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Supporting Information

Silica-supported $HClO_4$ promotes catalytic solvent- and metal-free O-H insertion reactions with diazo compounds

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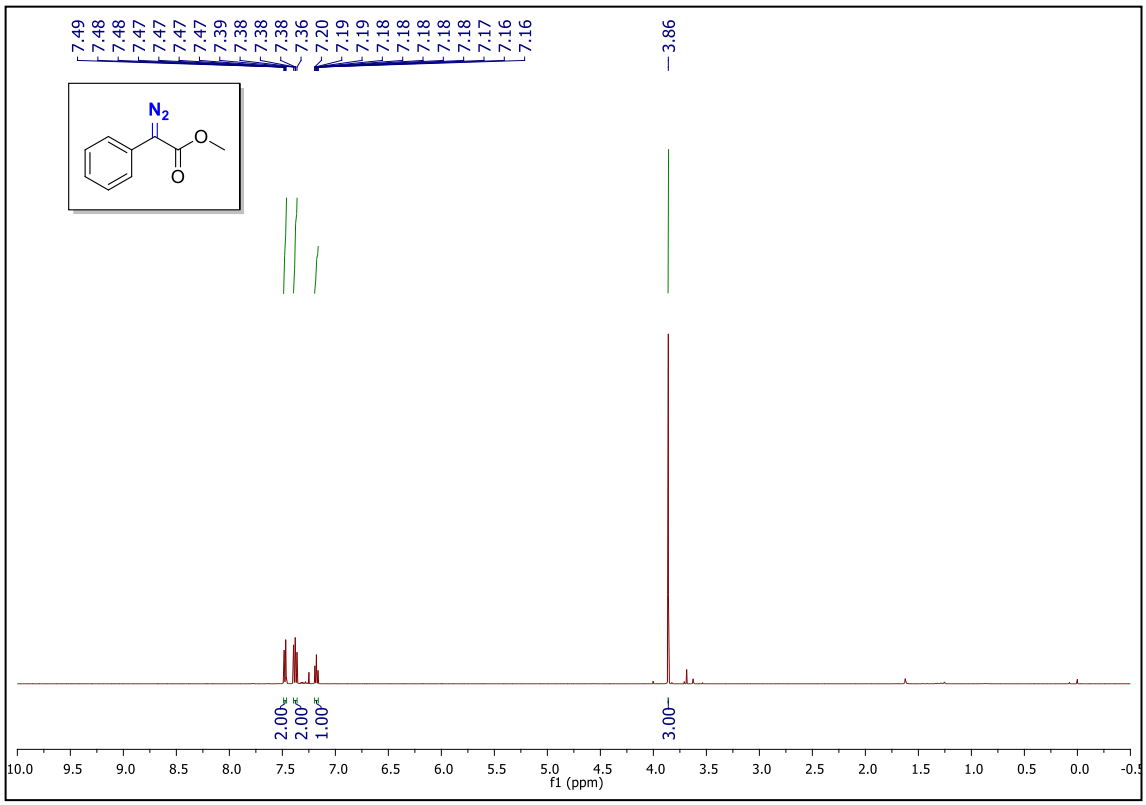
SUMMARY

GENERAL INFORMATION

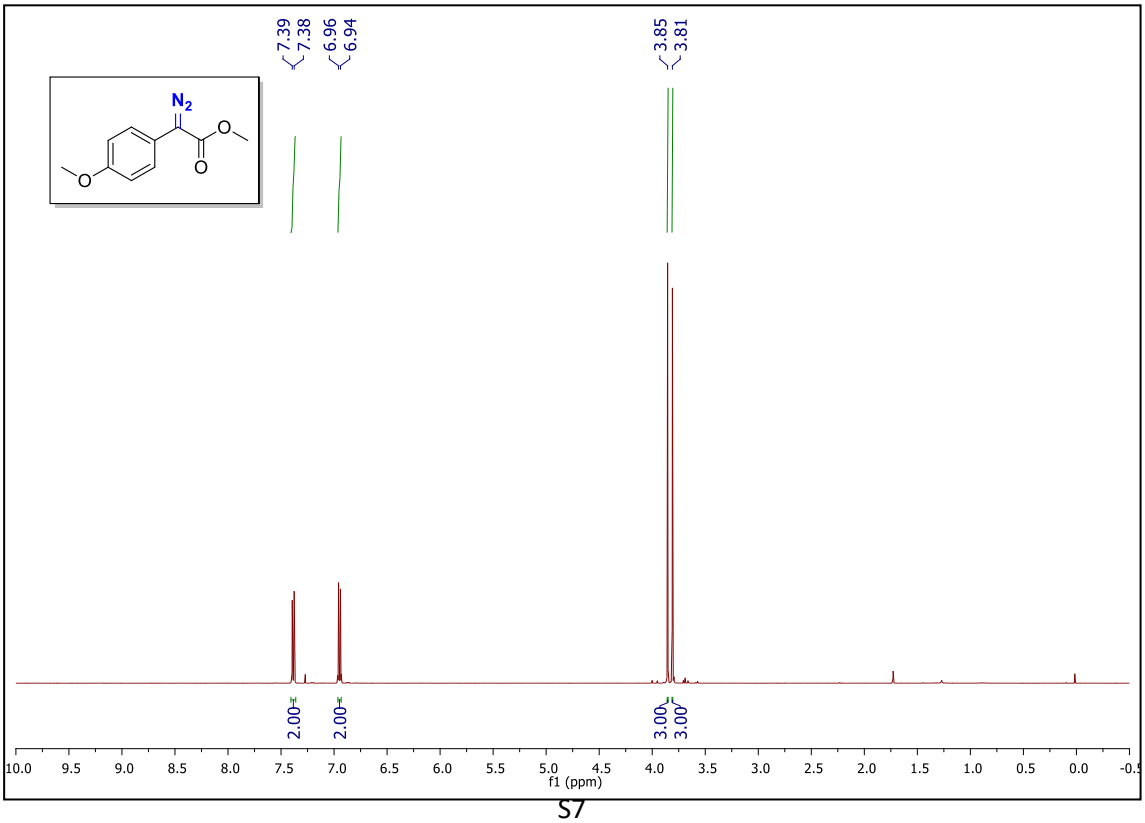
All solvents were dried and distilled prior to use by standard procedures. Reagents were purchased at the highest commercial quality from Sigma-Aldrich and used without further purification, unless otherwise stated. Diazo compounds employed in this work are known and were prepared according to the literature.[33-39] Ethyl diazoacetate is commercially available. Reactions were monitored by thin layer chromatography (TLC), carried out on 0.25 mm silica gel plates using UV light as visualizing agent and potassium permanganate in aqueous KOH for staining. Column chromatography was performed using silica gel 60 (particle size 0.063-0.210 mm). Unless stated otherwise, all the yields refer to isolated products after flash column chromatography. The solvent mixtures employed in TLC analysis and in flash column chromatography purifications are reported as volume by volume and in percentages. Proton nuclear magnetic resonance (^{1}H NMR) spectra were recorded using 500 MHz equipment. For ^{1}H NMR spectra, chemical shifts (δ) are referenced from TMS (0.00 ppm). Coupling constants (*J*) are reported in Hz. For multiplicities the following abbreviations were used: s, singlet; d, doublet; t, triplet; q, quartet; m, multiplet; dd, double doublet; bs, broad singlet; dt, double triplet. Carbon nuclear magnetic resonance (^{13}C NMR) spectra were recorded using a NMR spectrometer at 125 MHz. For ^{13}C NMR spectra, chemical shifts (δ) are given from $CDCl_3$ (77.0 ppm). Infrared spectra were obtained using FT-IR at 4.0 cm^{-1} resolution and are reported in wavenumbers. Melting points were determined using a digital melting point apparatus and were not corrected. High resolution mass spectra (HRMS) were recorded using electron spray ionization (ESI) (Hybrid linear ion trap–orbitrap FT-MS and QqTOF/MS).

SPECTRA DATA

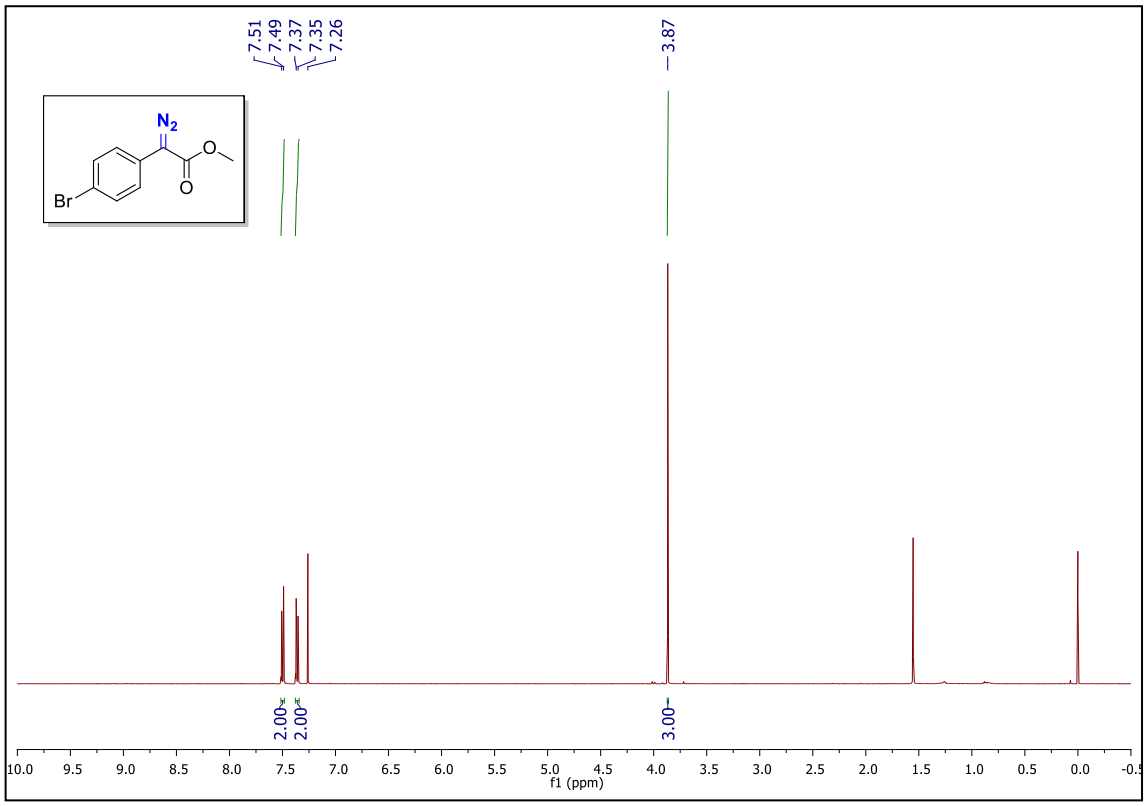
^{1}H NMR (500 MHz, $CDCl_3$) Methyl phenyldiazoacetate **1**



