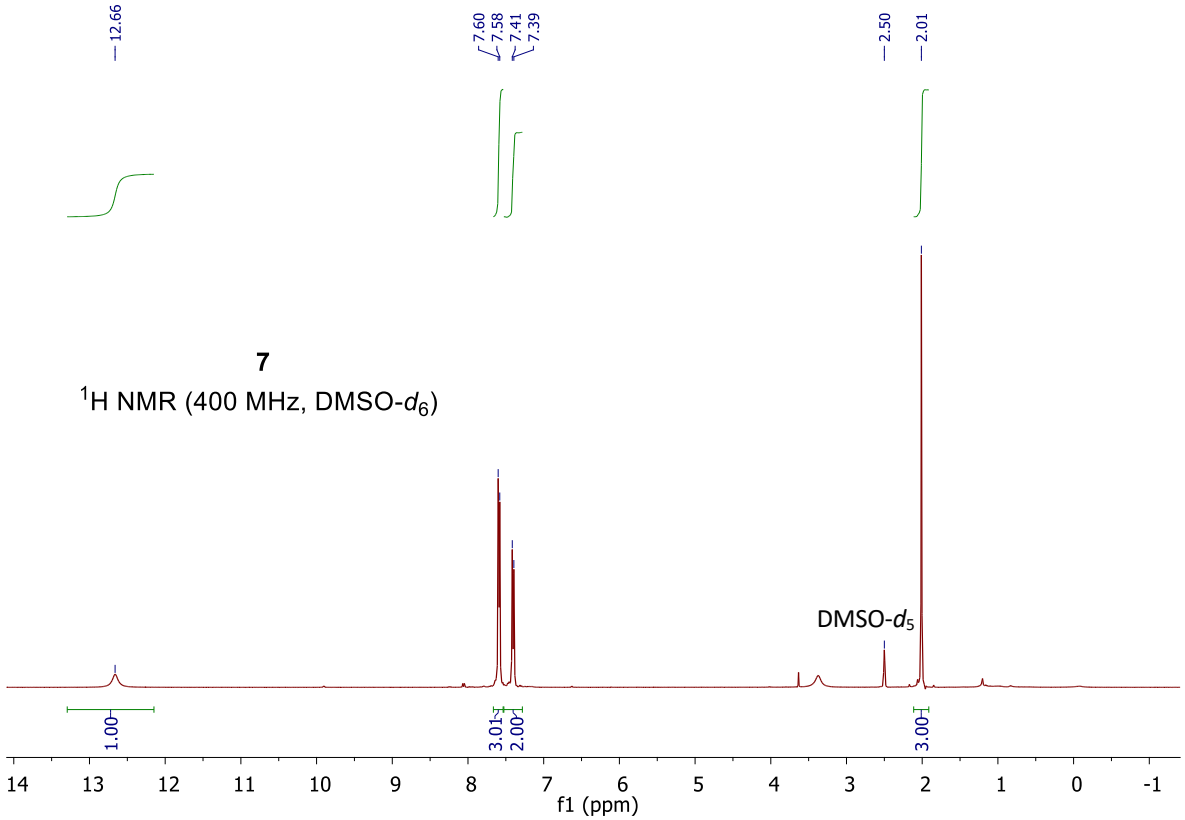
OH
O
7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7
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3.01
2.00
3.00
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12
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8
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4
3
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1
0
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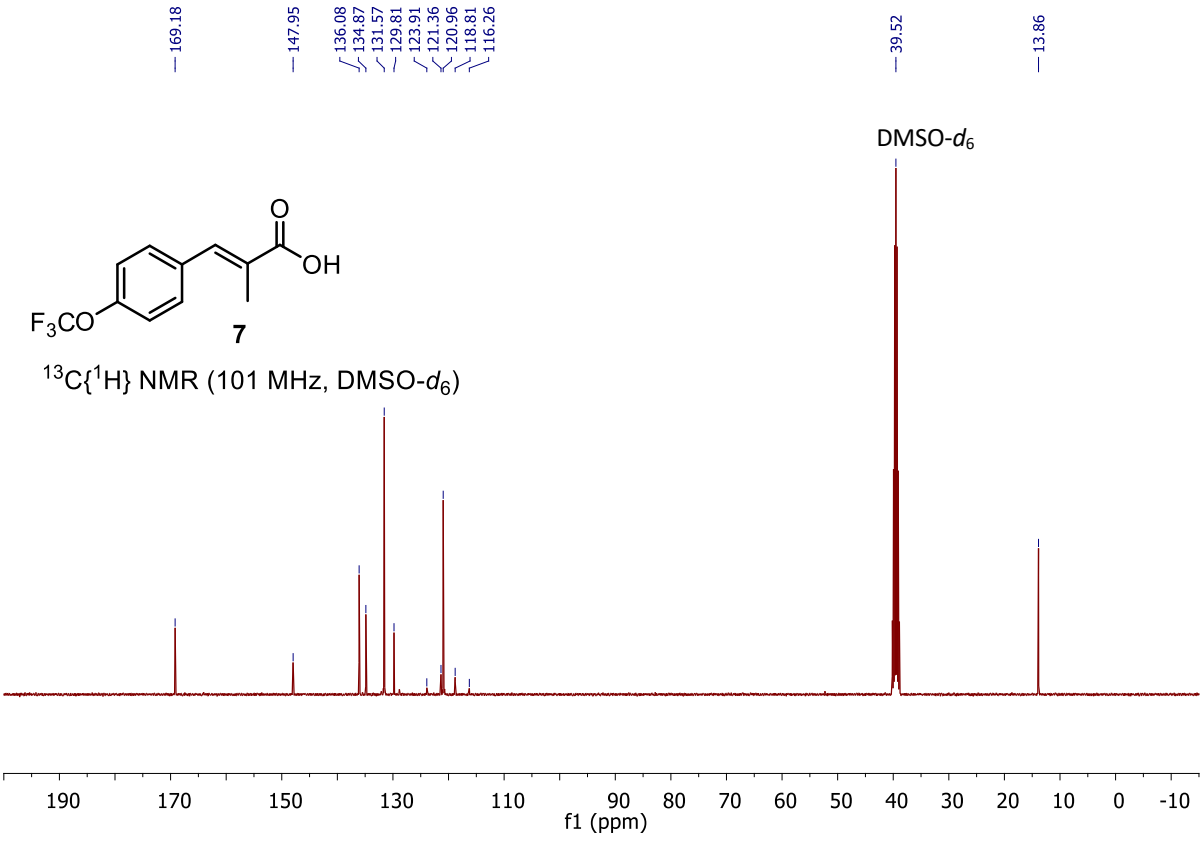
f1 (ppm)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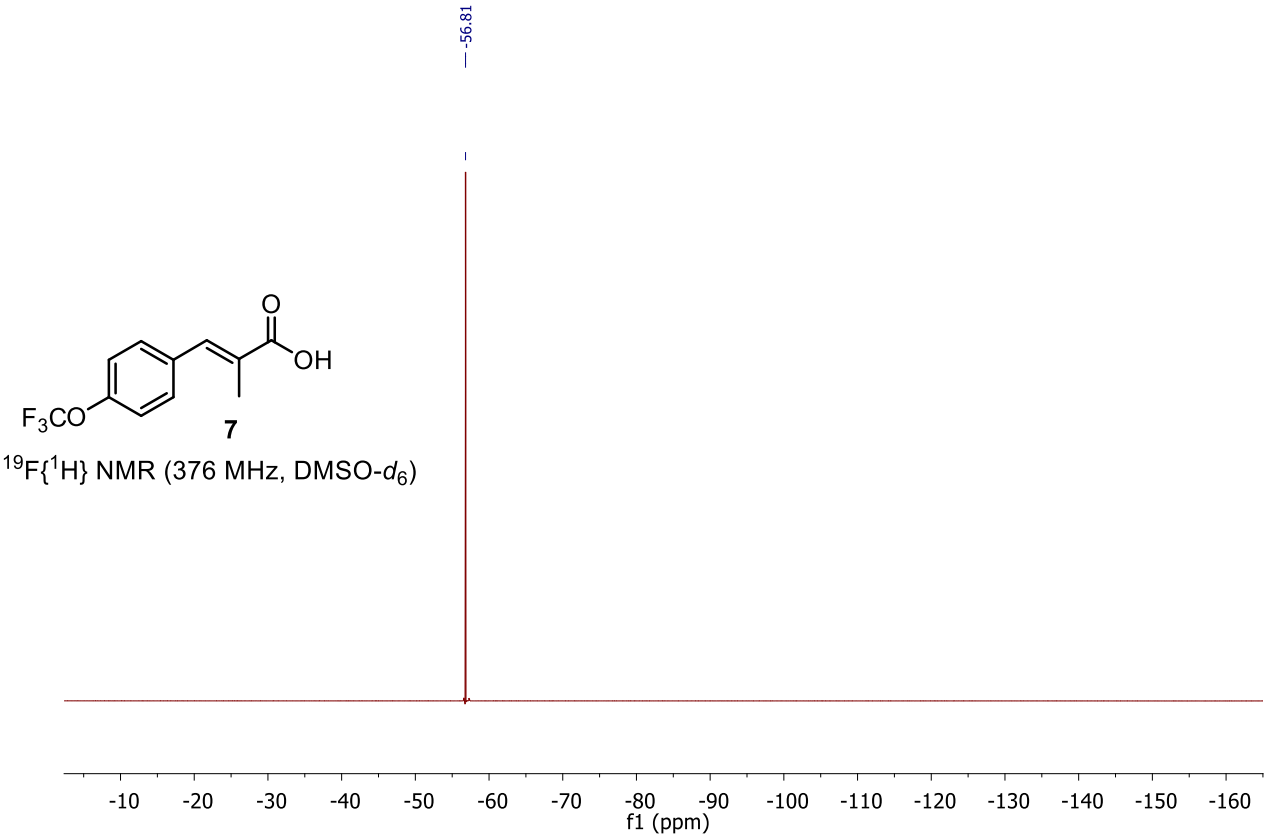
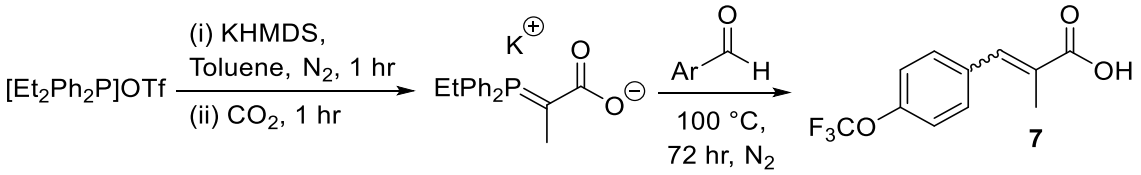
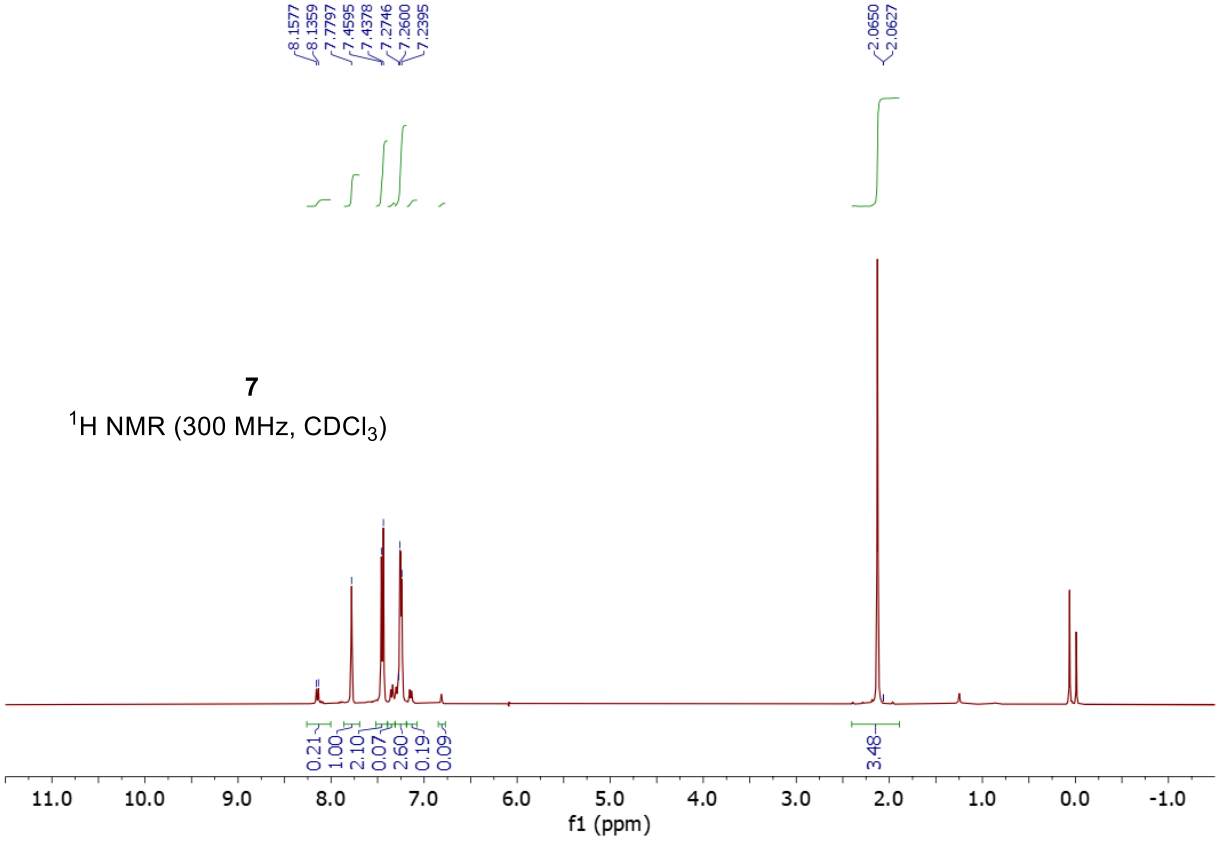
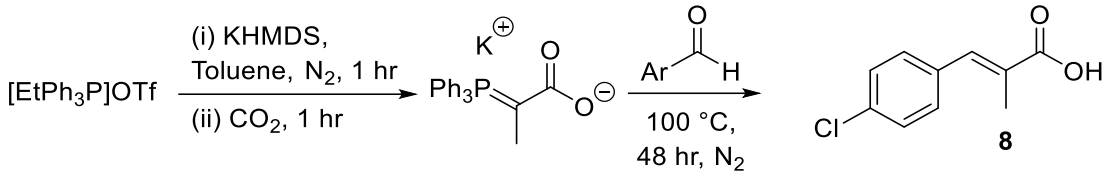
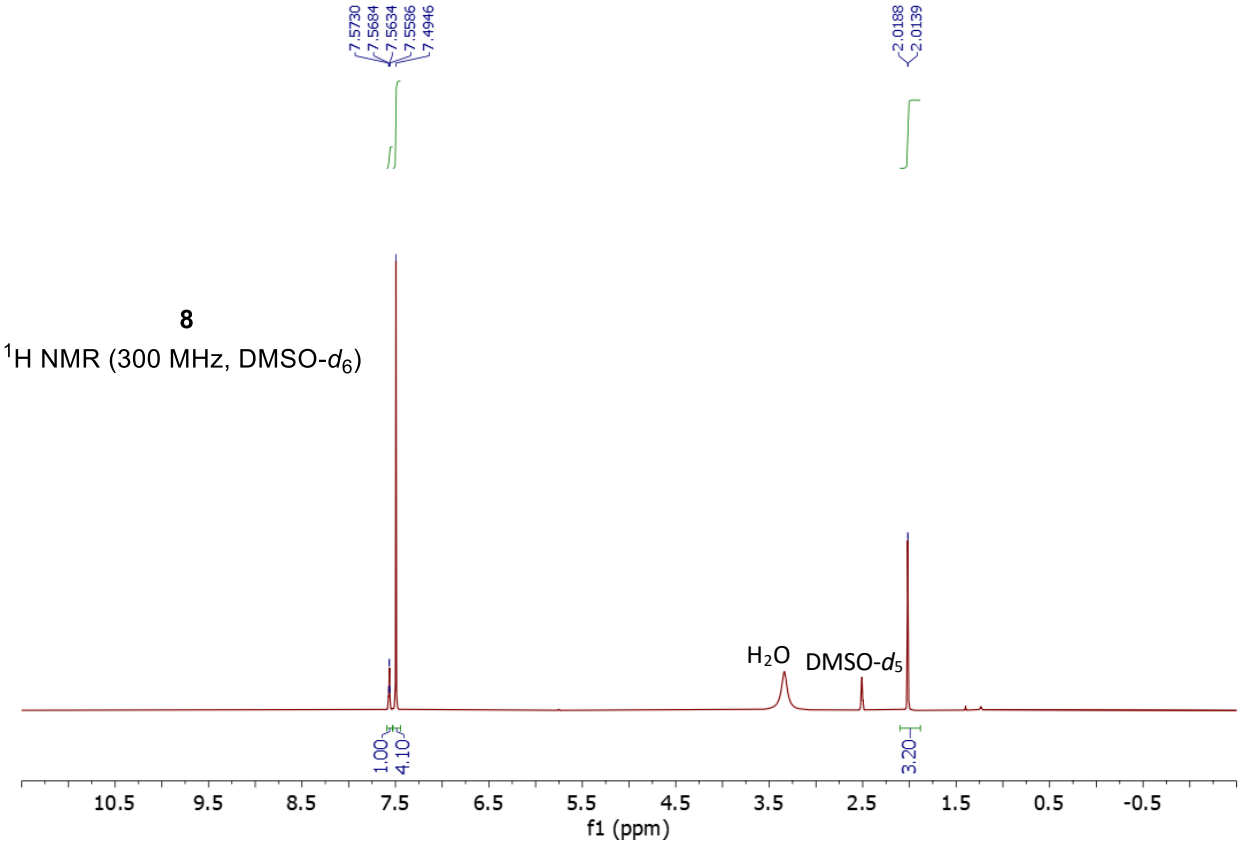
OH
O
7
13C{1H} NMR (101 MHz, DMSO-d6)
190
170
150
130
110
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)