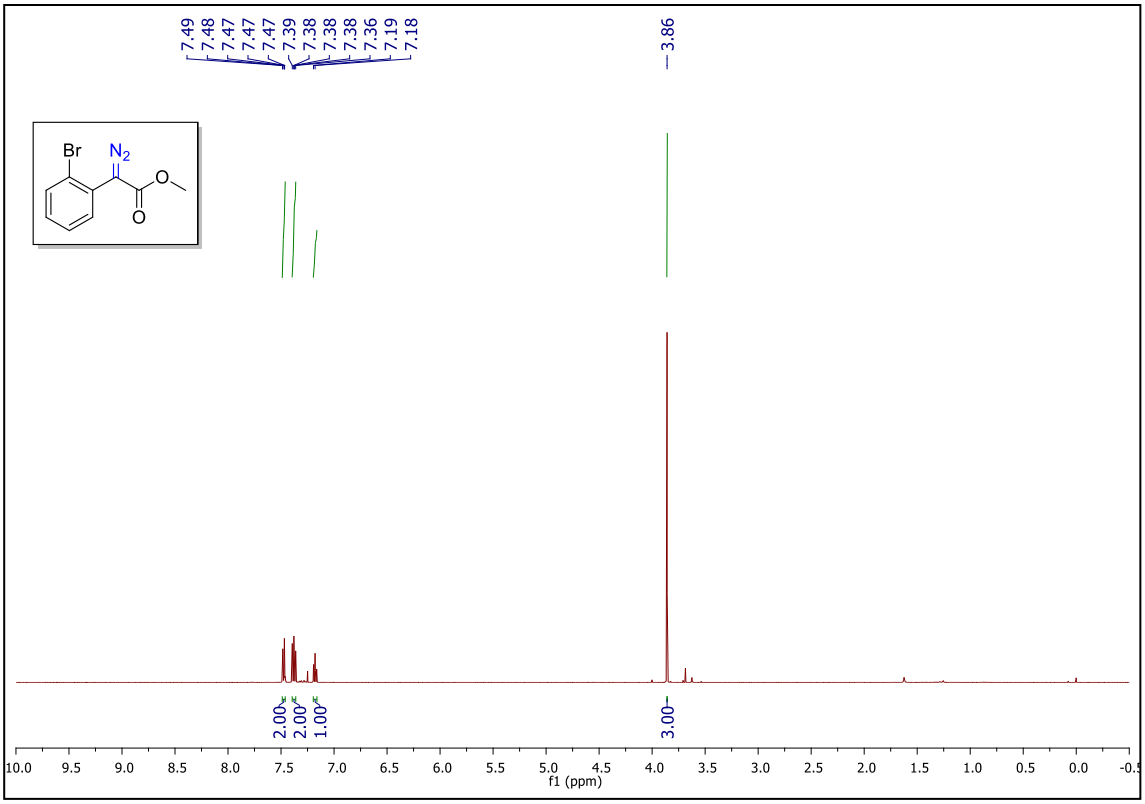
^{1}H NMR (500 MHz, $CDCl_3$) Methyl 2-diazo-2-(4-methoxypheny)acetate **11**



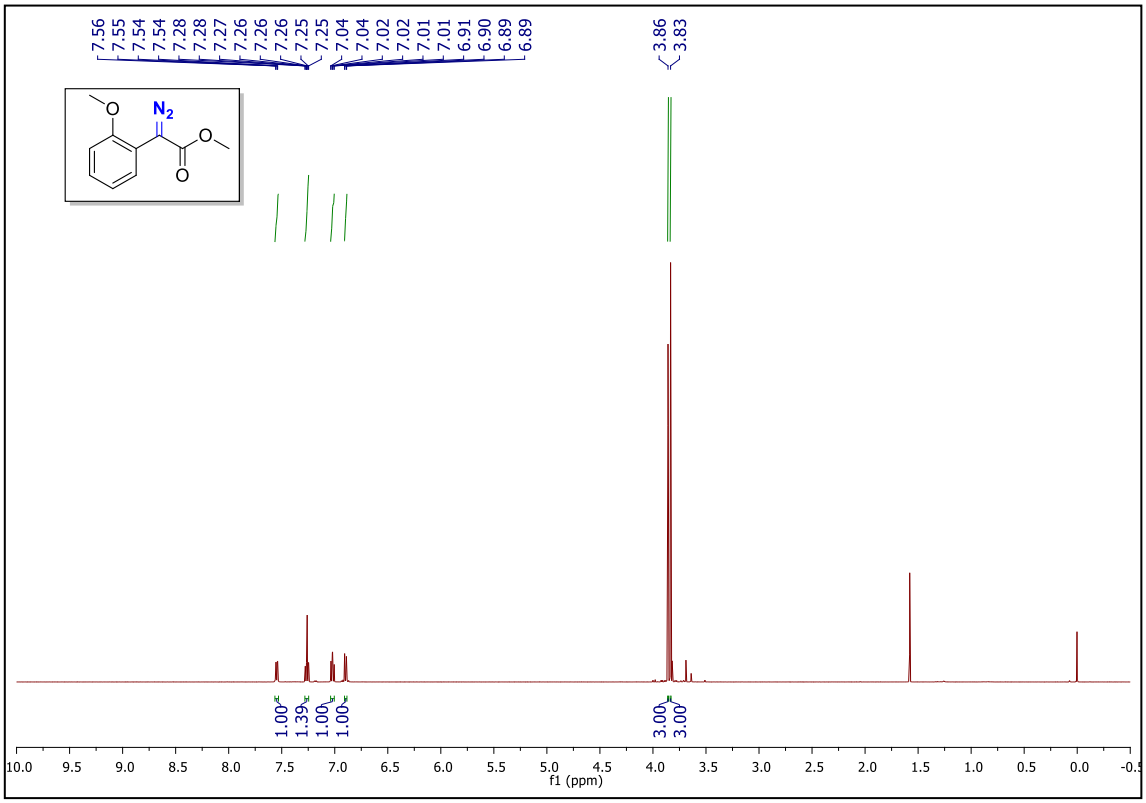
^{1}H NMR (500 MHz, $CDCl_3$) Methyl 4-bromophenyldiazoacetate **12**



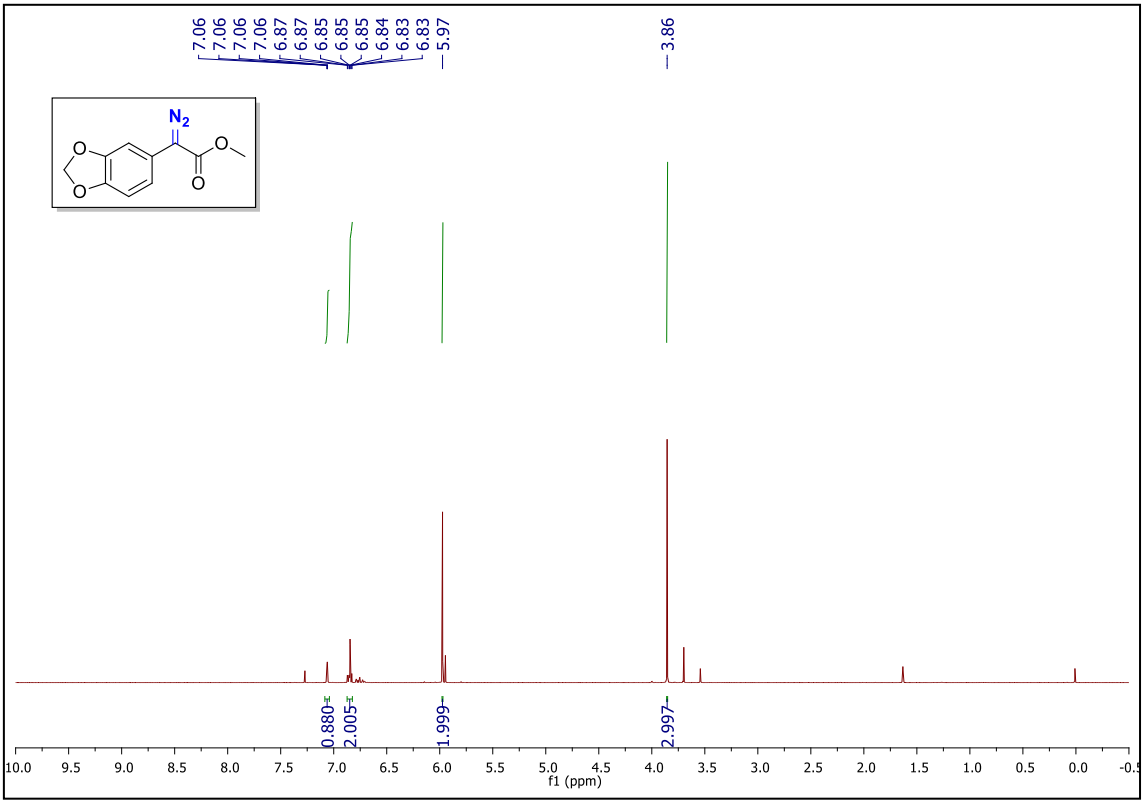
^{1}H NMR (500 MHz, $CDCl_3$) Methyl 2-(2-bromophenyl)-2-diazoacetate **13**



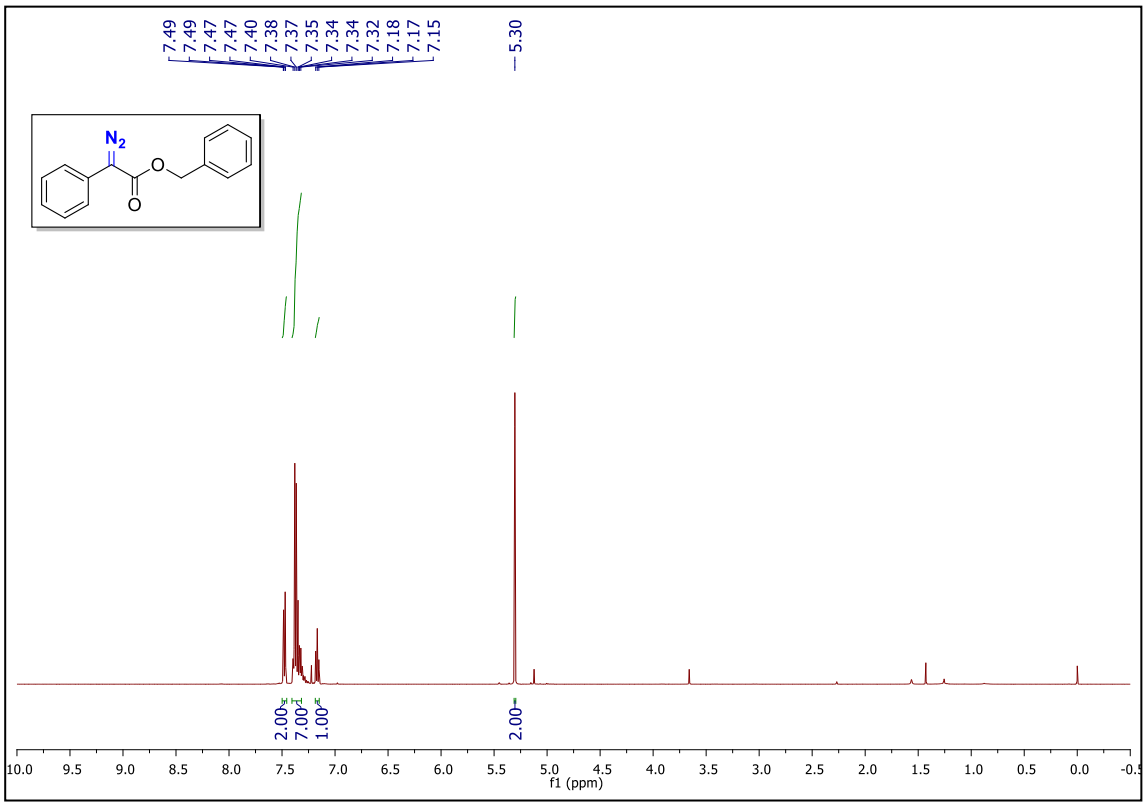
^{1}H NMR (500 MHz, $CDCl_3$) Methyl 2-methoxyphenyldiazoacetate **14**