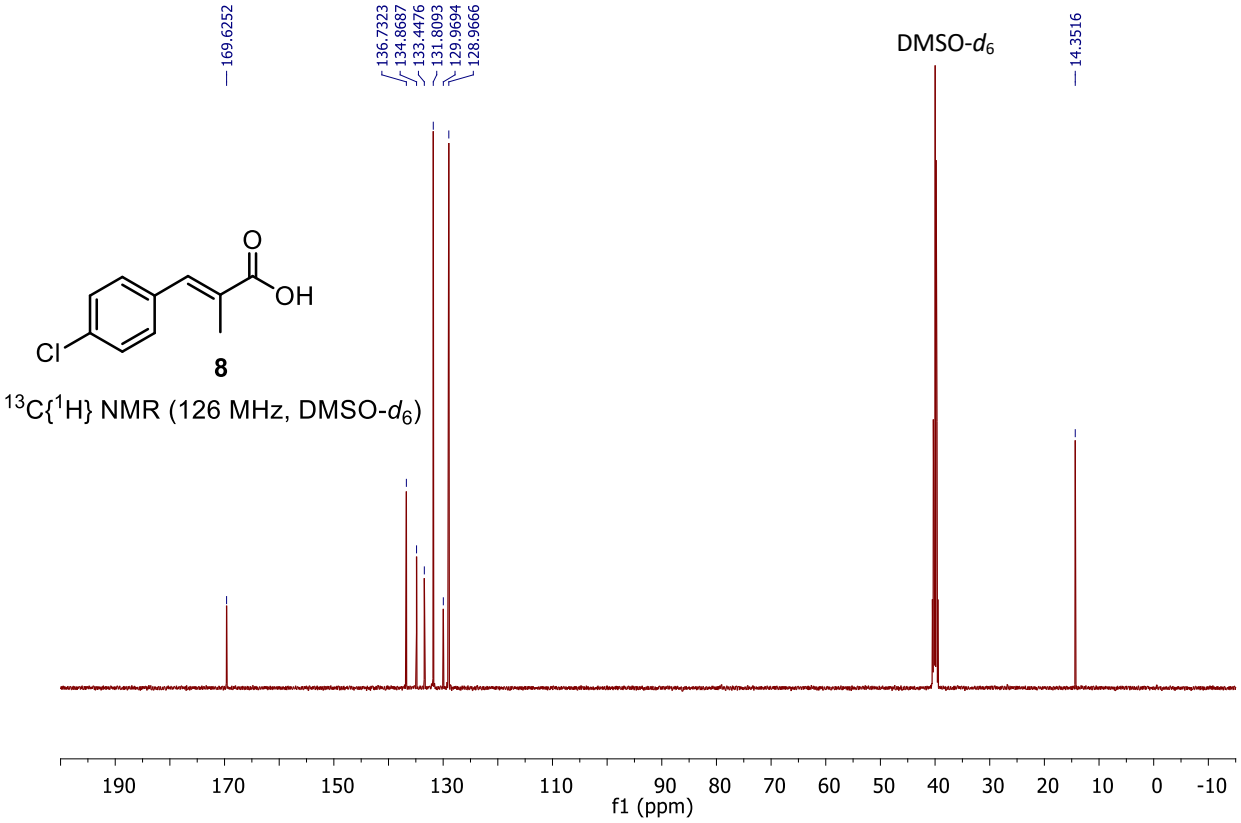

-56.81
O
OH
F3CO
7
19F{1H} NMR (376 MHz, DMSO-d6)
-10 -20 -30 -40 -50 -60 -70 -80 -90 -100 -110 -120 -130 -140 -150 -160
f1 (ppm)

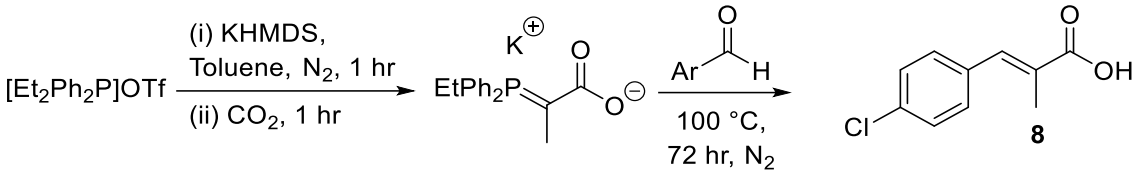

[Et2Ph2P]OTf
(i) KHMDS,
Toluene, N2, 1 hr
(ii) CO2, 1 hr
K
O
EtPh2P
O
Ar
H
100 °C,
72 hr, N2
O
OH
F3CO
7

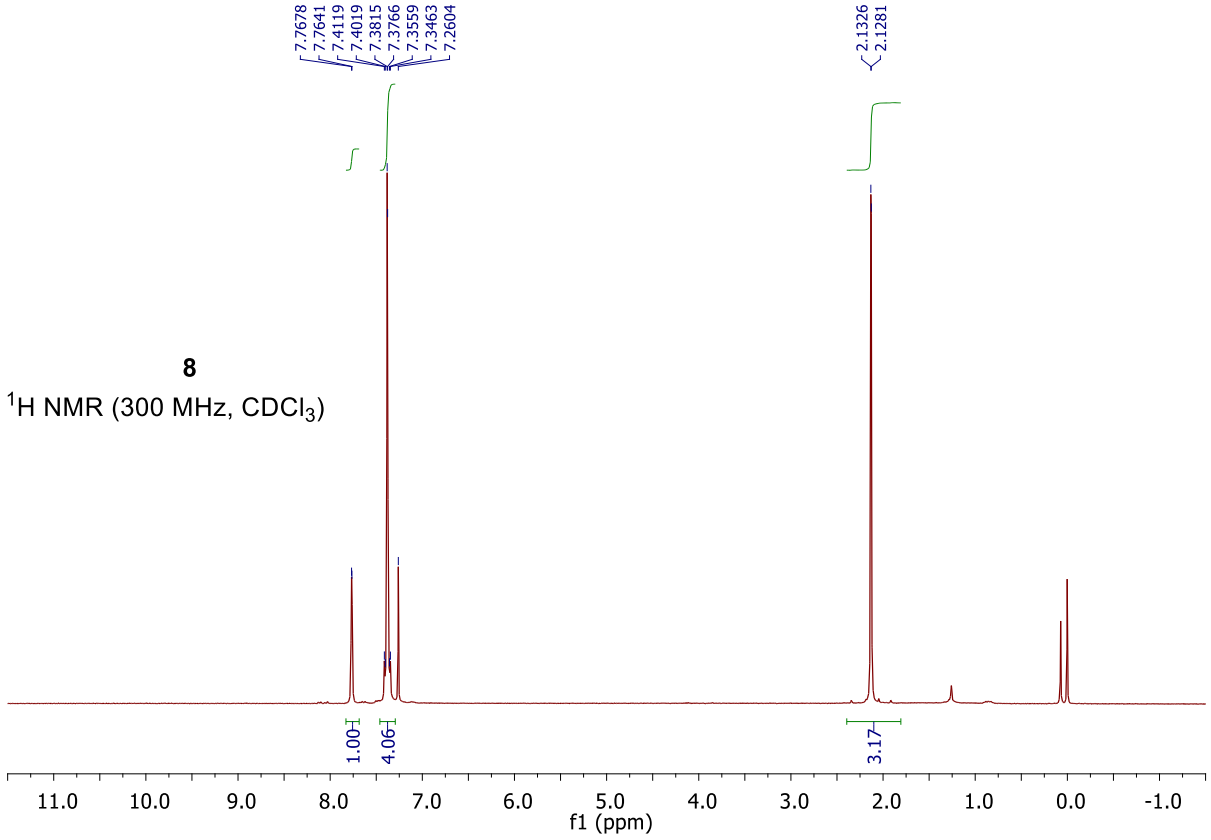

8.1577
8.1359
7.7797
7.4595
7.4378
7.2746
7.2600
7.2395
2.0650
2.0627
7
1H NMR (300 MHz, CDCl3)
0.21
1.00
2.10
0.07
2.60
0.19
0.09
3.48
11.0 10.0 9.0 8.0 7.0 6.0 5.0 4.0 3.0 2.0 1.0 0.0 -1.0
f1 (ppm)

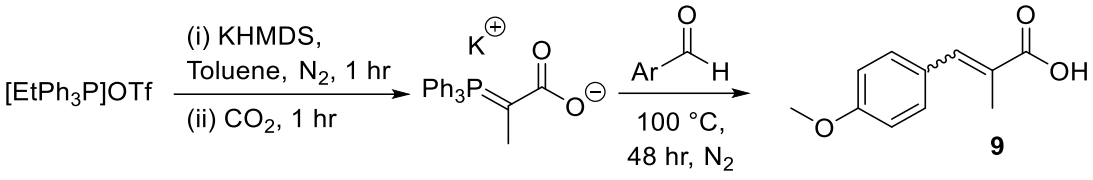

[EtPh3P]OTf
(i) KHMDS,
Toluene, N2, 1 hr
(ii) CO2, 1 hr
K
Ph3P
O
O
Ar
H
100 °C,
48 hr, N2
Cl
OH
8

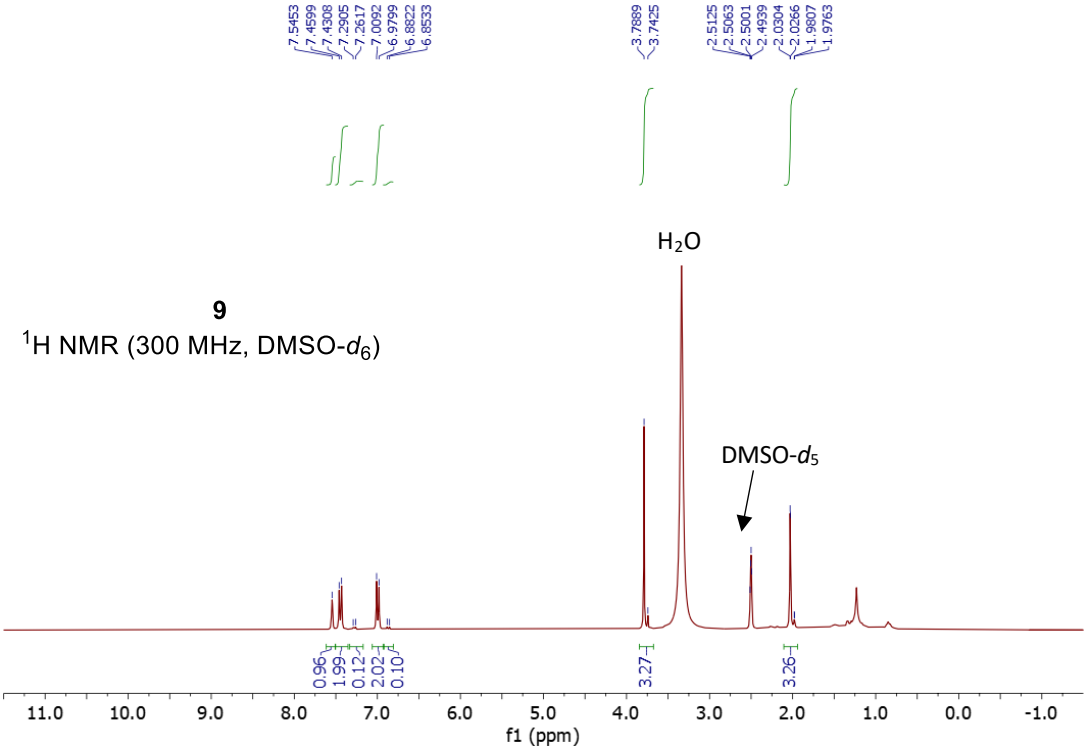

7.5730
7.5684
7.5634
7.5586
7.4946
2.0188
2.0139
8
1H NMR (300 MHz, DMSO-d6)
H2O
DMSO-d5
1.00
4.10
3.20
10.5
9.5
8.5
7.5
6.5
5.5
4.5
3.5
2.5
1.5
0.5
-0.5
f1 (ppm)


169.6252
136.7323
134.8687
133.4476
131.8093
129.9694
128.9666
DMSO-d6
14.3516
Cl
OH
8
13C{1H} NMR (126 MHz, DMSO-d6)
190
170
150
130
110
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)


[Et2Ph2P]OTf
(i) KHMDS,
Toluene, N2, 1 hr
(ii) CO2, 1 hr
K
O
EtPh2P
O
Ar
H
100 °C,
72 hr, N2
O
OH
Cl
8

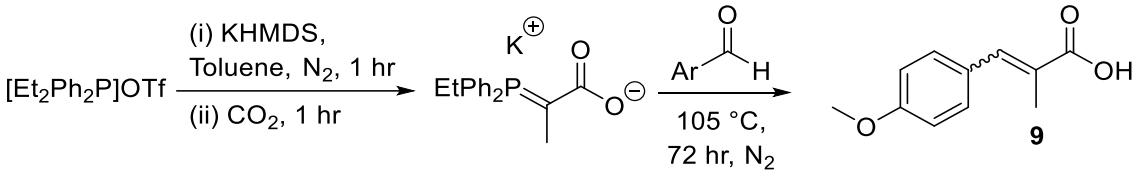

7.7678
7.7641
7.4119
7.4019
7.3815
7.3766
7.3559
7.3463
7.2604
2.1326
2.1281
8
1H NMR (300 MHz, CDCl3)
1.00
4.06
3.17
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
f1 (ppm)

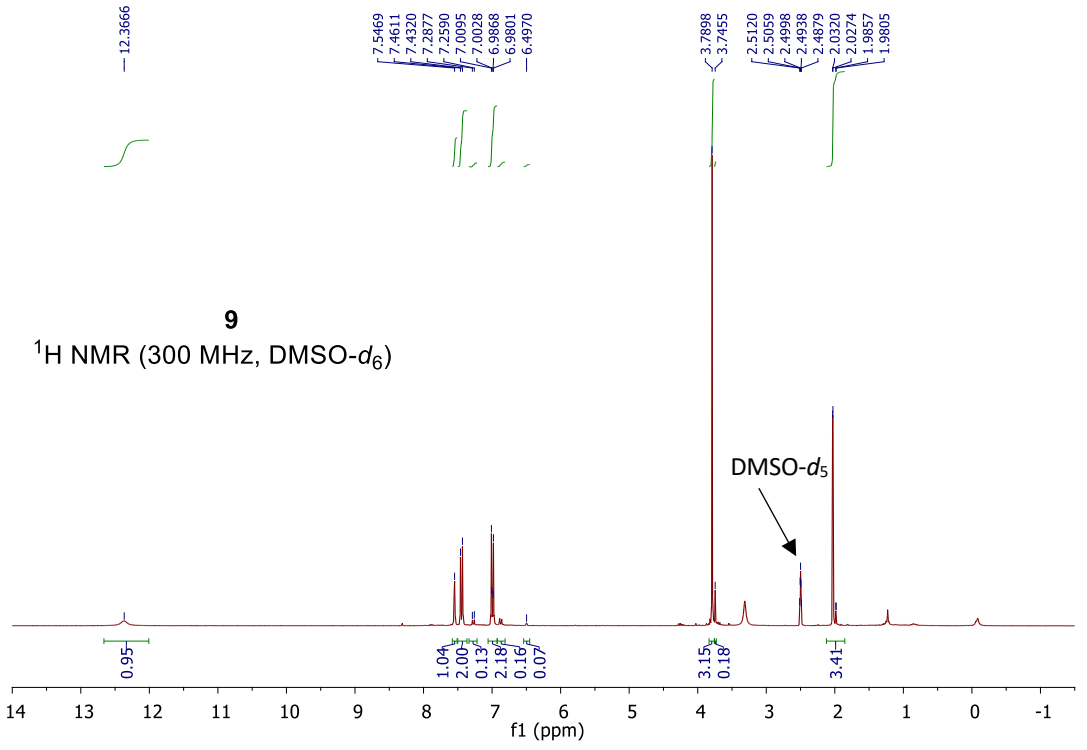




9

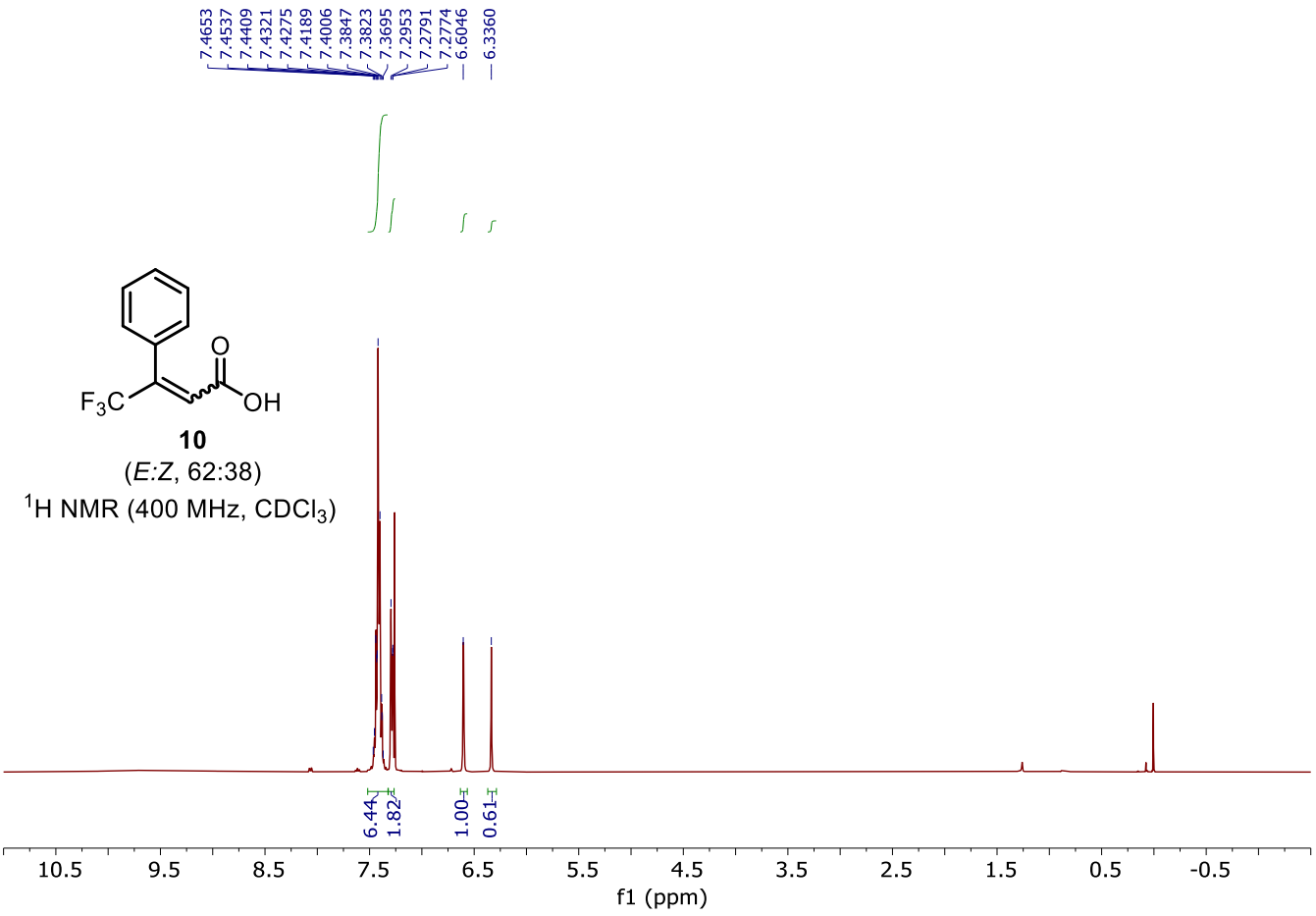
^{1}H NMR (300 MHz, DMSO-d_6)

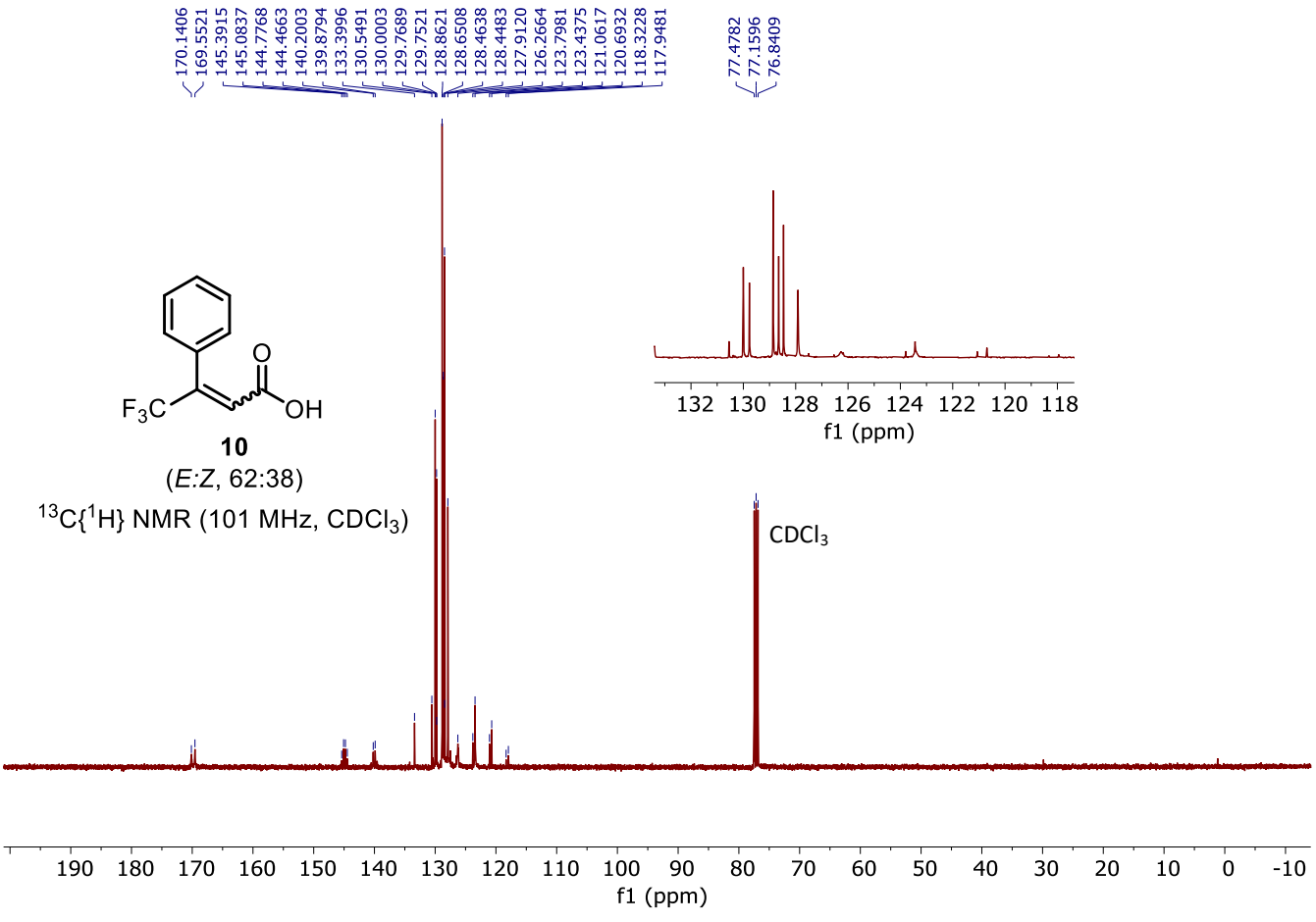


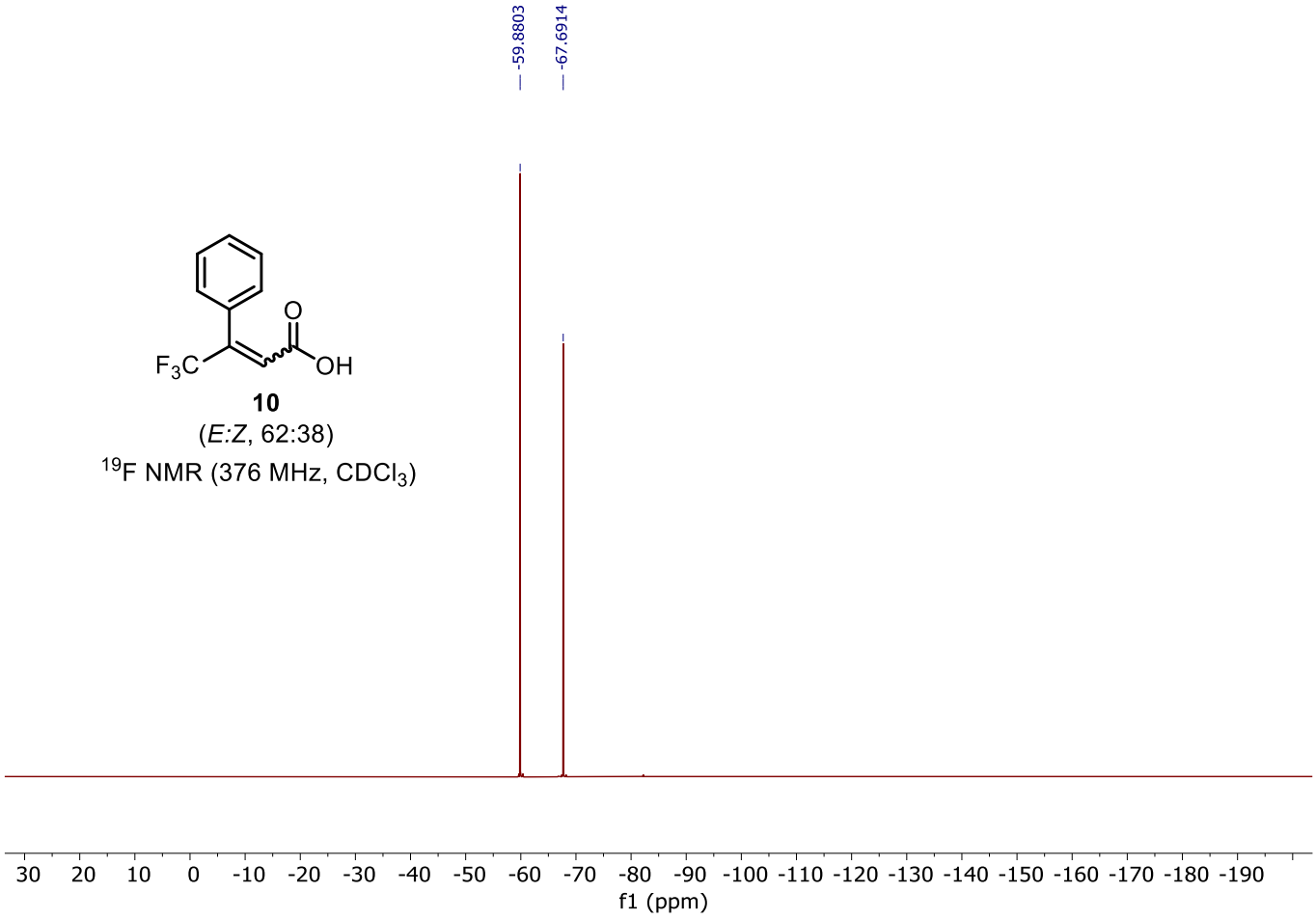


9

^{1}H NMR (300 MHz, DMSO-d_6)


7.4653
7.4537
7.4409
7.4321
7.4275
7.4189
7.4006
7.3847
7.3823
7.3695
7.2953
7.2791
7.2774
6.6046
6.3360
F3C
O
OH
10
(E:Z, 62:38)
1H NMR (400 MHz, CDCl3)
6.44
1.82
1.00
0.61
10.5
9.5
8.5
7.5
6.5
5.5
4.5
3.5
2.5
1.5
0.5
-0.5
f1 (ppm)