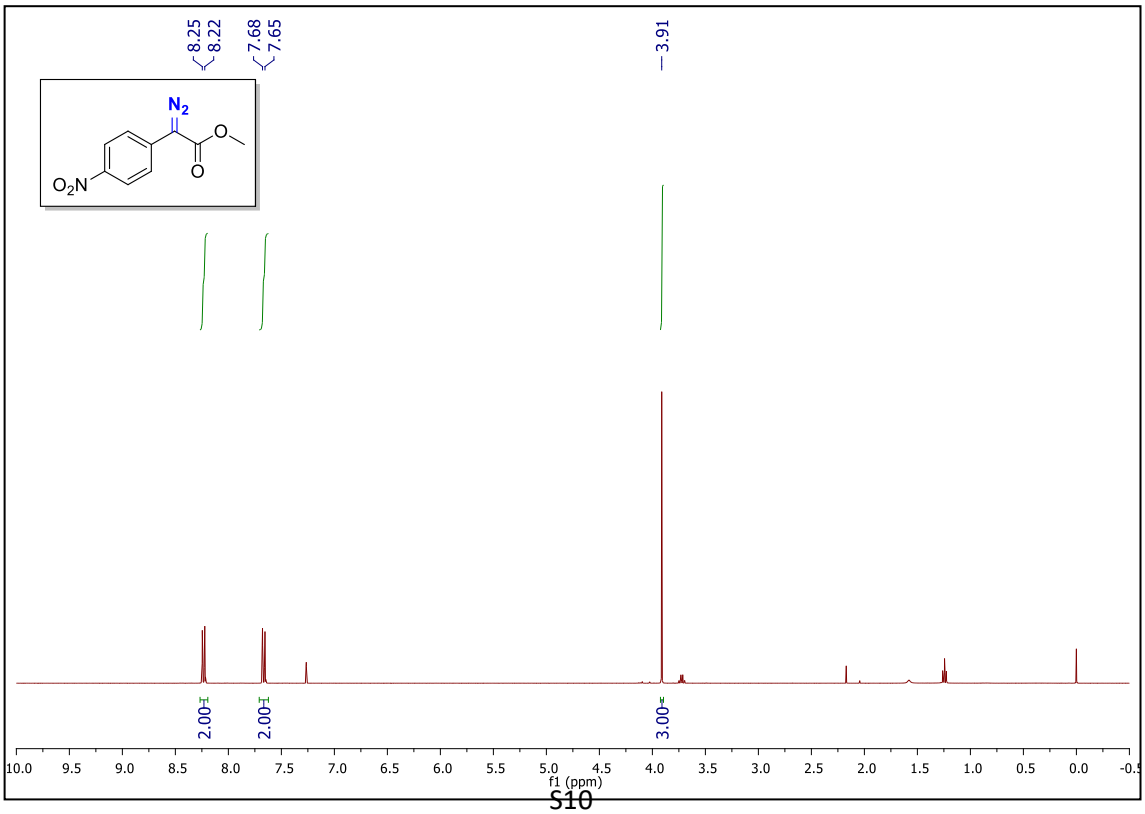
^{1}H NMR (500 MHz, $CDCl_3$) Methyl (1,3-benzodioxole)diazoacetate **15**



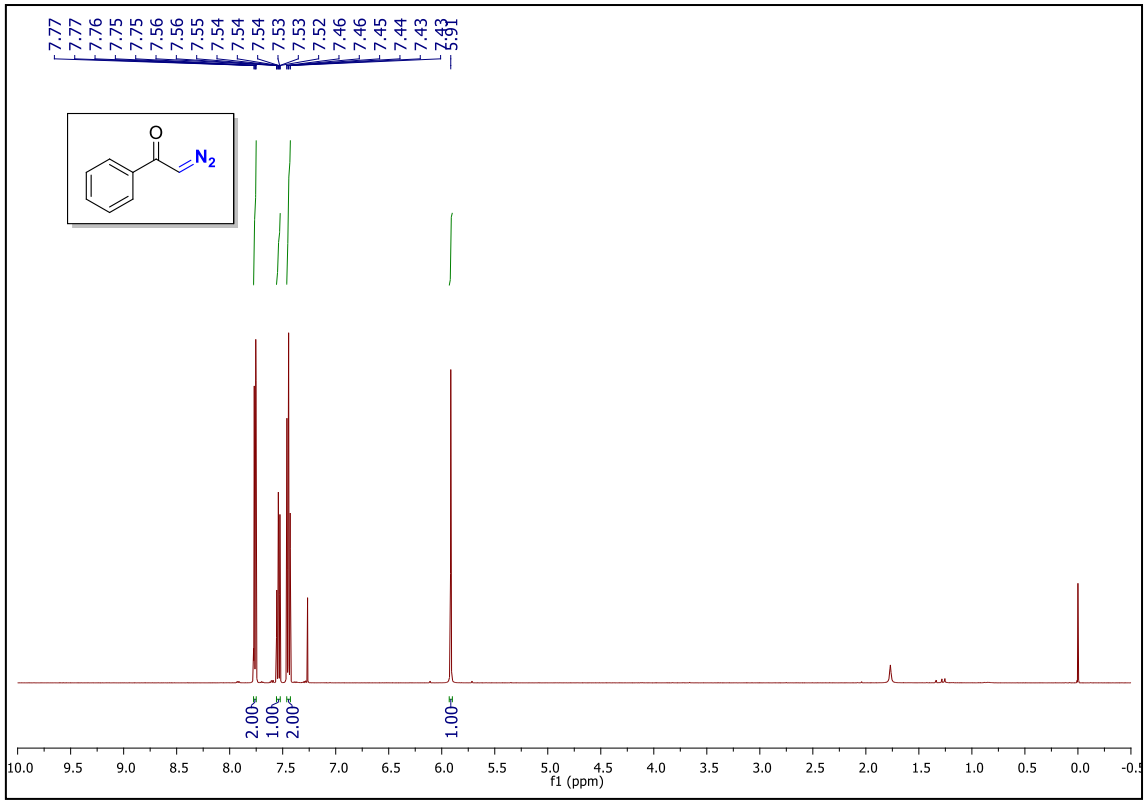
^{1}H NMR (500 MHz, $CDCl_3$) Benzyl 2-diazo-2-phenylacetate **16**



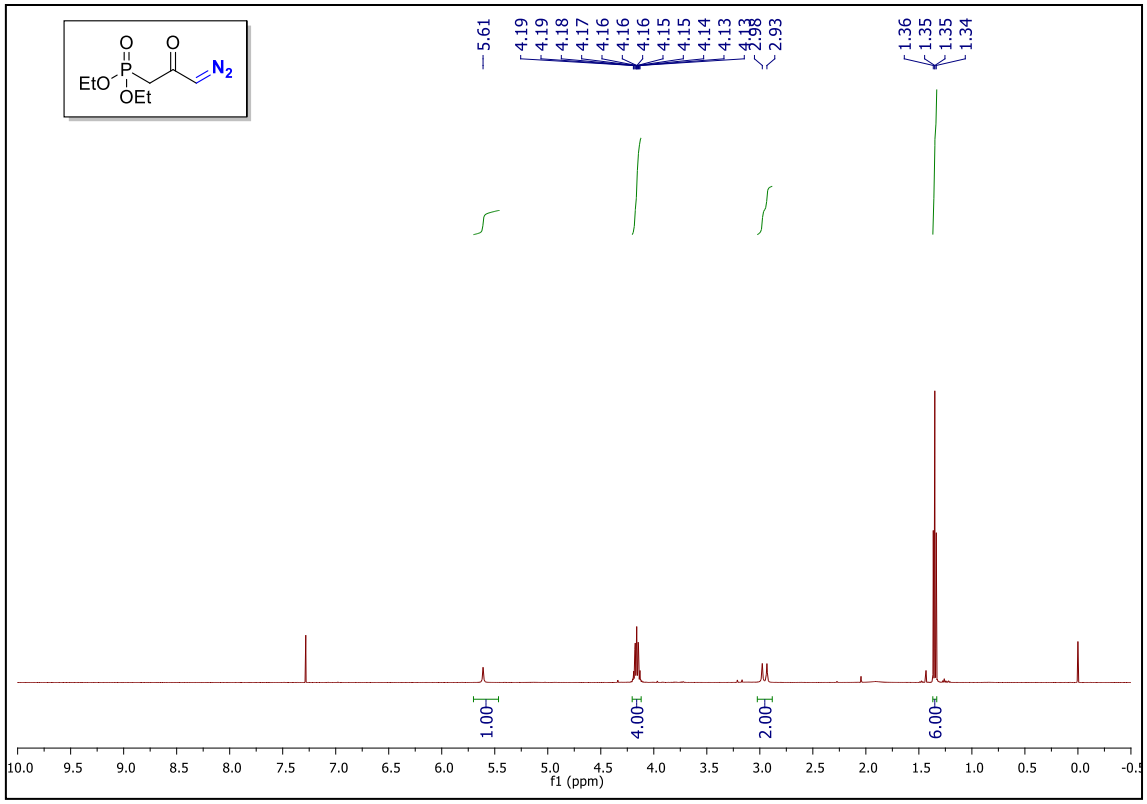
^{1}H NMR (500 MHz, $CDCl_3$) Methyl 4-nitrophenyldiazoacetate **17**