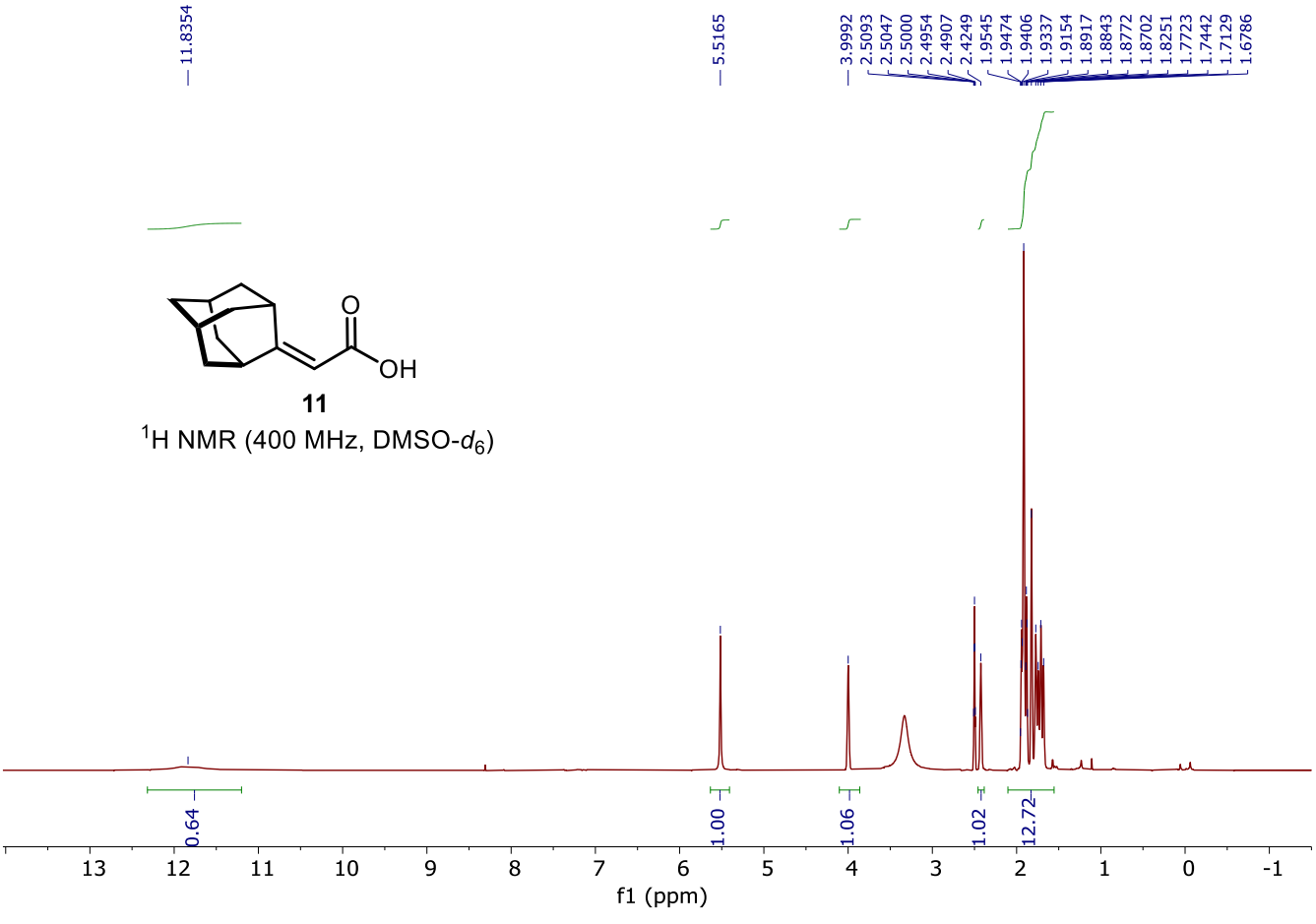

170.1406
169.5521
145.3915
145.0837
144.7768
144.4663
140.2003
139.8794
133.3996
130.5491
130.0003
129.7689
129.7521
128.8621
128.6508
128.4638
128.4483
127.9120
126.2664
123.7981
123.4375
121.0617
120.6932
118.3228
117.9481
77.4782
77.1596
76.8409
F3C
O
OH
10
(E:Z, 62:38)
13C{1H} NMR (101 MHz, CDCl3)
CDCl3
132
130
128
126
124
122
120
118
f1 (ppm)
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)



10

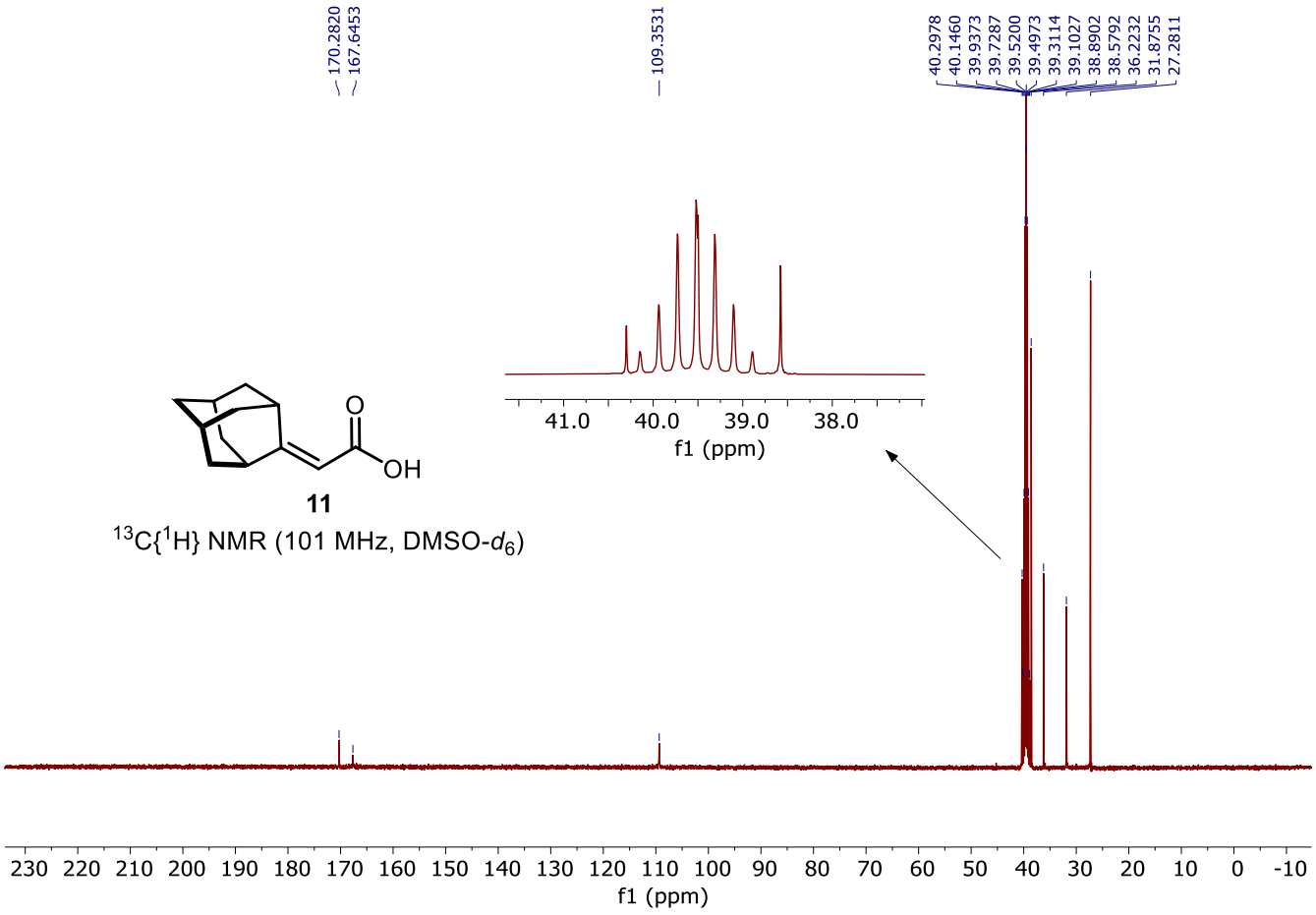
(*E*:*Z*, 62:38)

^{19}F NMR (376 MHz, $CDCl_3$)



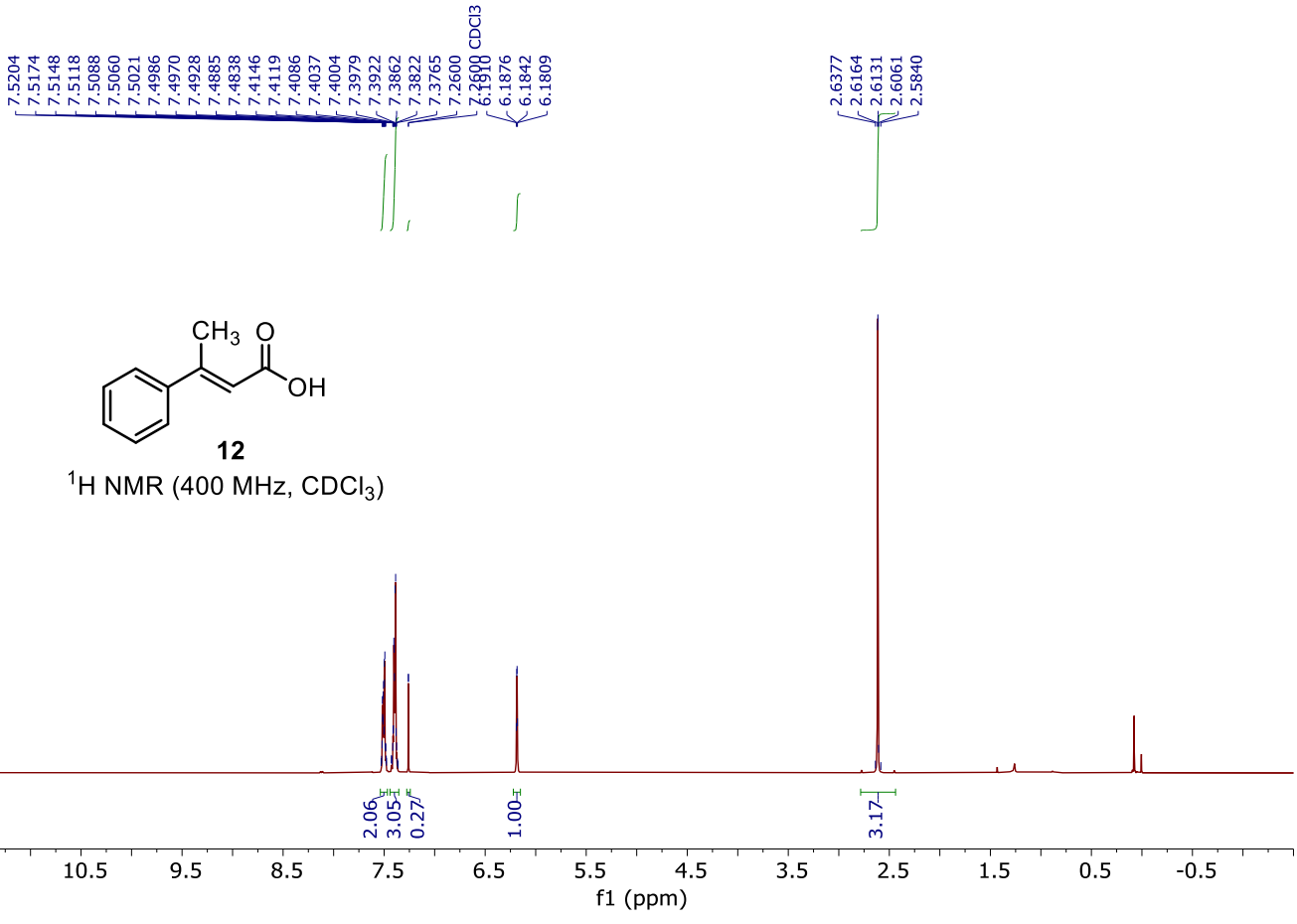
11

^{1}H NMR (400 MHz, DMSO-d_6)



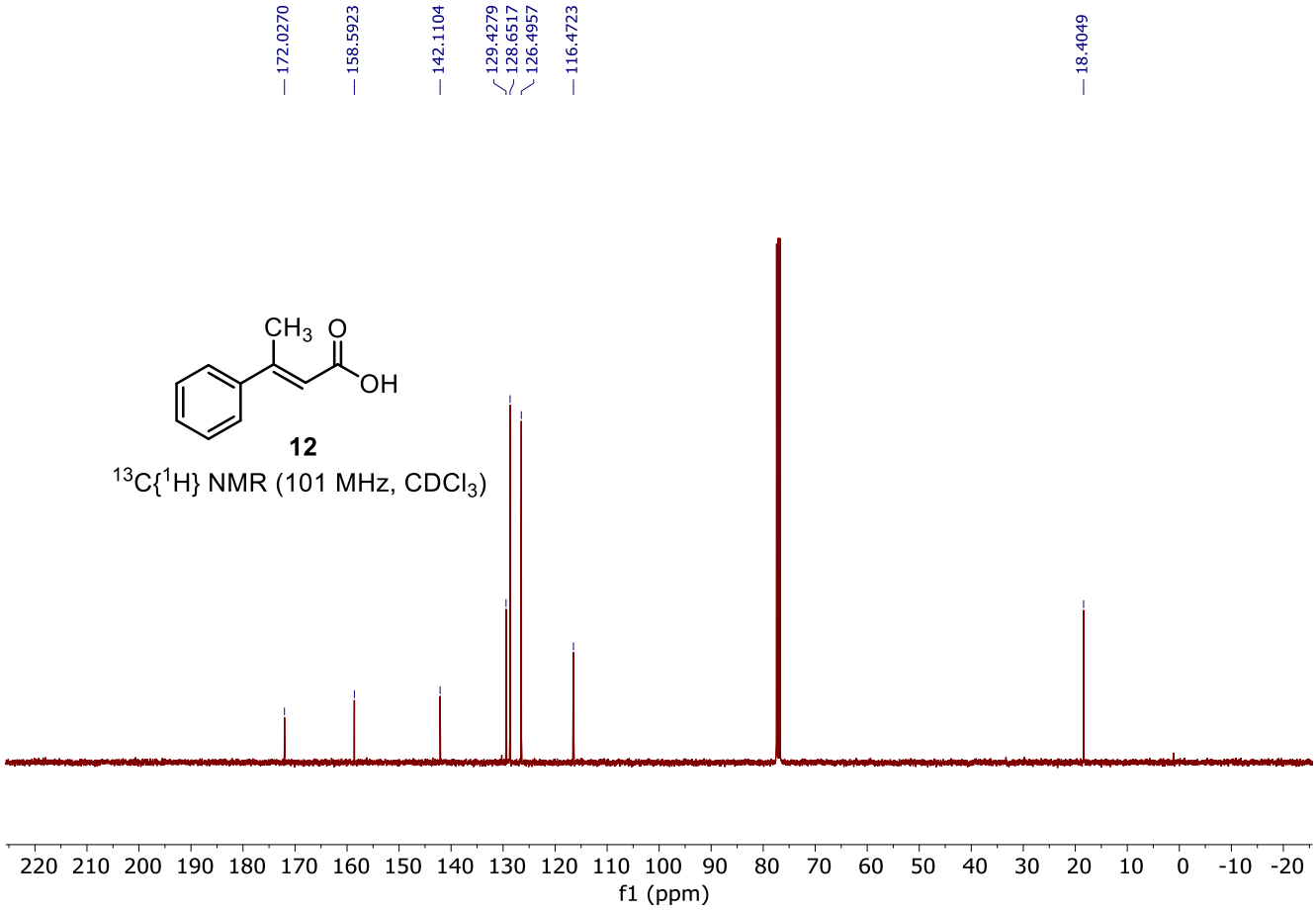
11

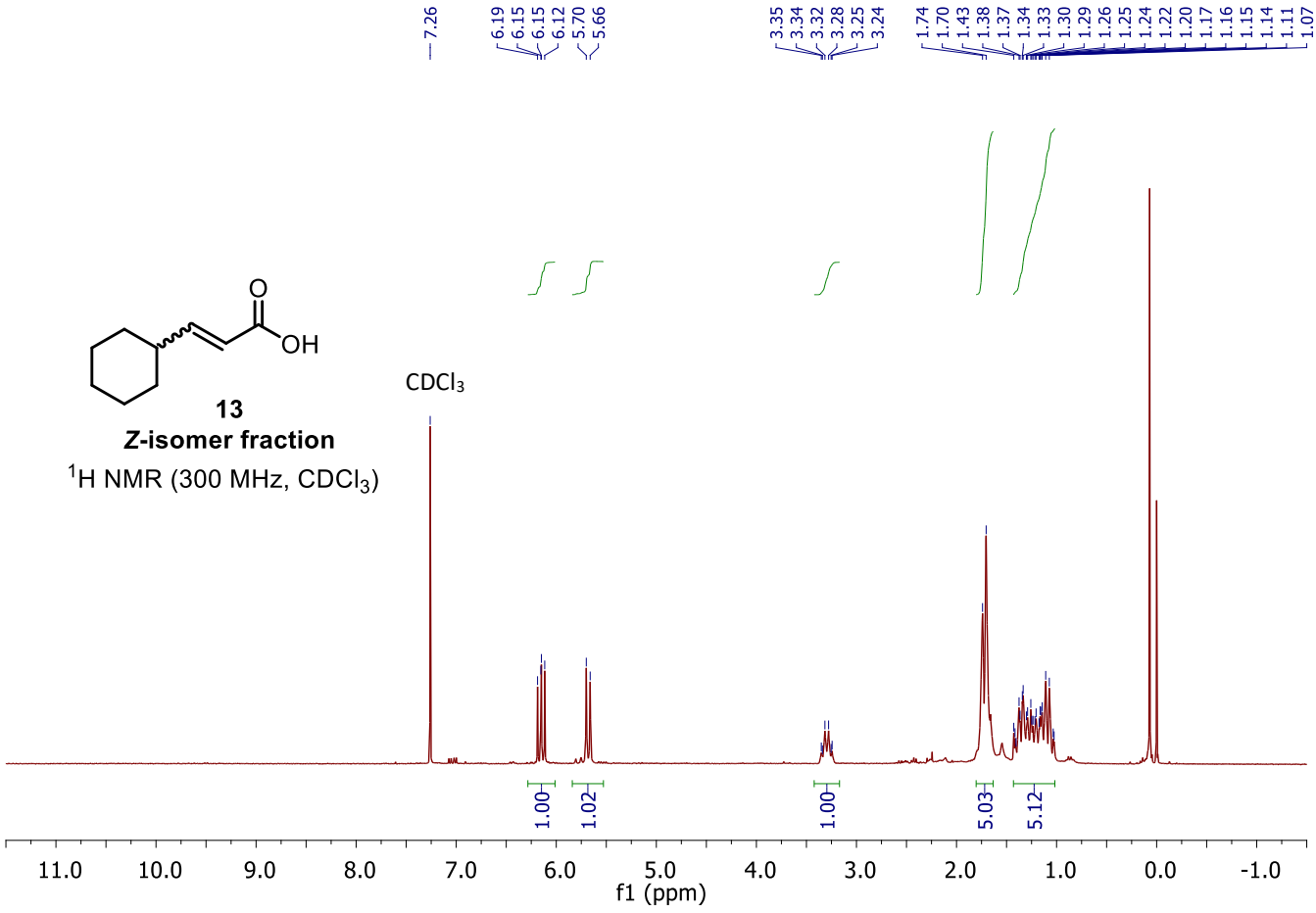
$^{13}C\{^{1}H\}$ NMR (101 MHz, DMSO-d_6)

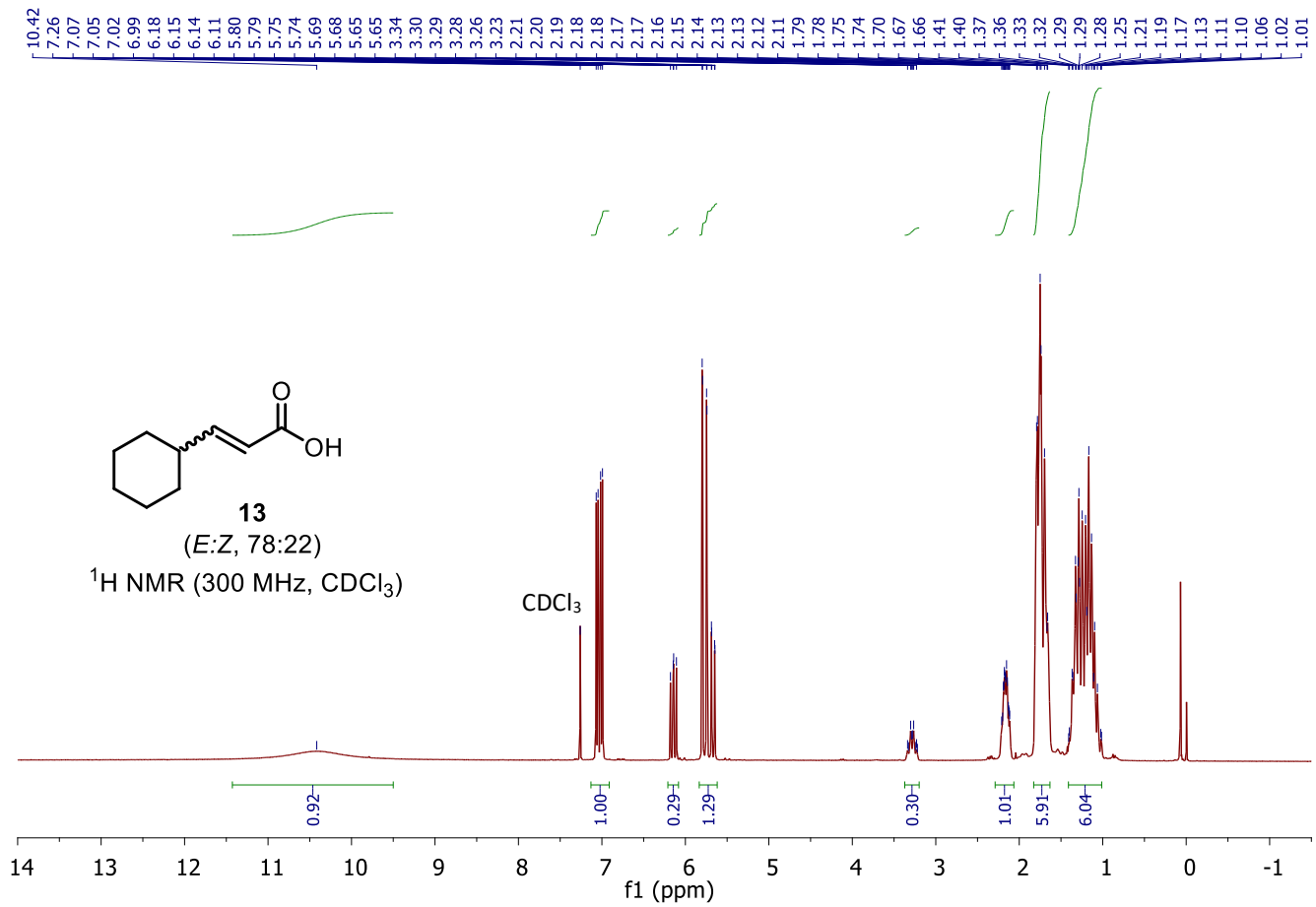


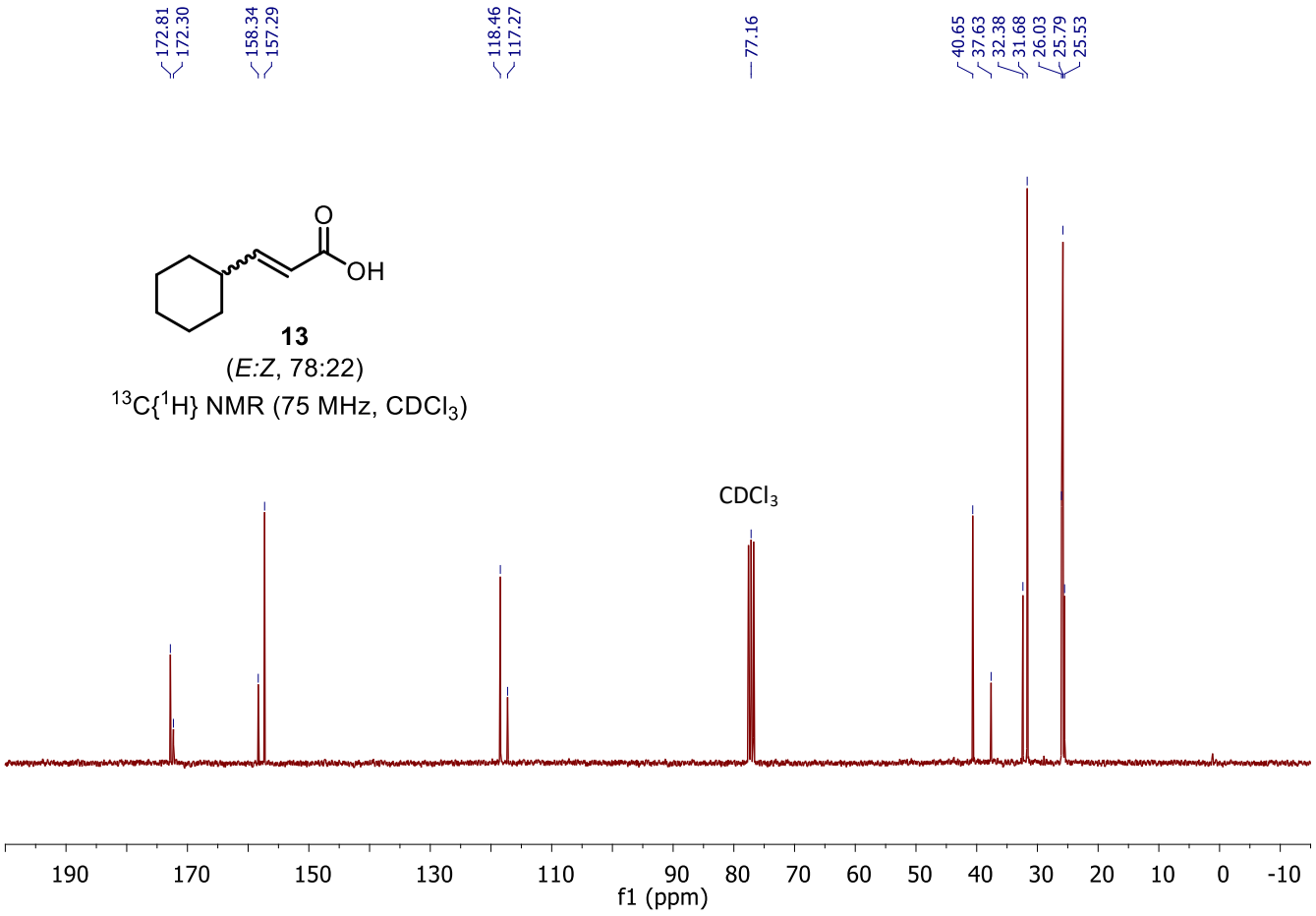
12

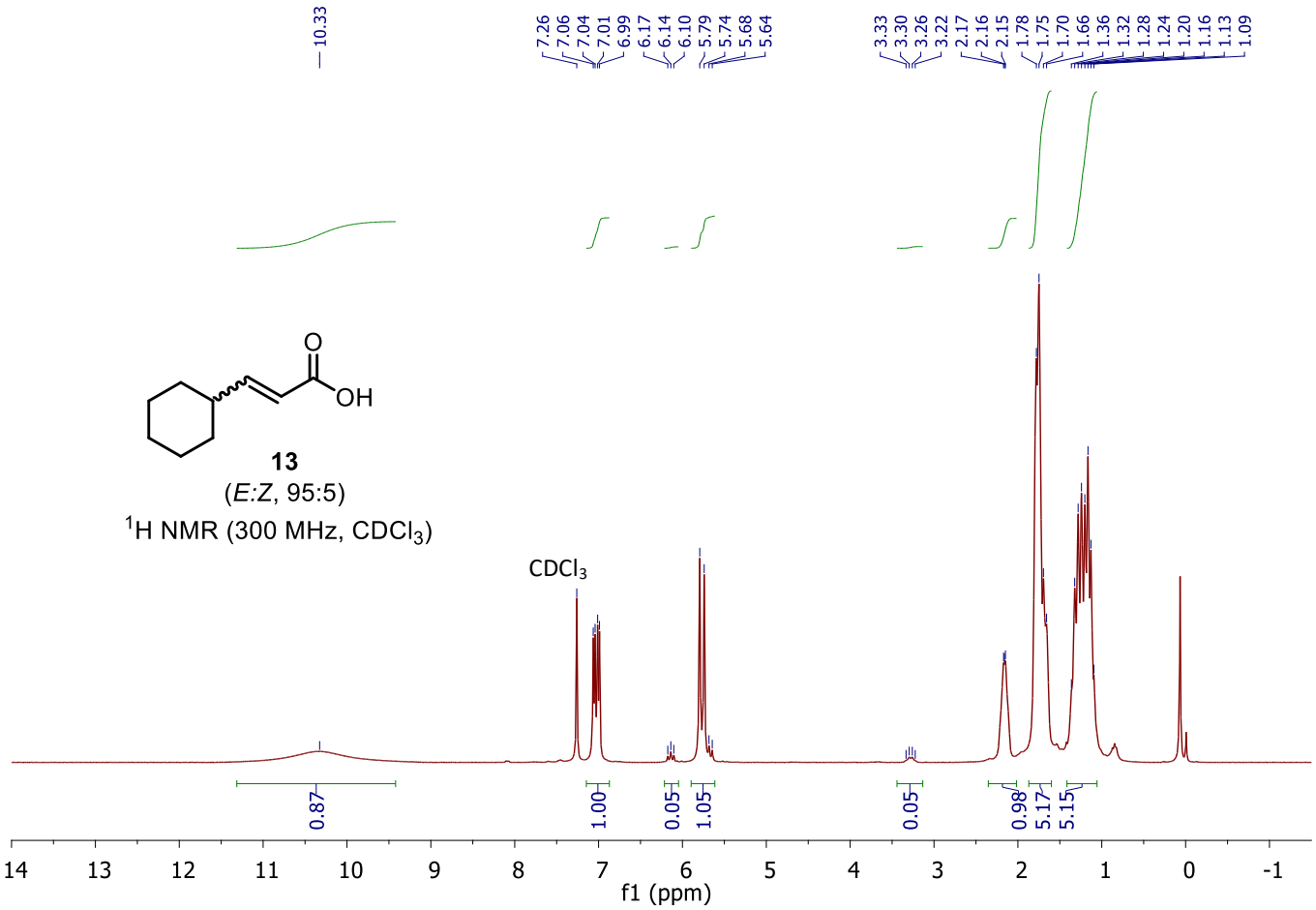
^{1}H NMR (400 MHz, $CDCl_3$)