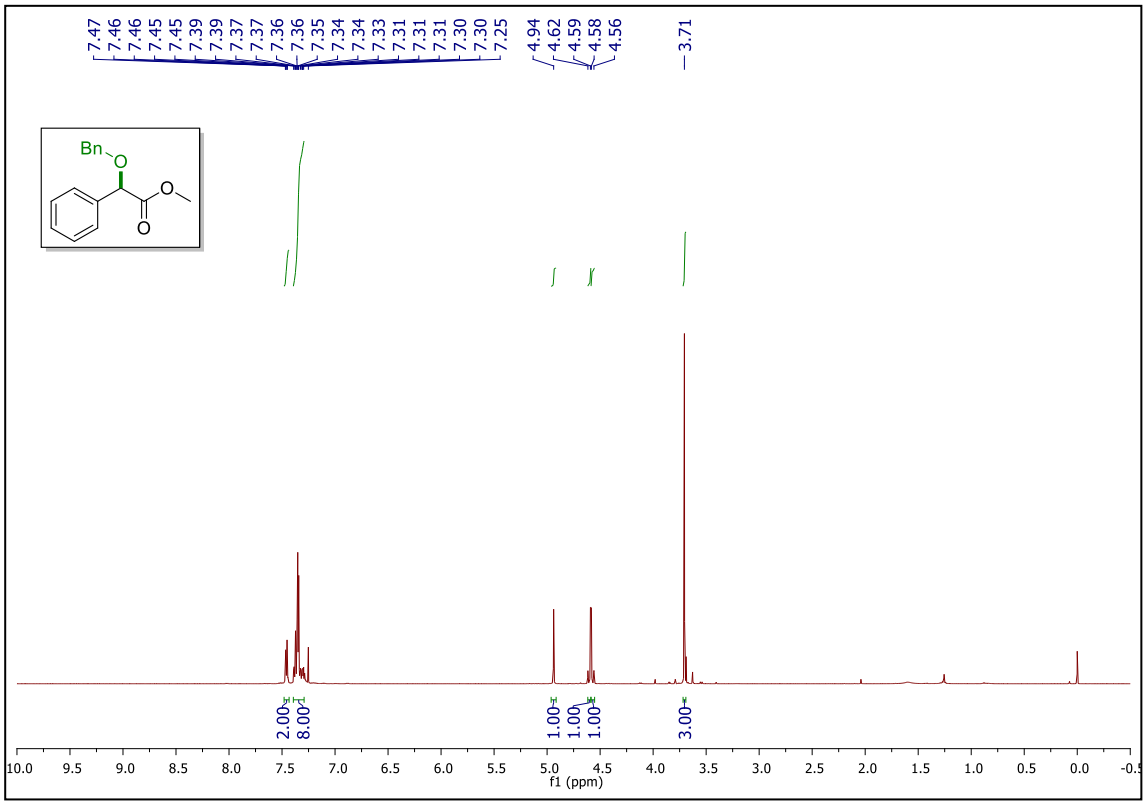
^{1}H NMR (500 MHz, $CDCl_3$) 2-diazo-1-phenylethanone **18**



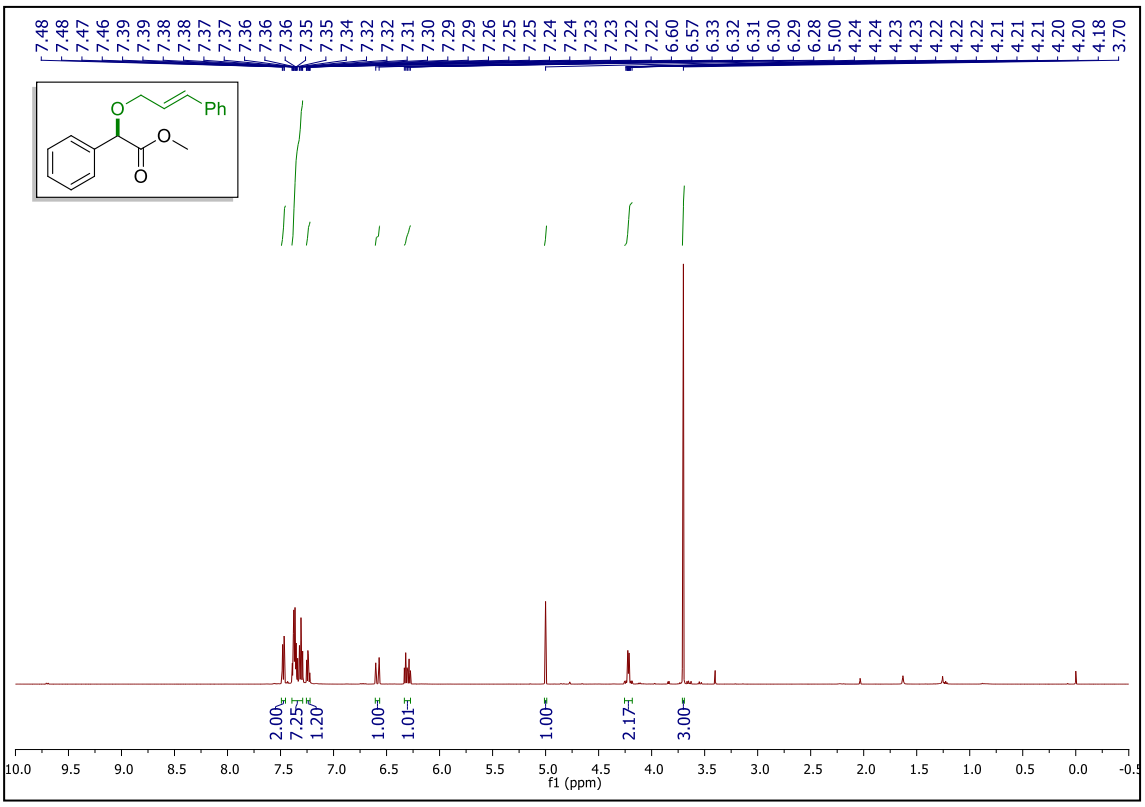
^{1}H NMR (500 MHz, $CDCl_3$) 3-diazo-2-oxopropylphosphonate **19**



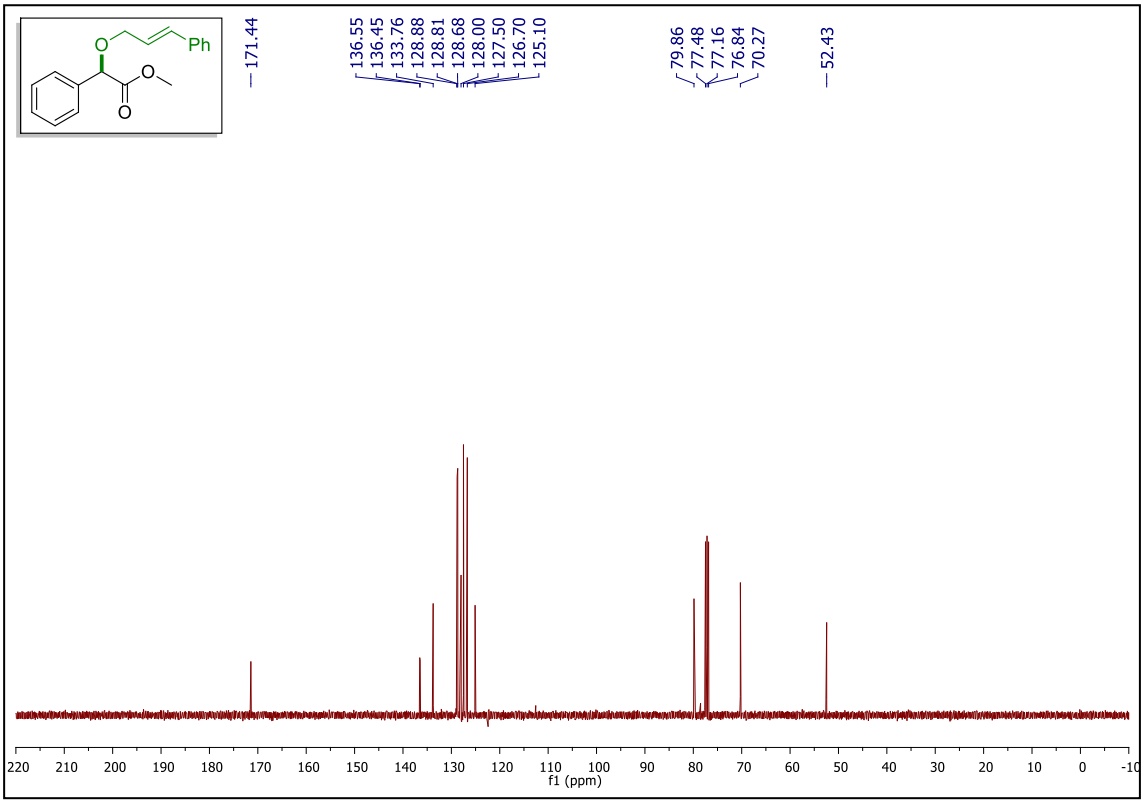
^{1}H NMR (500 MHz, $CDCl_3$) Methyl 2-benzyloxy-2-phenylacetate **2**



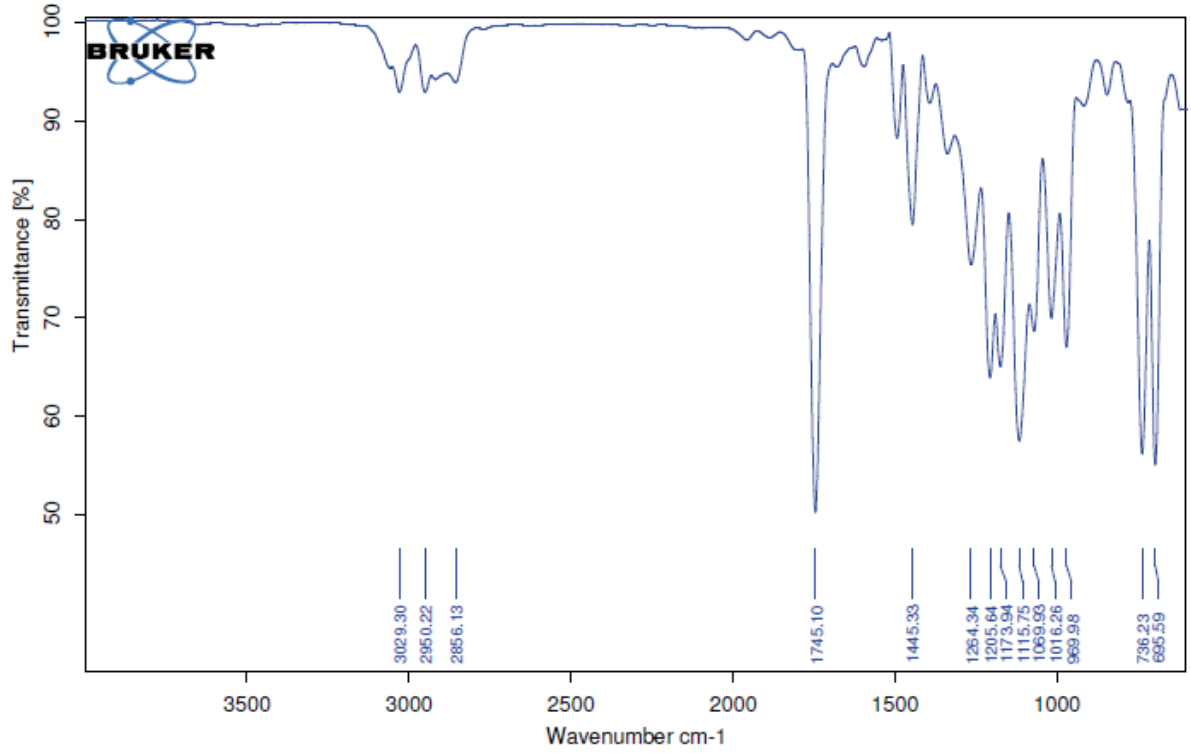
^{1}H NMR (500 MHz, $CDCl_3$) Methyl 2-(cinnamyloxy)-2-phenylacetate **3**



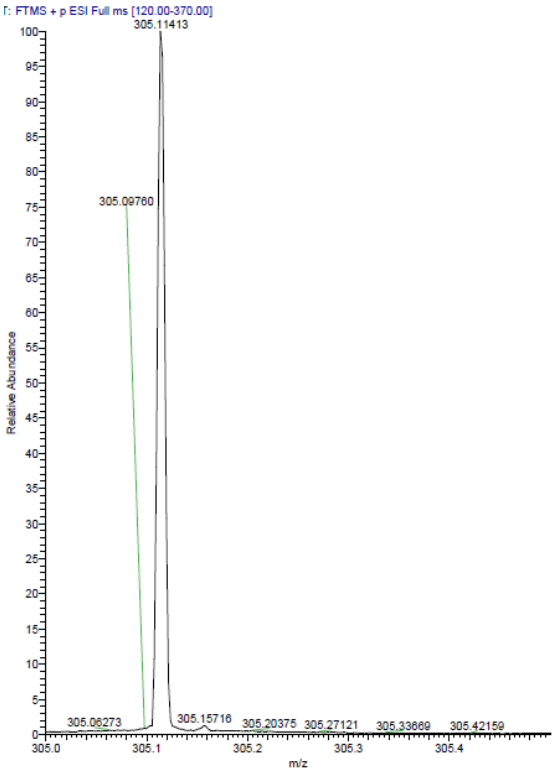
^{13}C NMR (125 MHz, $CDCl_3$) Methyl 2-(cinnamyloxy)-2-phenylacetate **3**



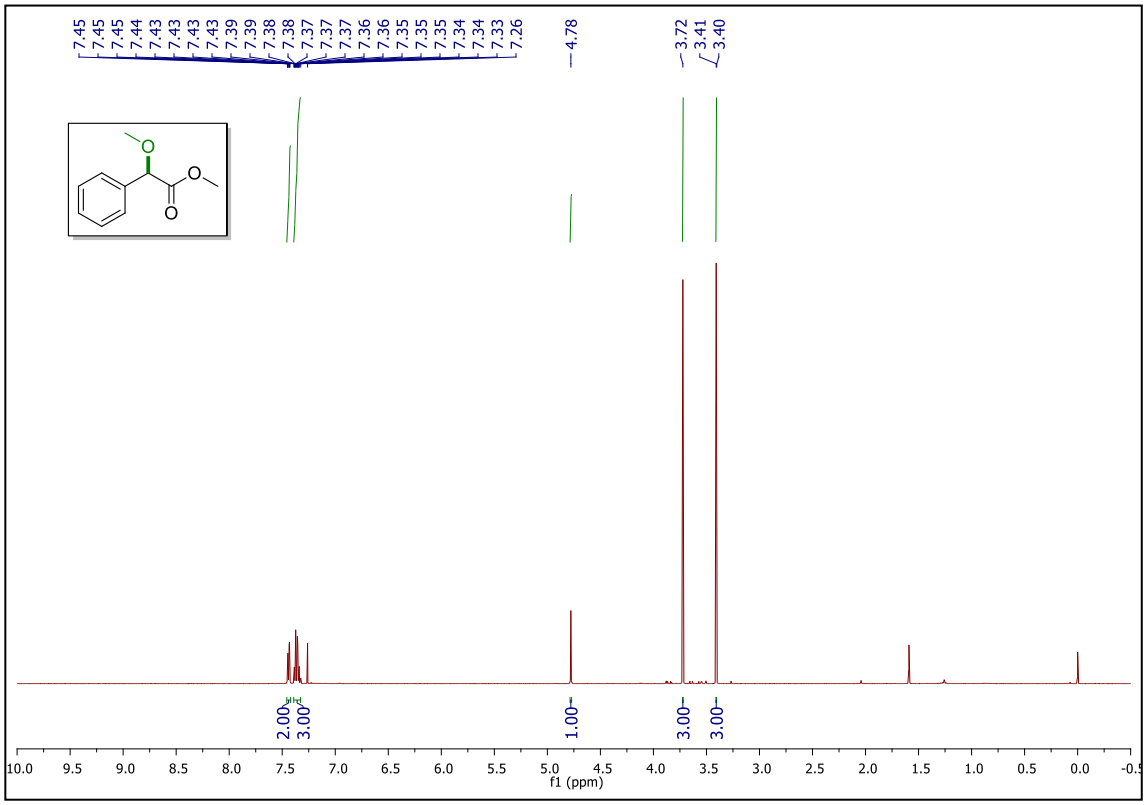
IR Methyl 2-(cinnamyloxy)-2-phenylacetate **3**



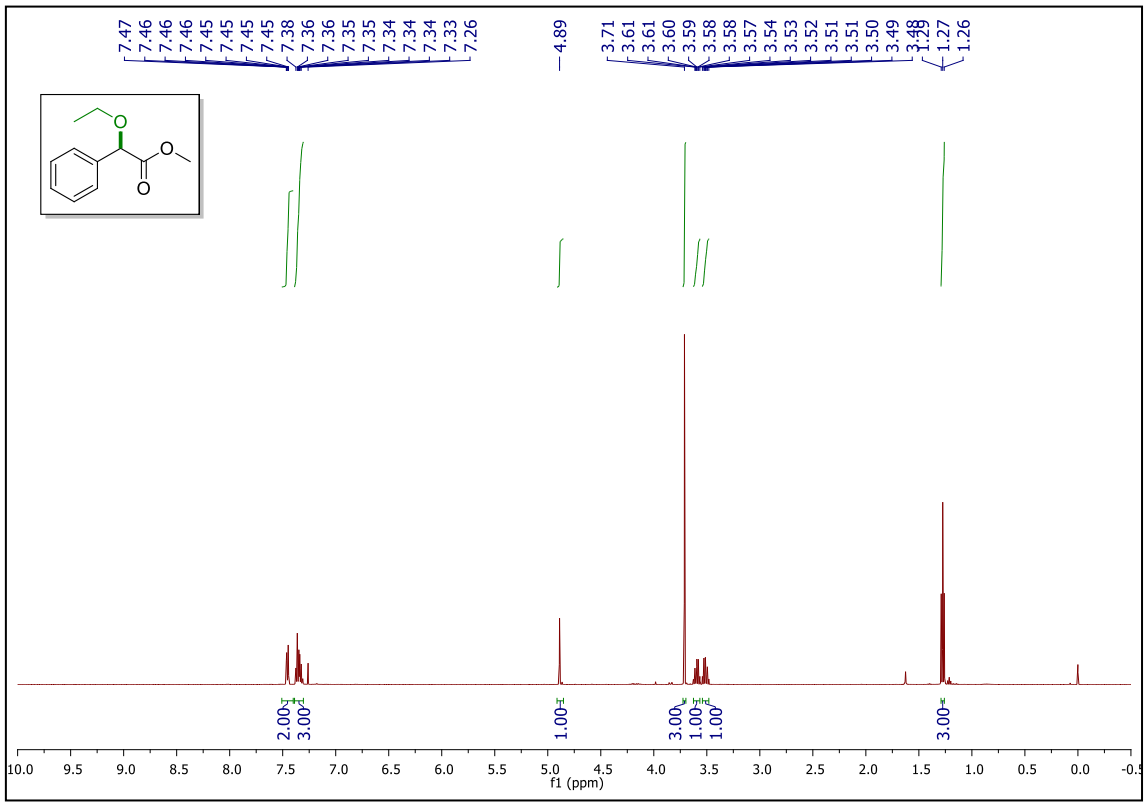
HRMS (ESI-TOF) Methyl 2-(cinnamyloxy)-2-phenylacetate **3**



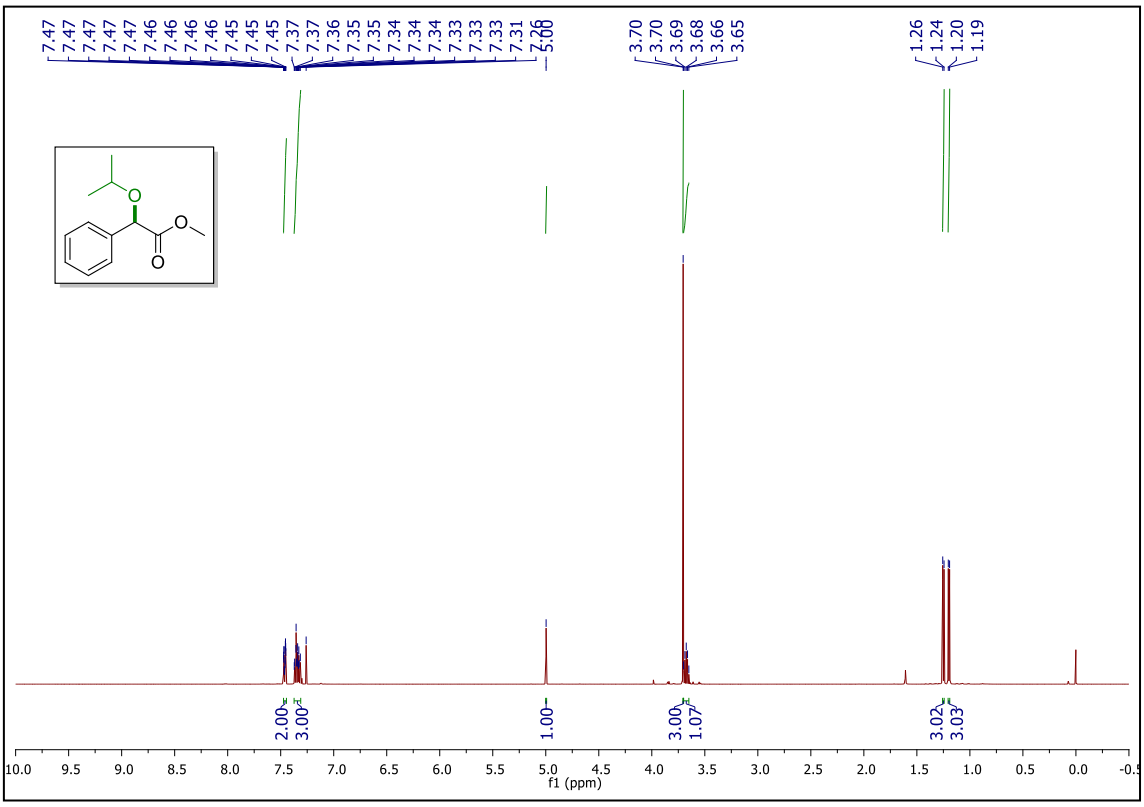
^{1}H NMR (500 MHz, $CDCl_3$) Methyl 2-methoxy-2-phenylacetate **4**