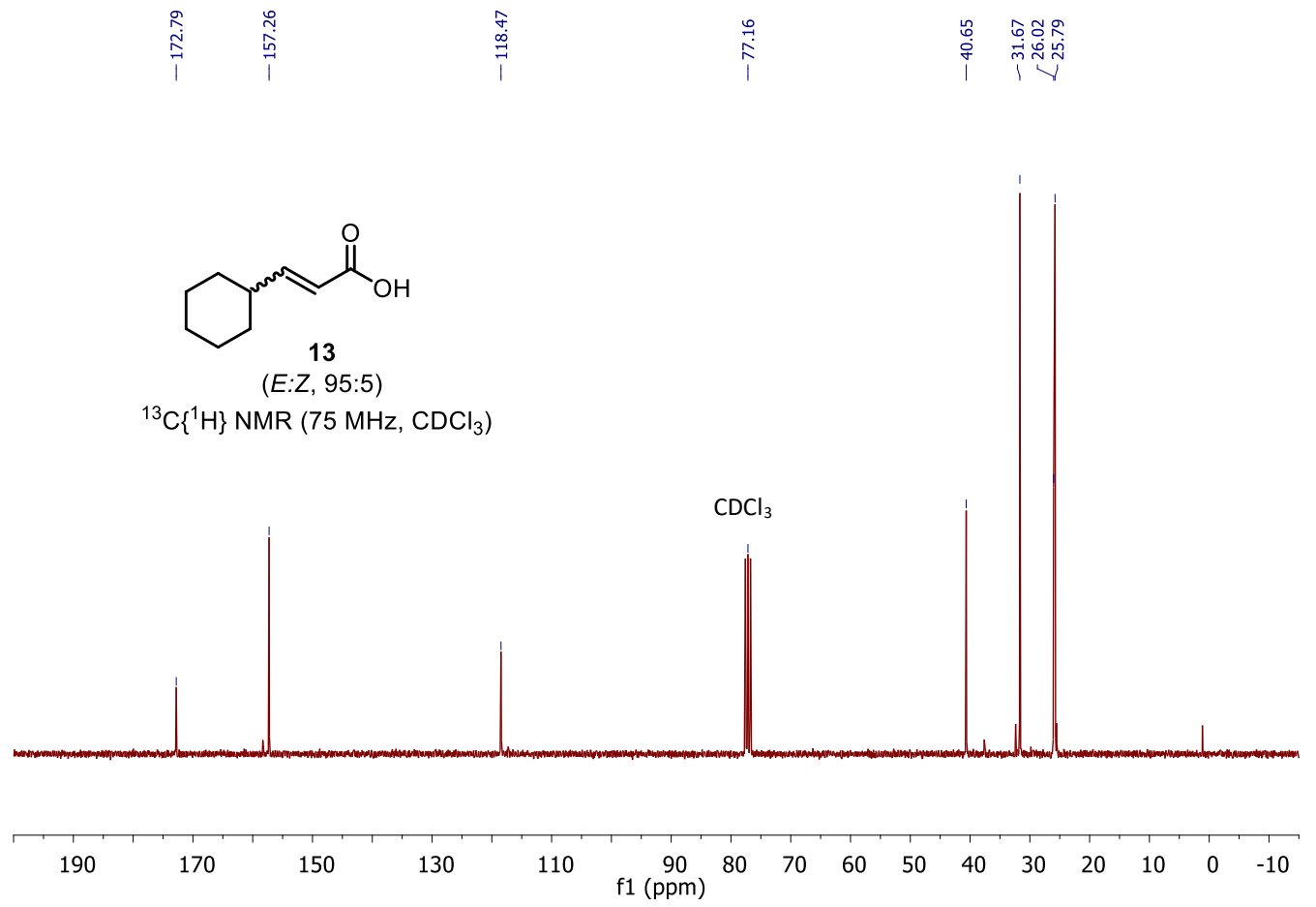

172.0270
158.5923
142.1104
129.4279
128.6517
126.4957
116.4723
18.4049
CH3 O
OH
12
13C{1H} NMR (101 MHz, CDCl3)
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10 -20
f1 (ppm)

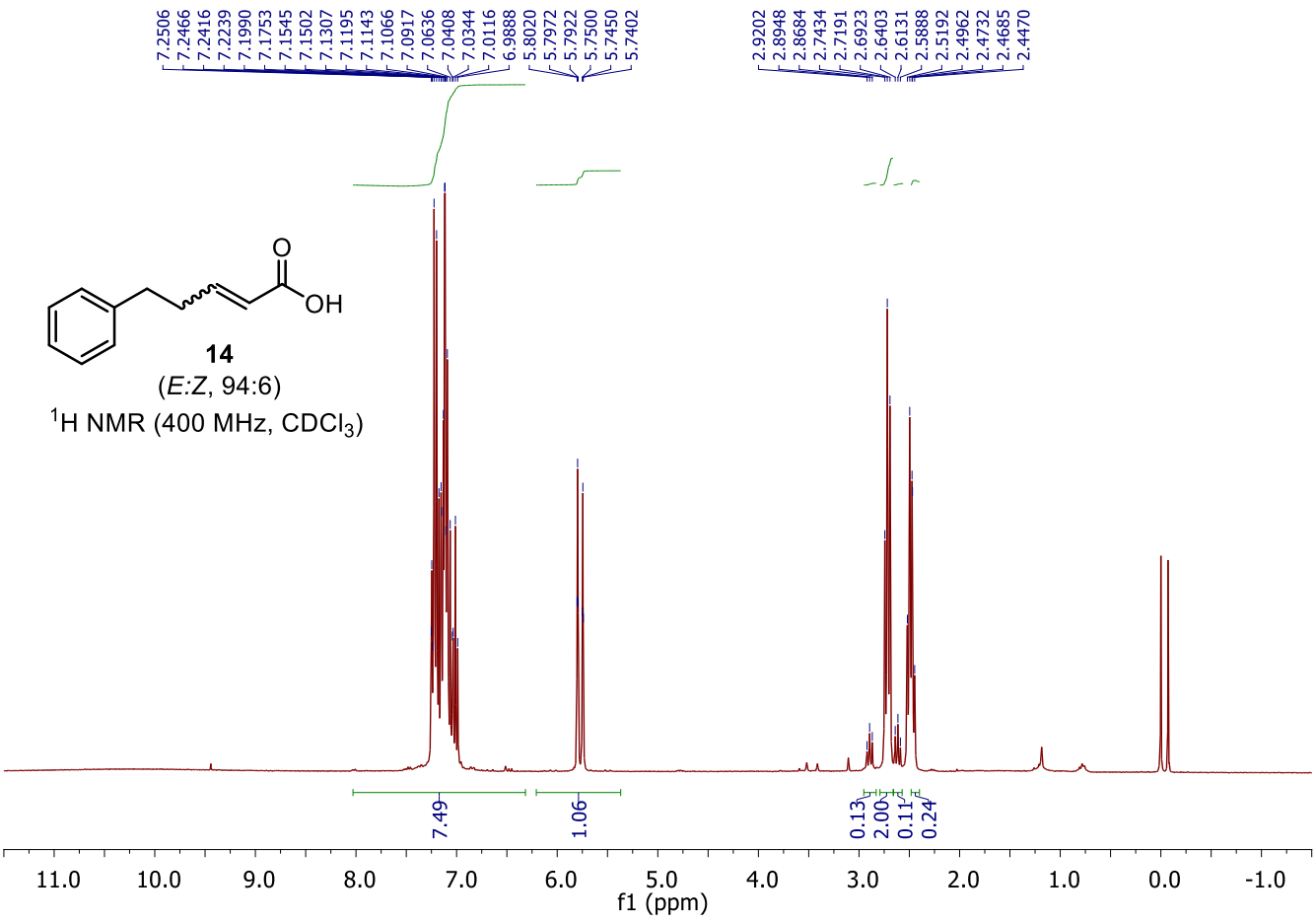

7.26
6.19
6.15
6.15
6.12
5.70
5.66
3.35
3.34
3.32
3.28
3.25
3.24
1.74
1.70
1.43
1.38
1.37
1.34
1.33
1.30
1.29
1.26
1.25
1.24
1.22
1.20
1.17
1.16
1.15
1.14
1.11
1.07
O
OH
13
Z-isomer fraction
1H NMR (300 MHz, CDCl3)
CDCl3
1.00
1.02
1.00
5.03
5.12
11.0 10.0 9.0 8.0 7.0 6.0 5.0 4.0 3.0 2.0 1.0 0.0 -1.0
f1 (ppm)

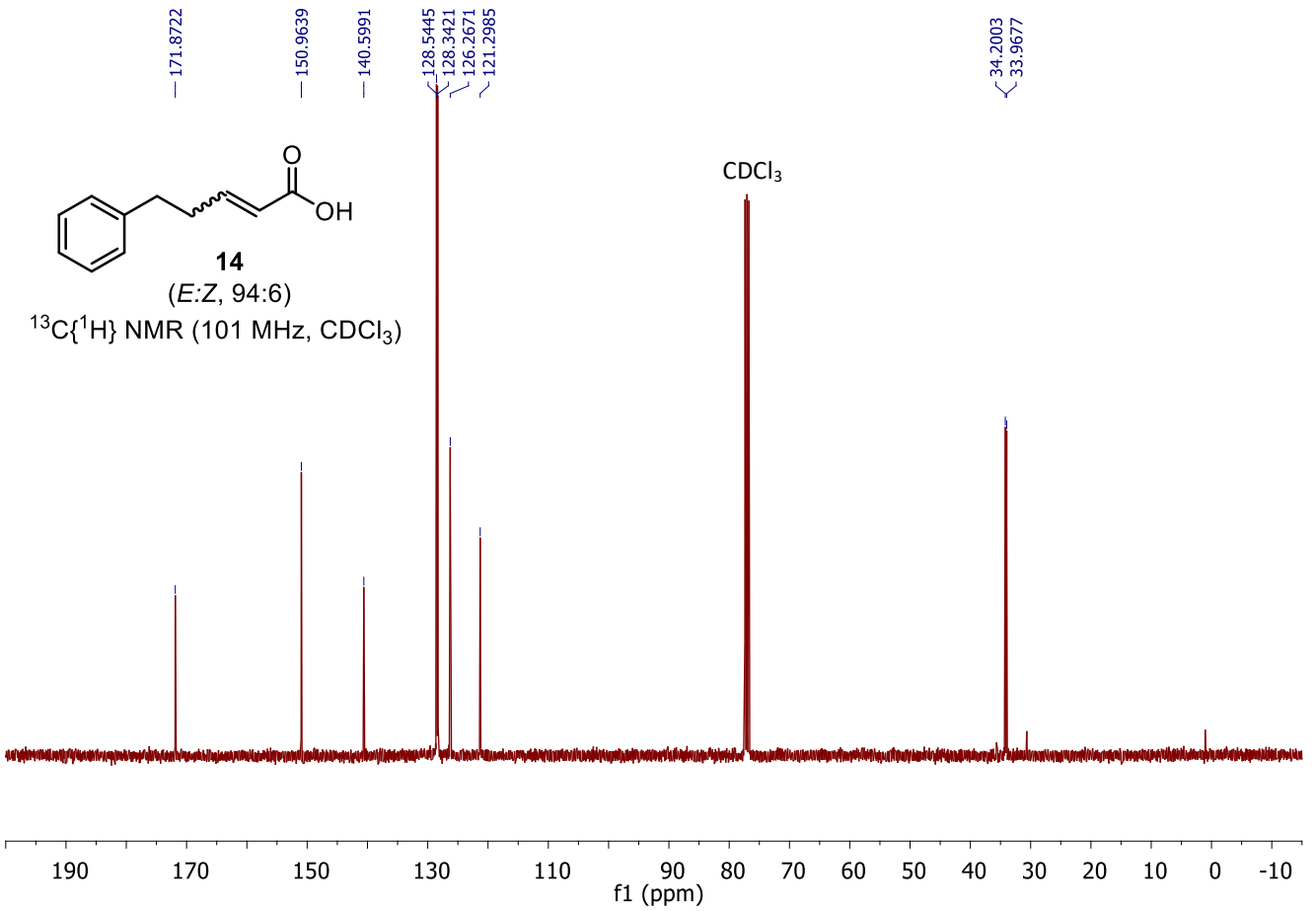

10.42
7.26
7.07
7.05
7.02
6.99
6.18
6.15
6.14
6.11
5.80
5.79
5.75
5.74
5.69
5.68
5.65
5.65
3.34
3.30
3.29
3.28
3.26
3.23
2.21
2.20
2.19
2.18
2.18
2.17
2.17
2.16
2.15
2.14
2.13
2.13
2.12
2.11
1.79
1.78
1.75
1.74
1.70
1.67
1.66
1.41
1.40
1.37
1.36
1.33
1.32
1.29
1.29
1.28
1.25
1.21
1.19
1.17
1.13
1.11
1.10
1.06
1.02
1.01
O
OH
13
(E:Z, 78:22)
1H NMR (300 MHz, CDCl3)
CDCl3
0.92
1.00
0.29
1.29
0.30
1.01
5.91
6.04
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
f1 (ppm)

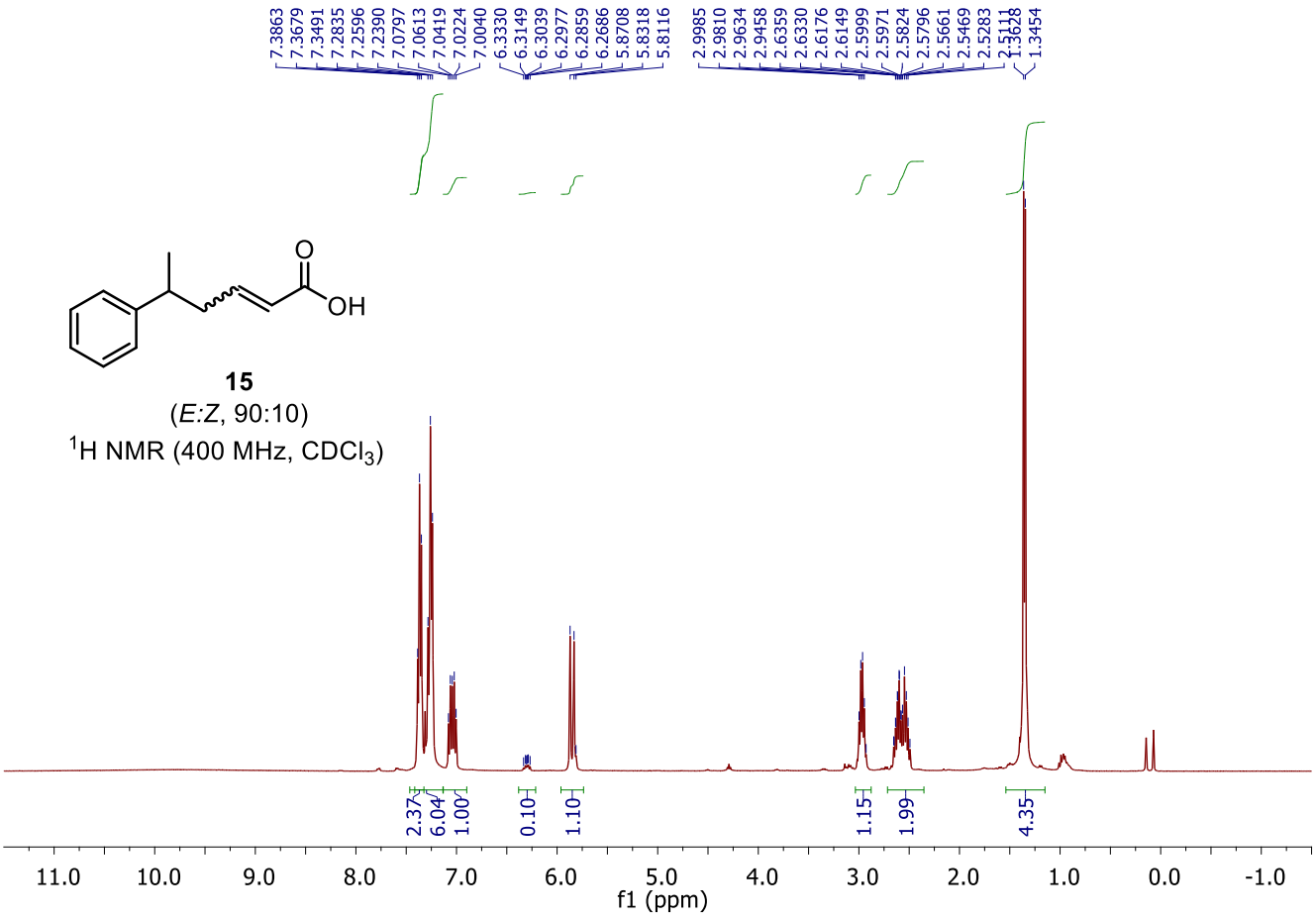

172.81
172.30
158.34
157.29
118.46
117.27
77.16
40.65
37.63
32.38
31.68
26.03
25.79
25.53
O
OH
13
(E:Z, 78:22)
13C{1H} NMR (75 MHz, CDCl3)
CDCl3
190
170
150
130
110
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)