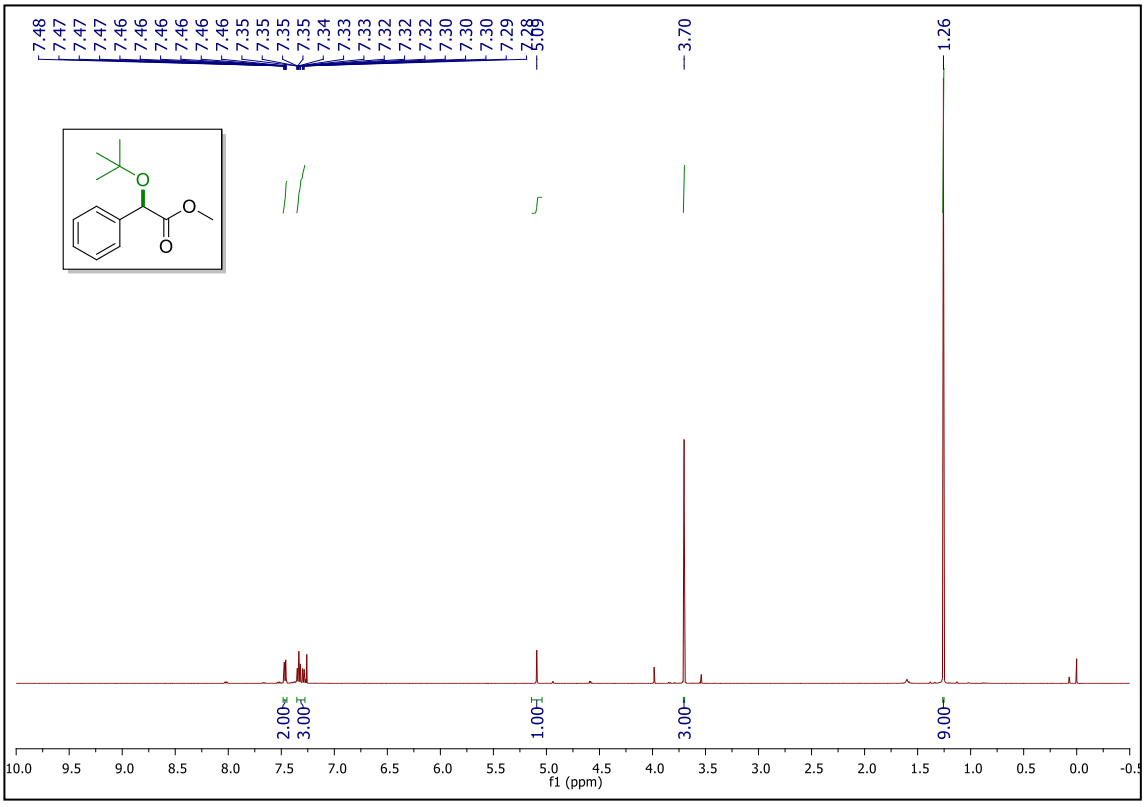
^{1}H NMR (500 MHz, $CDCl_3$) Ethoxy-phenyl-acetic acid methyl ester **5**



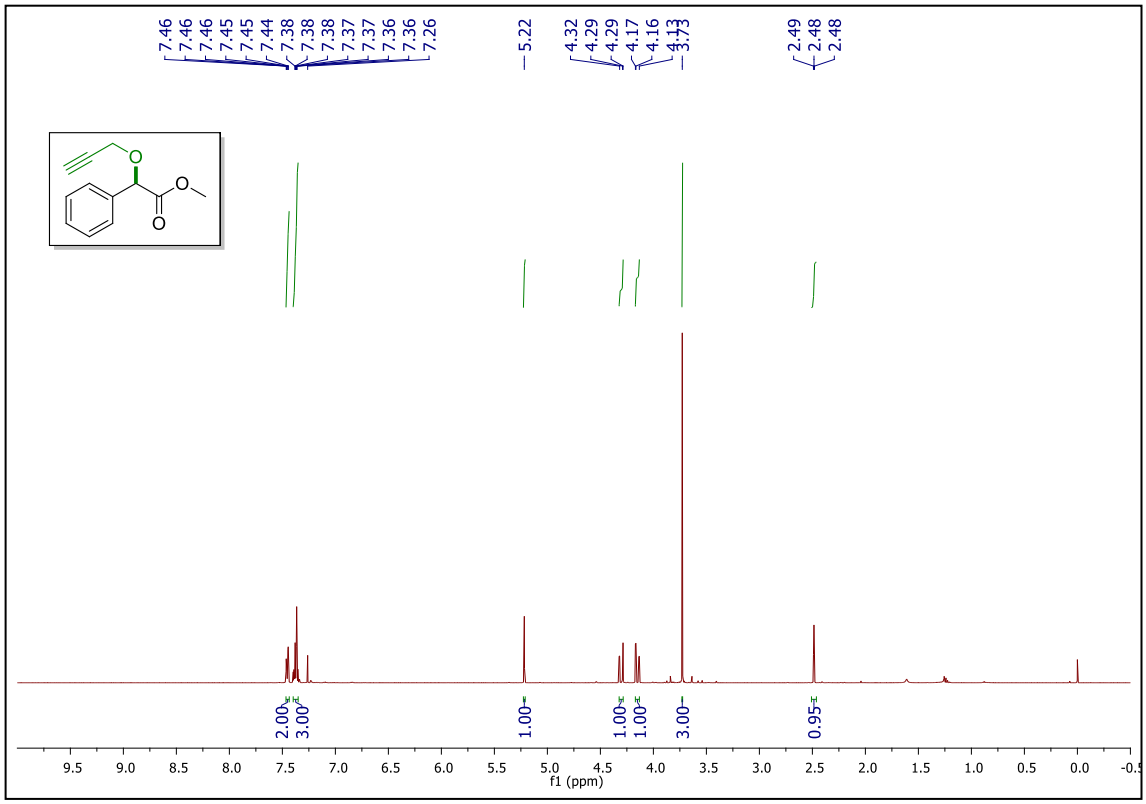
^{1}H NMR (500 MHz, $CDCl_3$) Isopropoxy-phenyl-acetic acid methyl ester **6**



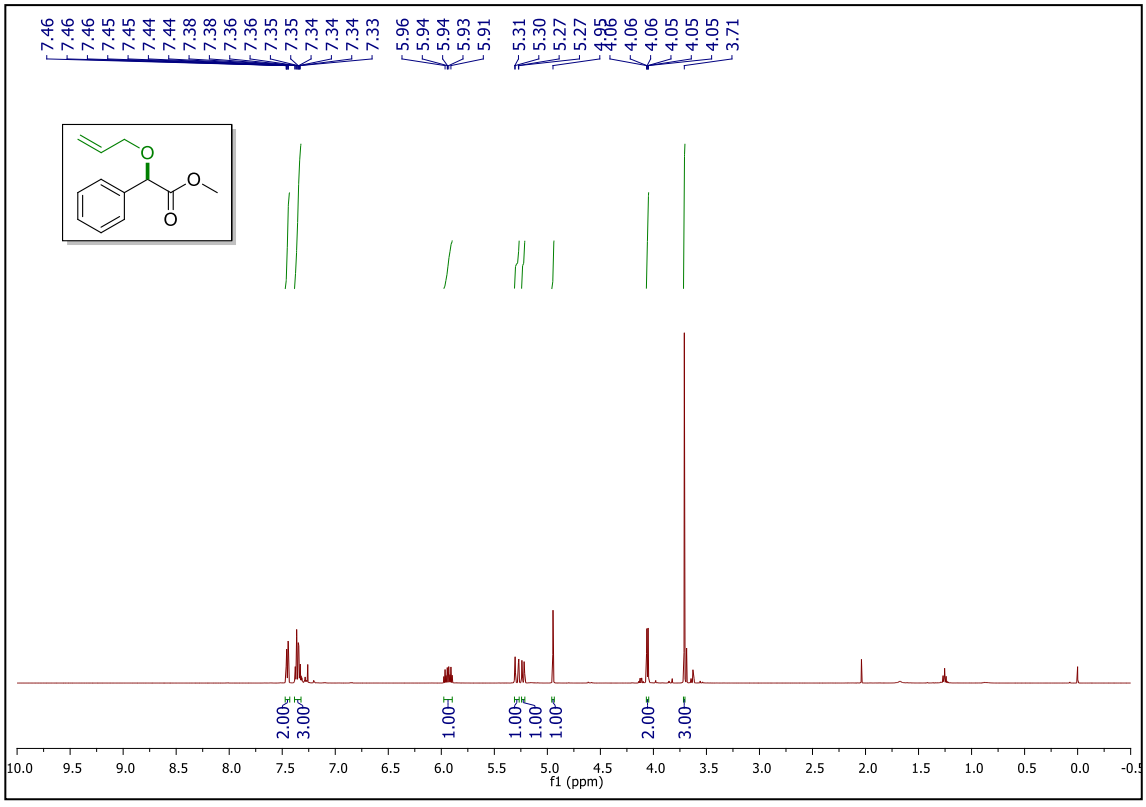
^{1}H NMR (500 MHz, $CDCl_3$) Methyl 2-tert-butoxy-2-phenylacetate **7**



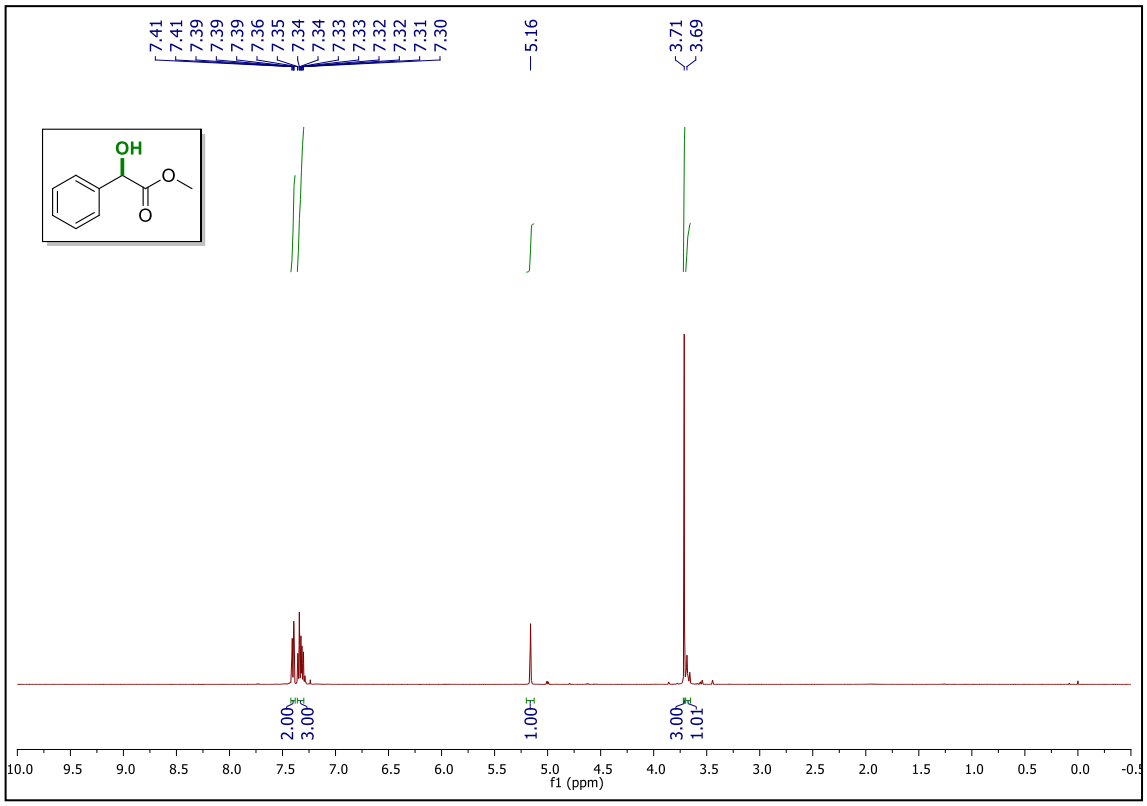
^{1}H NMR (500 MHz, $CDCl_3$) Methyl 2-phenyl-2-(prop-2-ynyloxy)acetate **8**



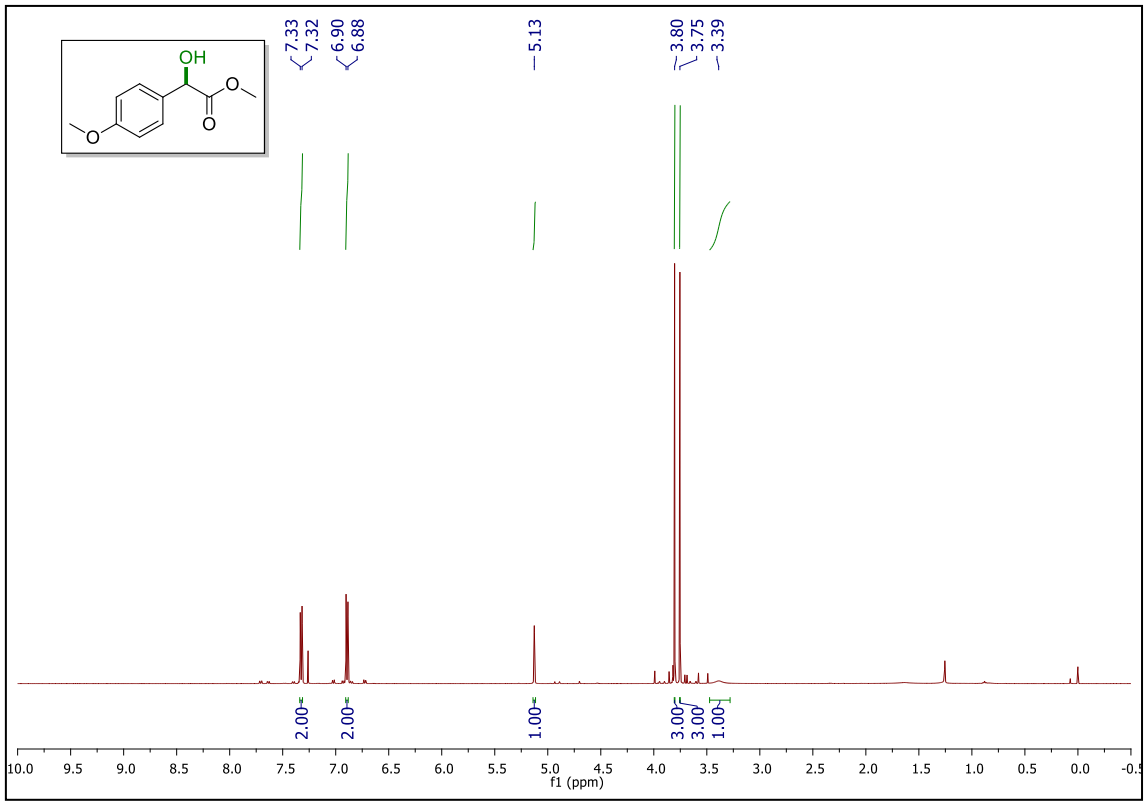
^{1}H NMR (500 MHz, $CDCl_3$) Methyl 2-(allyloxy)-2-phenylacetate **9**



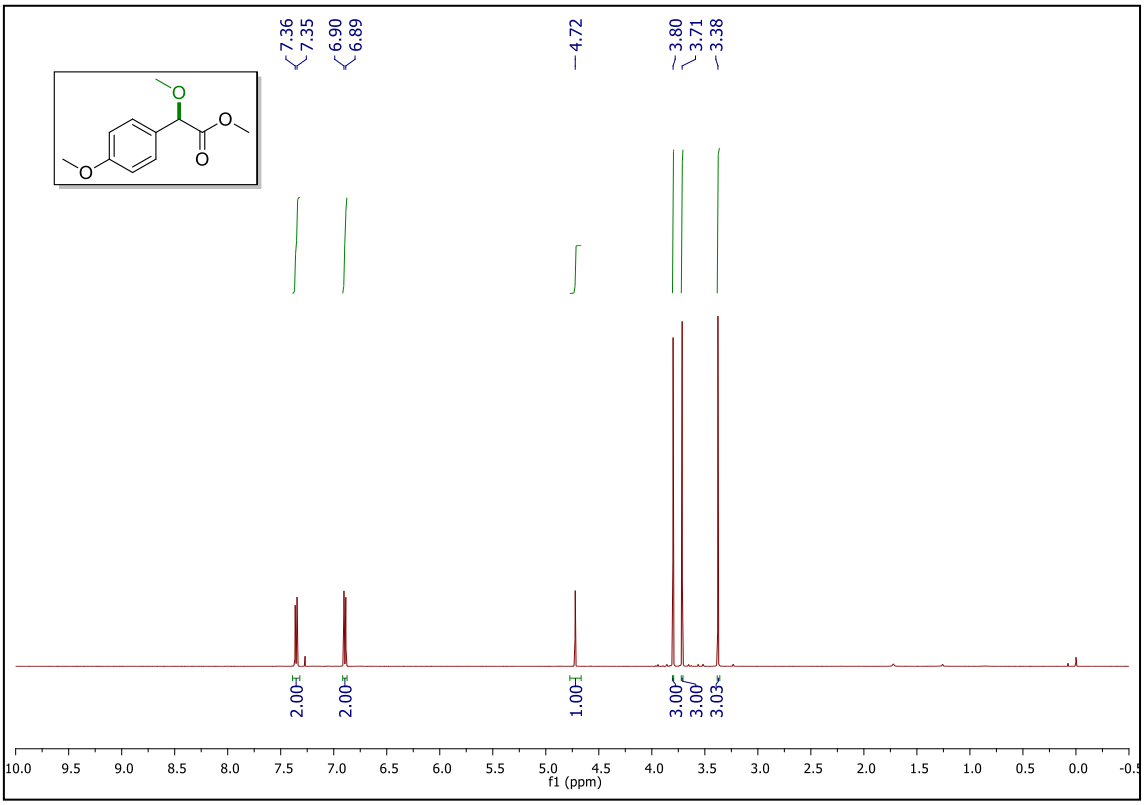
^{1}H NMR (500 MHz, $CDCl_3$) Methyl 2-hydroxy-2-phenylacetate **10**



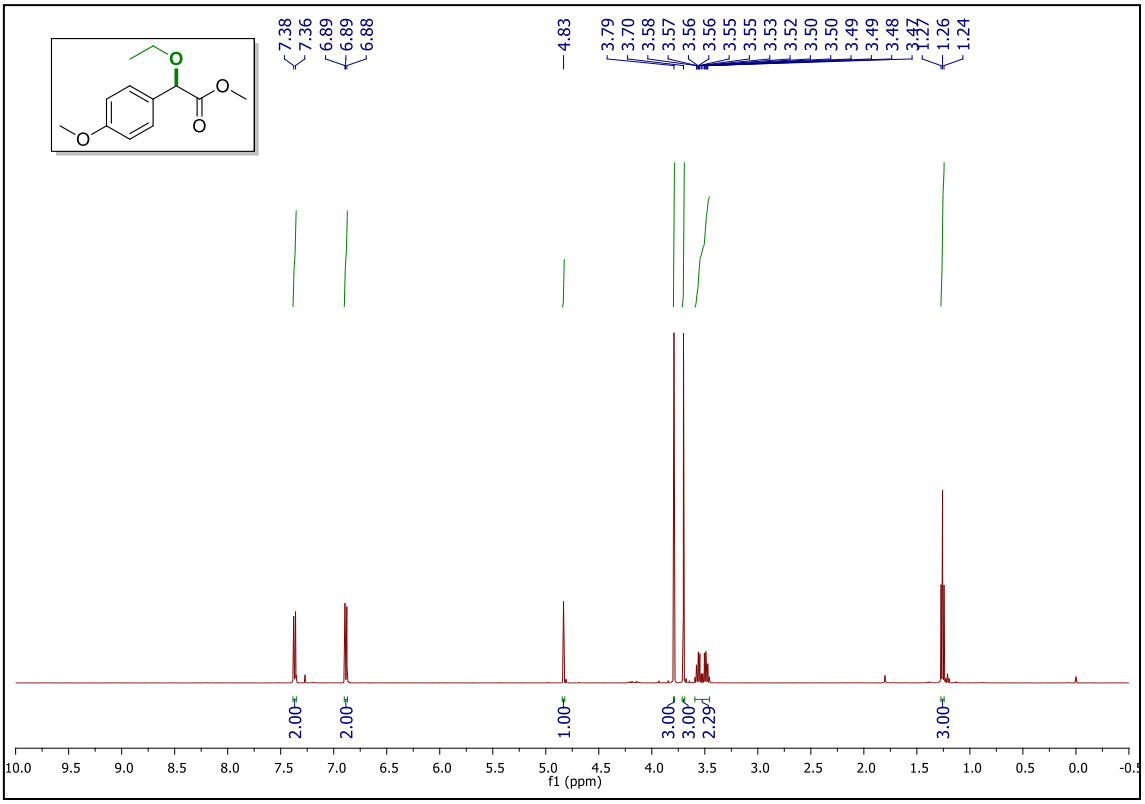
^{1}H NMR (500 MHz, $CDCl_3$) Methyl 2-hydroxy-2-(4-methoxyphenyl)acetate **21**