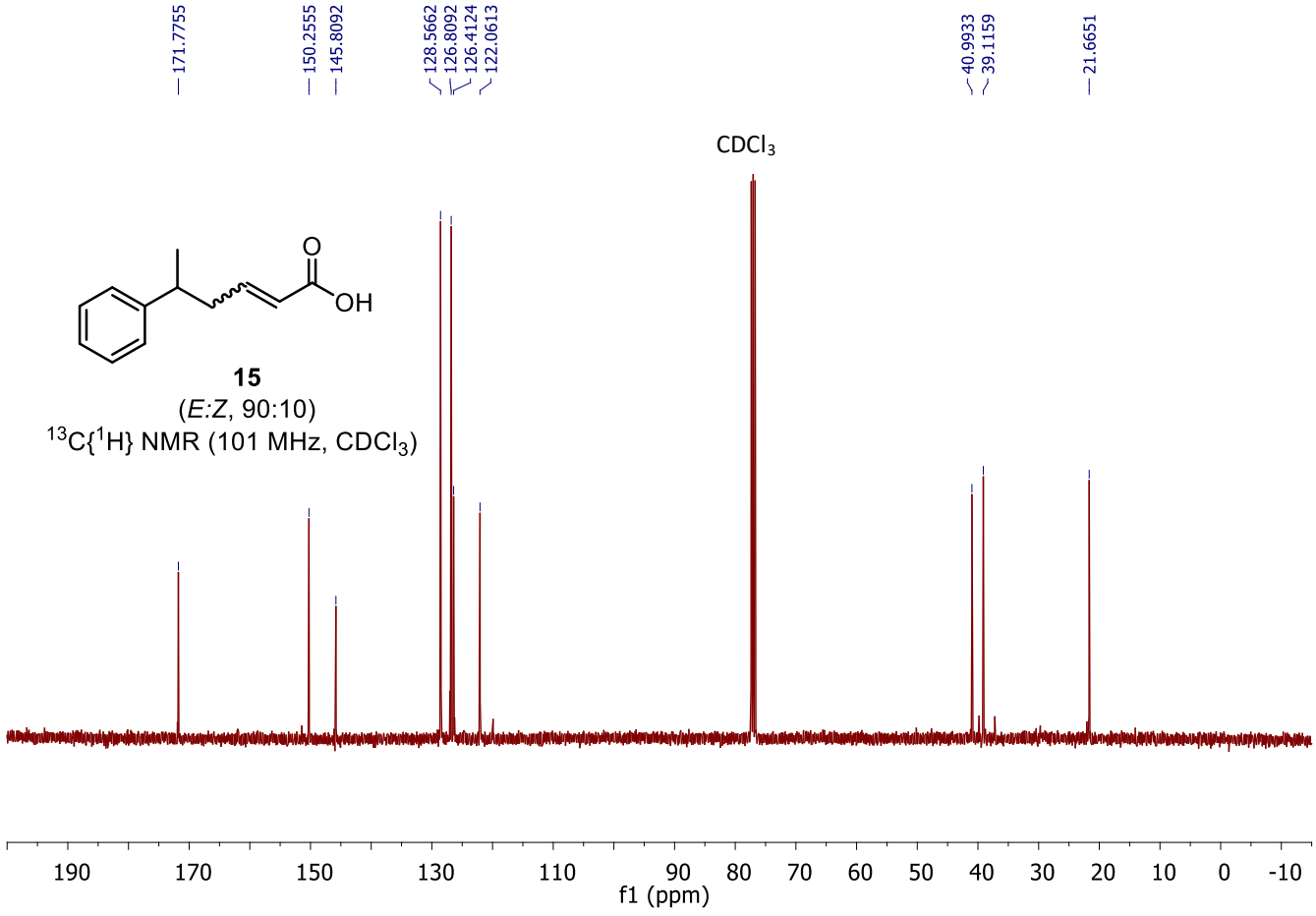

10.33
7.26
7.06
7.04
7.01
6.99
6.17
6.14
6.10
5.79
5.74
5.68
5.64
3.33
3.30
3.26
3.22
2.17
2.16
2.15
1.78
1.75
1.70
1.66
1.36
1.32
1.28
1.24
1.20
1.16
1.13
1.09
O
OH
13
(E:Z, 95:5)
1H NMR (300 MHz, CDCl3)
CDCl3
0.87
1.00
0.05
1.05
0.05
0.98
5.17
5.15
14 13 12 11 10 9 8 7 6 5 4 3 2 1 0 -1
f1 (ppm)

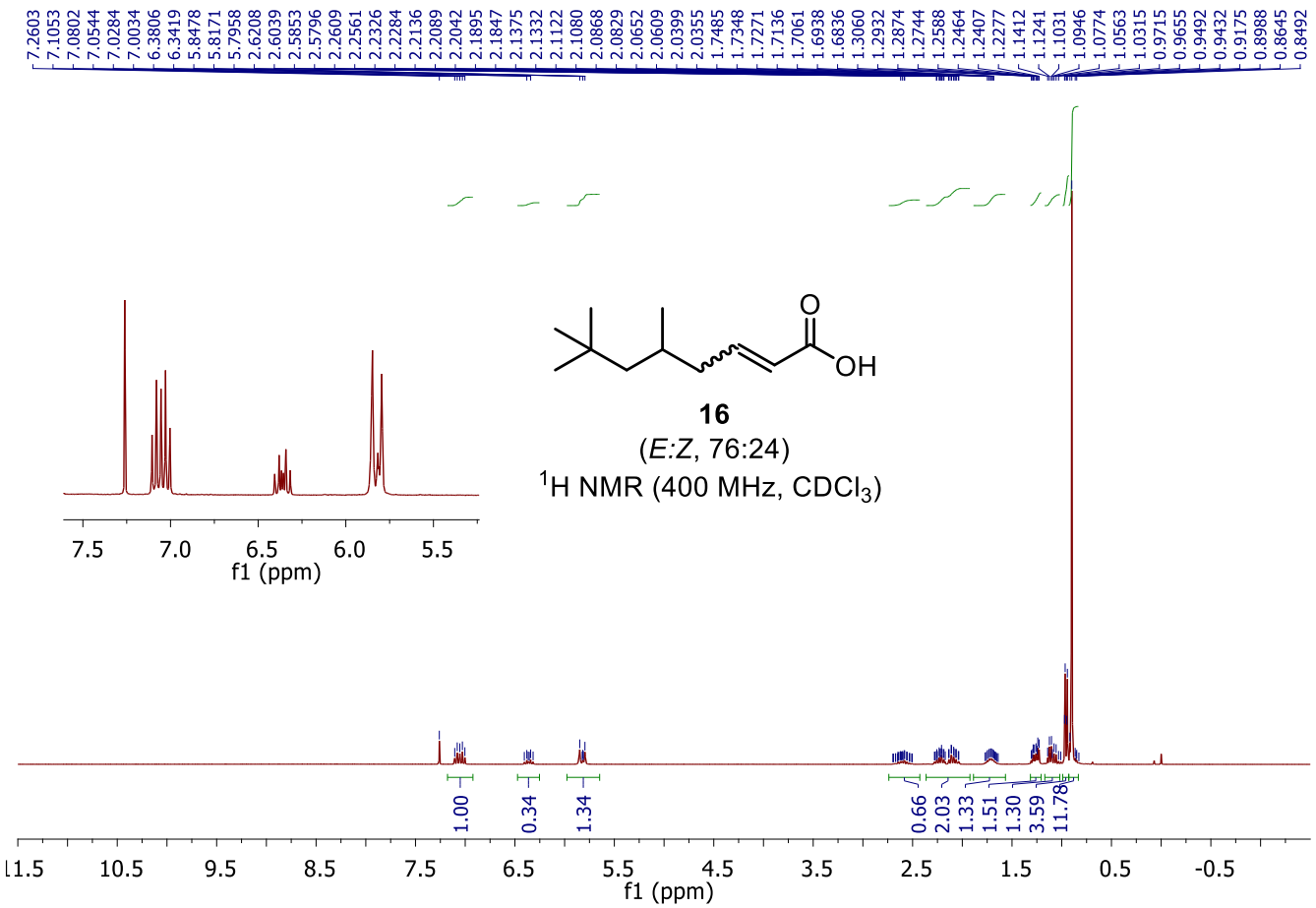

172.79
157.26
118.47
77.16
40.65
31.67
26.02
25.79
O
OH
13
(E:Z, 95:5)
13C{1H} NMR (75 MHz, CDCl3)
CDCl3
190 170 150 130 110 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)

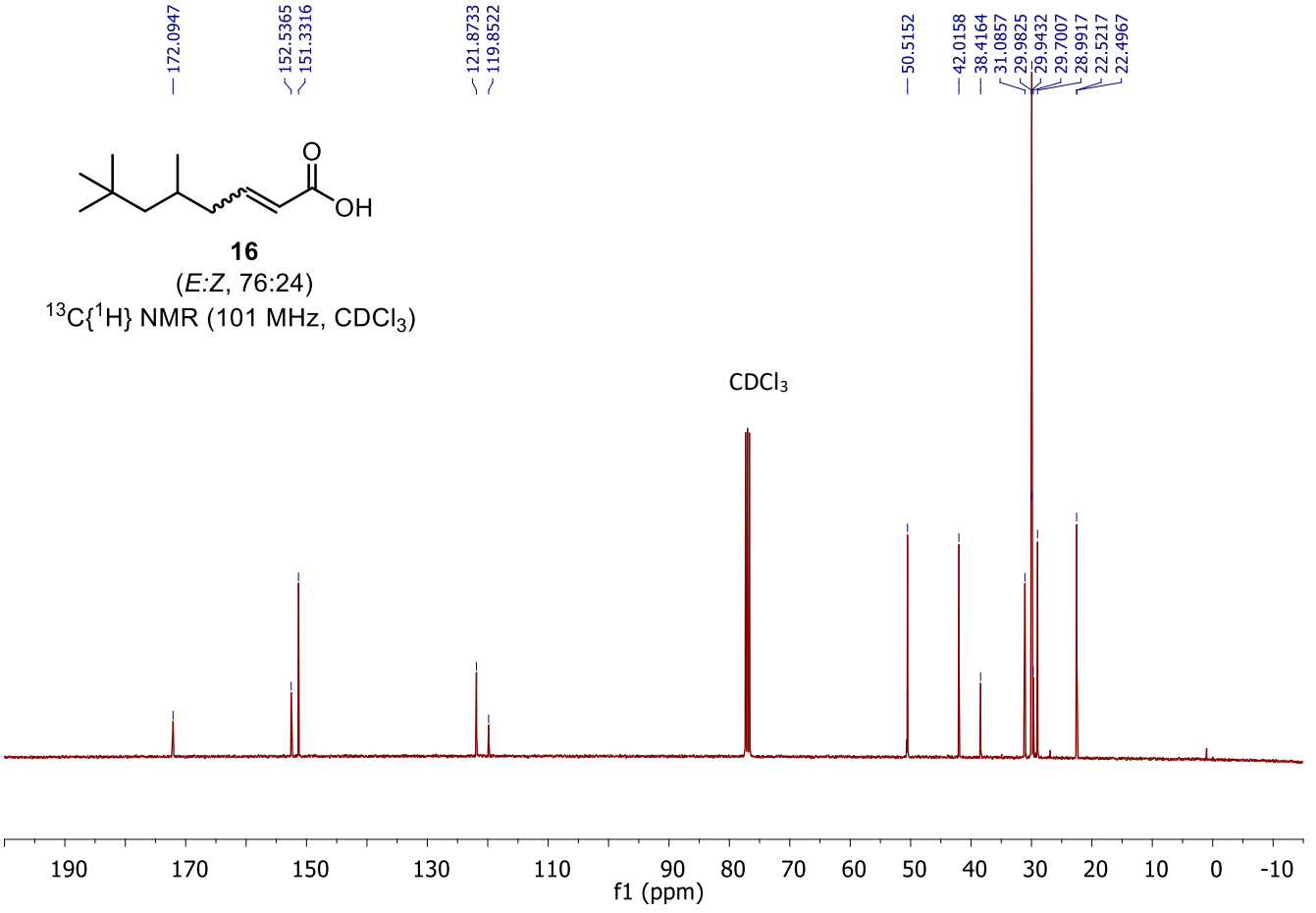

7.2506
7.2466
7.2416
7.2239
7.1990
7.1753
7.1545
7.1502
7.1307
7.1195
7.1143
7.1066
7.0917
7.0636
7.0408
7.0344
7.0116
6.9888
5.8020
5.7972
5.7922
5.7500
5.7450
5.7402
2.9202
2.8948
2.8684
2.7434
2.7191
2.6923
2.6403
2.6131
2.5888
2.5192
2.4962
2.4732
2.4685
2.4470
O
OH
14
(E:Z, 94:6)
1H NMR (400 MHz, CDCl3)
7.49
1.06
0.13
2.00
0.11
0.24
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
f1 (ppm)

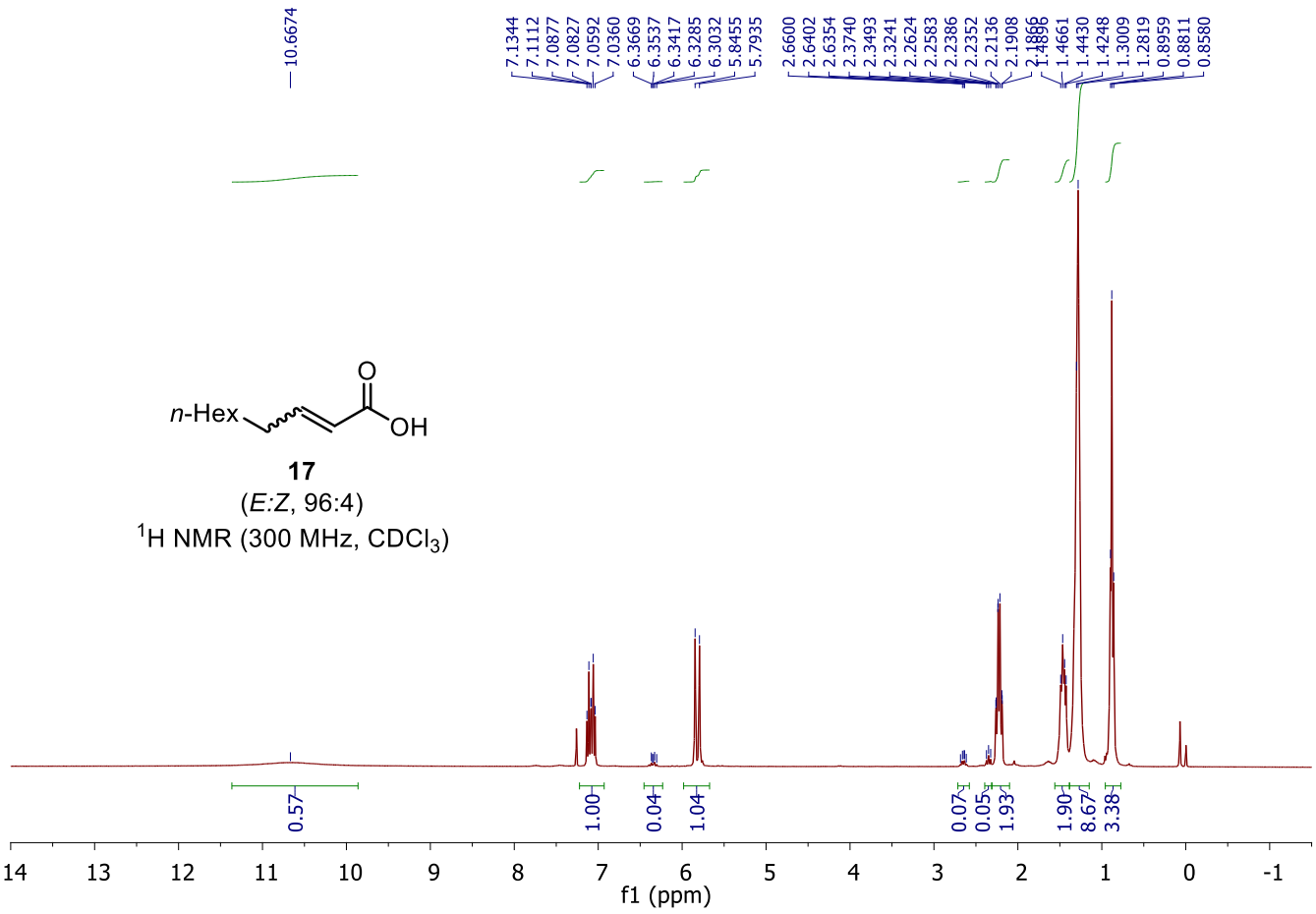

171.8722
150.9639
140.5991
128.5445
128.3421
126.2671
121.2985
34.2003
33.9677
CDCl3
O
OH
14
(E:Z, 94:6)
13C{1H} NMR (101 MHz, CDCl3)
190
170
150
130
110
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)


7.3863
7.3679
7.3491
7.2835
7.2596
7.2390
7.0797
7.0613
7.0419
7.0224
7.0040
6.3330
6.3149
6.3039
6.2977
6.2859
6.2686
5.8708
5.8318
5.8116
2.9985
2.9810
2.9634
2.9458
2.6359
2.6330
2.6176
2.6149
2.5999
2.5971
2.5824
2.5796
2.5661
2.5469
2.5283
1.3628
1.3454
O
OH
15
(E:Z, 90:10)
1H NMR (400 MHz, CDCl3)
2.37
6.04
1.00
0.10
1.10
1.15
1.99
4.35
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
f1 (ppm)


171.7755
150.2555
145.8092
128.5662
126.8092
126.4124
122.0613
40.9933
39.1159
21.6651
CDCl3
O
OH
15
(E:Z, 90:10)
13C{1H} NMR (101 MHz, CDCl3)
190
170
150
130
110
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)


7.2603 7.1053 7.0802 7.0544 7.0284 7.0034 6.3806 6.3419 5.8478 5.8171 5.7958 2.6208 2.6039 2.5853 2.5796 2.2609 2.2561 2.2326 2.2284 2.2136 2.2089 2.2042 2.1895 2.1847 2.1375 2.1332 2.1122 2.1080 2.0868 2.0829 2.0652 2.0609 2.0399 2.0355 1.7485 1.7348 1.7271 1.7136 1.7061 1.6938 1.6836 1.3060 1.2932 1.2874 1.2744 1.2588 1.2464 1.2407 1.2277 1.1412 1.1241 1.1031 1.0946 1.0774 1.0563 1.0315 0.9715 0.9655 0.9492 0.9432 0.9175 0.8988 0.8645 0.8492
7.5 7.0 6.5 6.0 5.5
f1 (ppm)
O
OH
16
(E:Z, 76:24)
1H NMR (400 MHz, CDCl3)
1.00 0.34 1.34 0.66 2.03 1.33 1.51 1.30 3.59 11.78
11.5 10.5 9.5 8.5 7.5 6.5 5.5 4.5 3.5 2.5 1.5 0.5 -0.5
f1 (ppm)


172.0947
152.5365
151.3316
121.8733
119.8522
50.5152
42.0158
38.4164
31.0857
29.9825
29.9432
29.7007
28.9917
22.5217
22.4967
O
OH
16
(E:Z, 76:24)
13C{1H} NMR (101 MHz, CDCl3)
CDCl3
190 170 150 130 110 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)

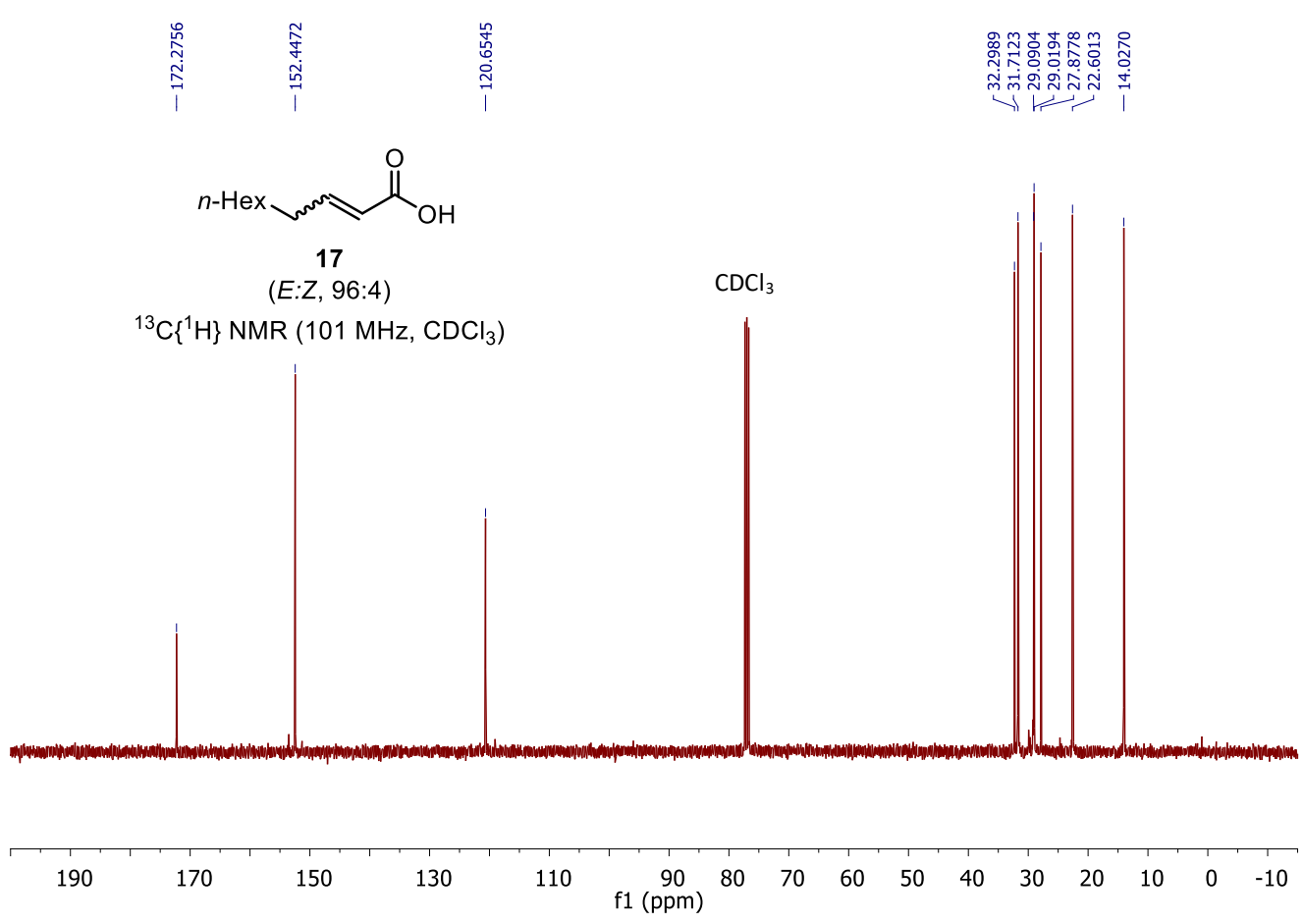


n-Hex, O, OH

17

(*E*:*Z*, 96:4)

^{1}H NMR (300 MHz, $CDCl_3$)

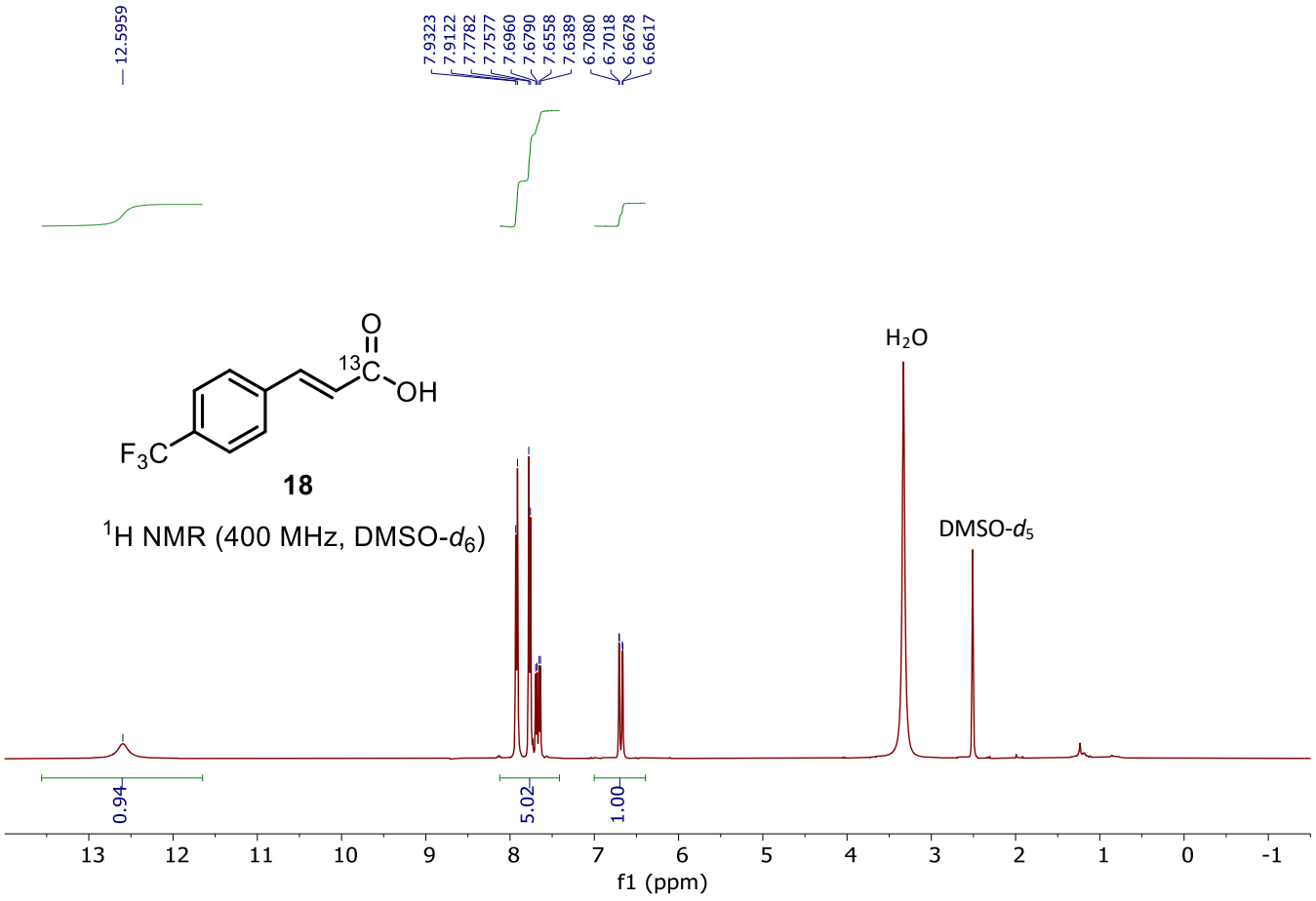


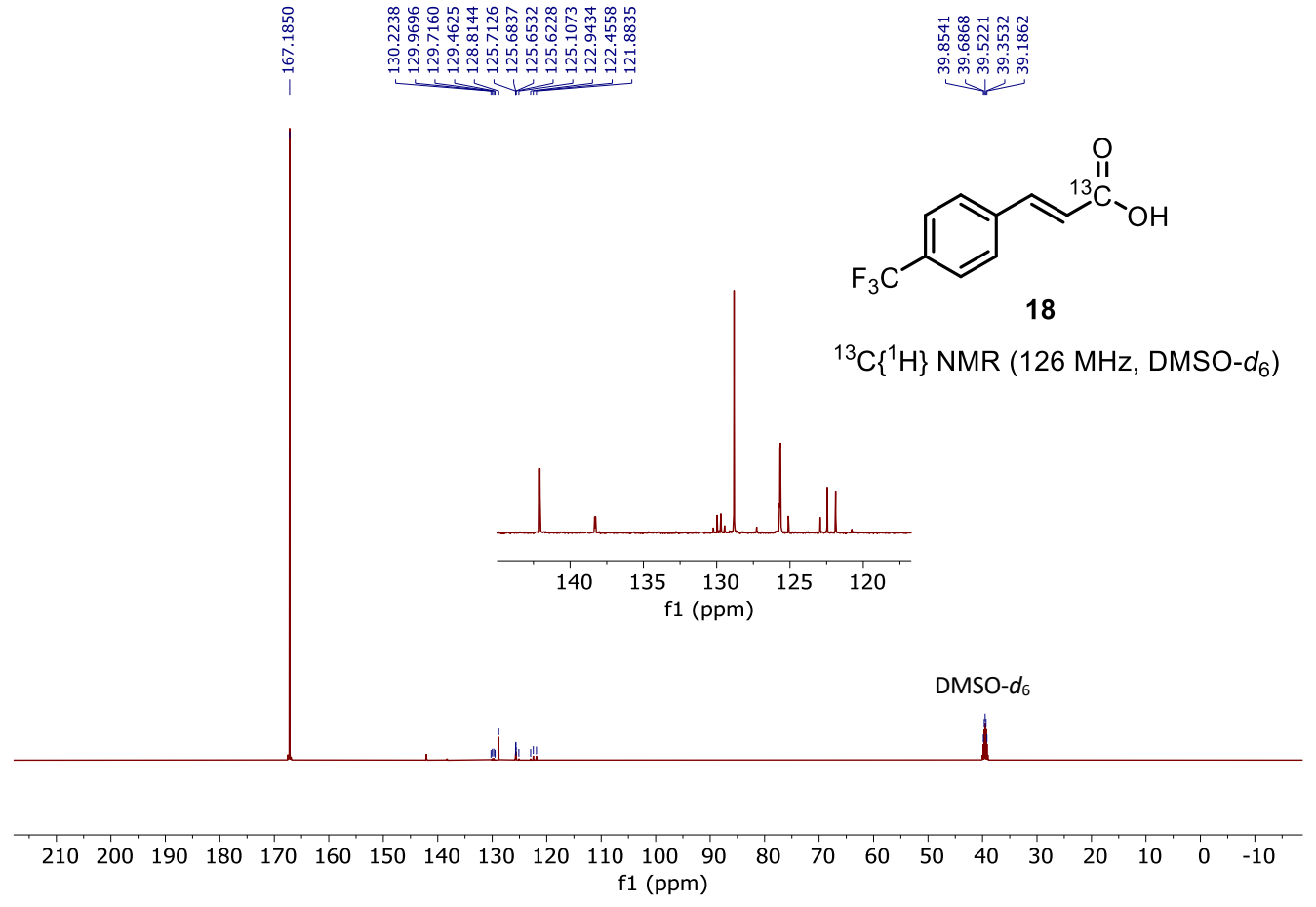
n-Hex, O, OH

17

(*E*:*Z*, 96:4)

$^{13}C\{^{1}H\}$ NMR (101 MHz, $CDCl_3$)


12.5959
7.9323
7.9122
7.7782
7.7577
7.6960
7.6790
7.6558
7.6389
6.7080
6.7018
6.6678
6.6617
O
13C
OH
F3C
18
1H NMR (400 MHz, DMSO-d6)
H2O
DMSO-d5
0.94
5.02
1.00
13 12 11 10 9 8 7 6 5 4 3 2 1 0 -1
f1 (ppm)


167.1850
130.2238
129.9696
129.7160
129.4625
128.8144
125.7126
125.6837
125.6532
125.6228
125.1073
122.9434
122.4558
121.8835
39.8541
39.6868
39.5221
39.3532
39.1862
O
13C
OH
F3C
18
13C{1H} NMR (126 MHz, DMSO-d6)
140 135 130 125 120
f1 (ppm)
DMSO-d6
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)