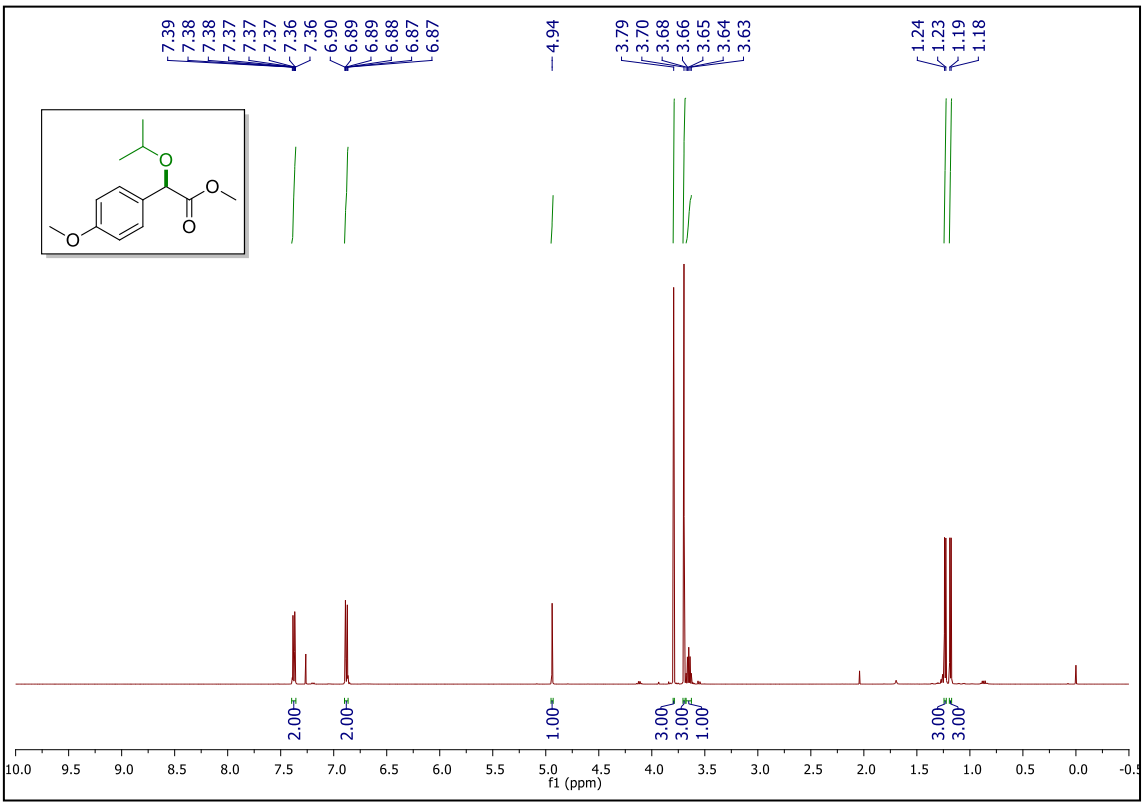
^{1}H NMR (500 MHz, $CDCl_3$) Methyl 2-methoxy-2-(4-methoxyphenyl)acetate **22**



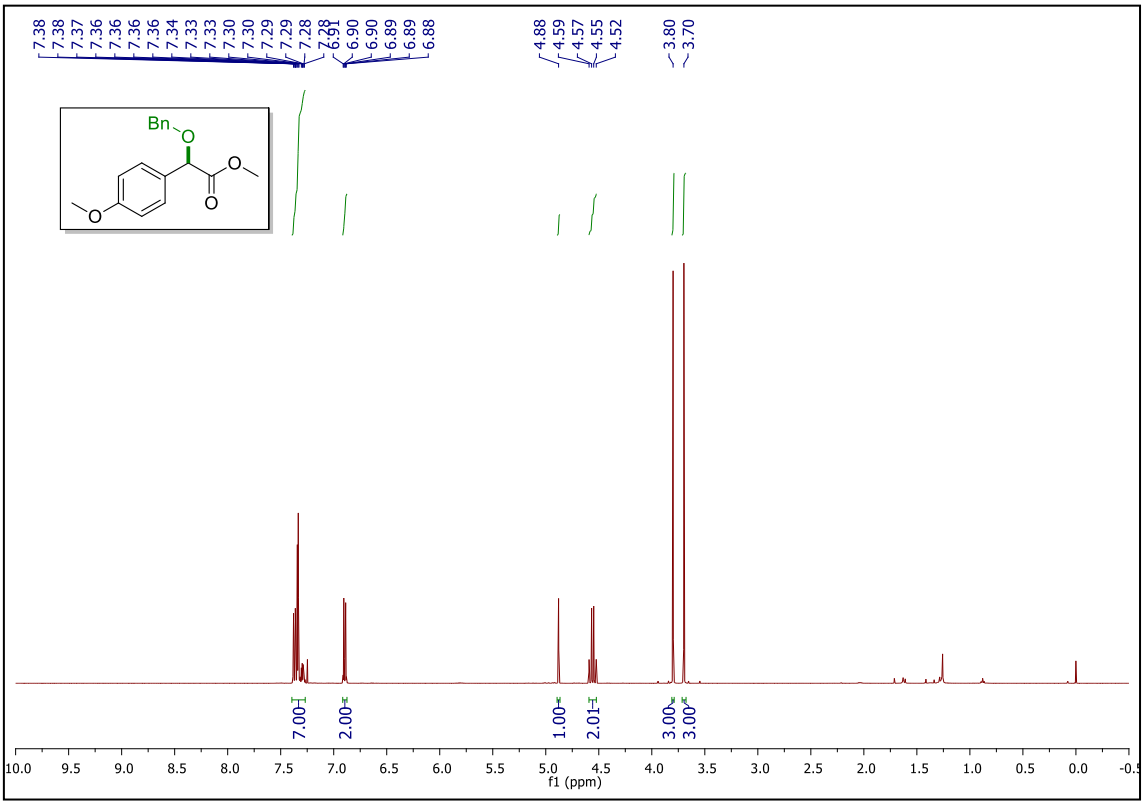
^{1}H NMR (500 MHz, $CDCl_3$) Methyl 2-ethoxy-2-(4-methoxy phenyl)acetate **23**



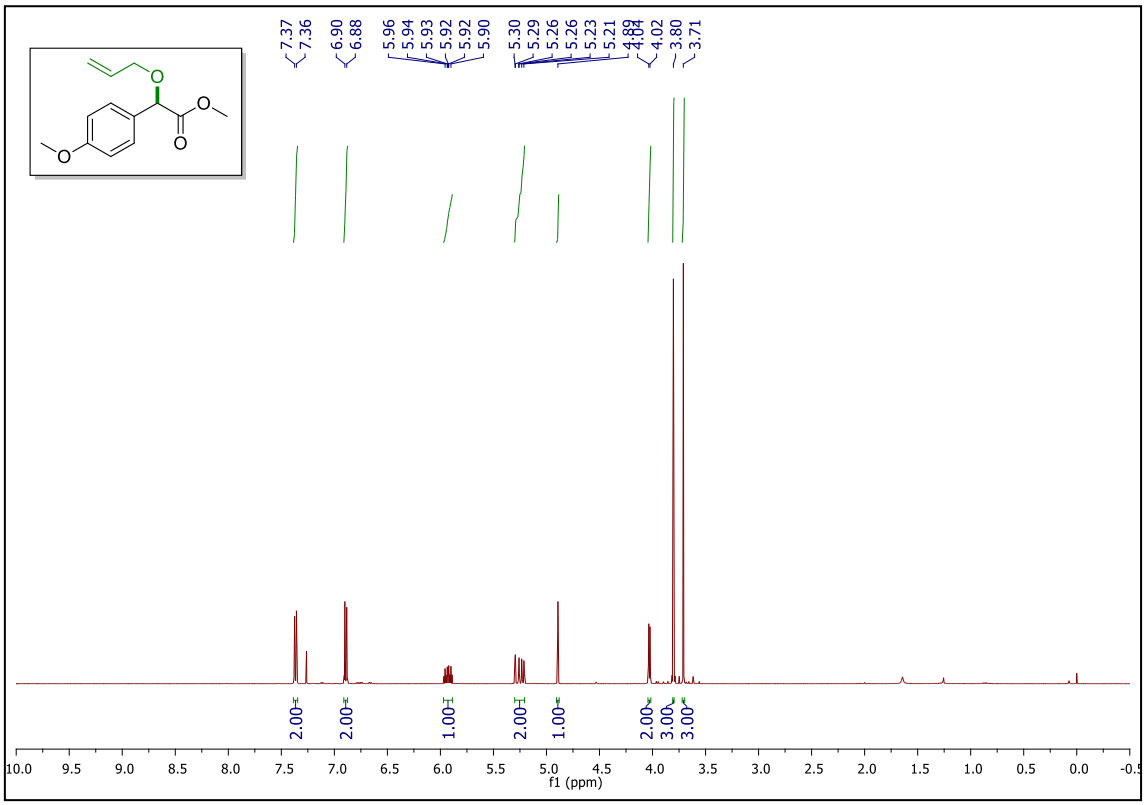
^{1}H NMR (500 MHz, $CDCl_3$) Methyl 2-isopropanoxy-2-(4-methoxyphenyl)acetate **24**



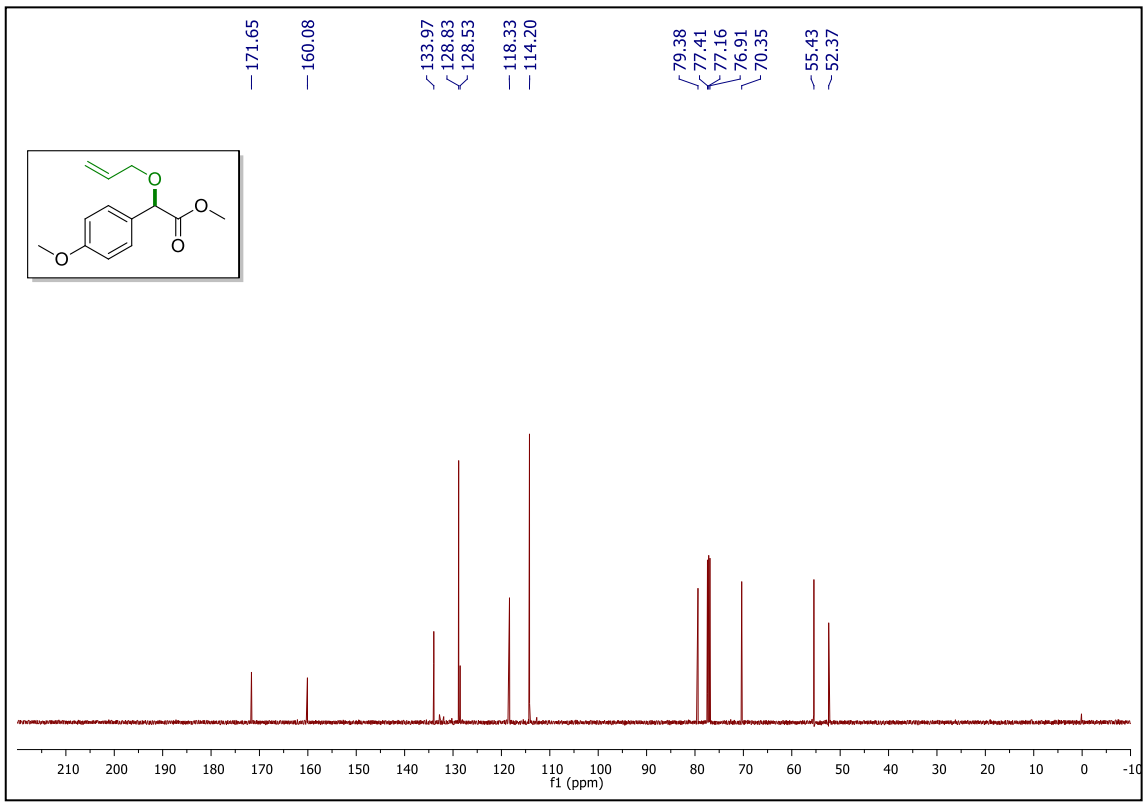
^{1}H NMR (500 MHz, $CDCl_3$) Methyl 2-(benzyloxy)-2-(4-methoxyphenyl)acetate **25**



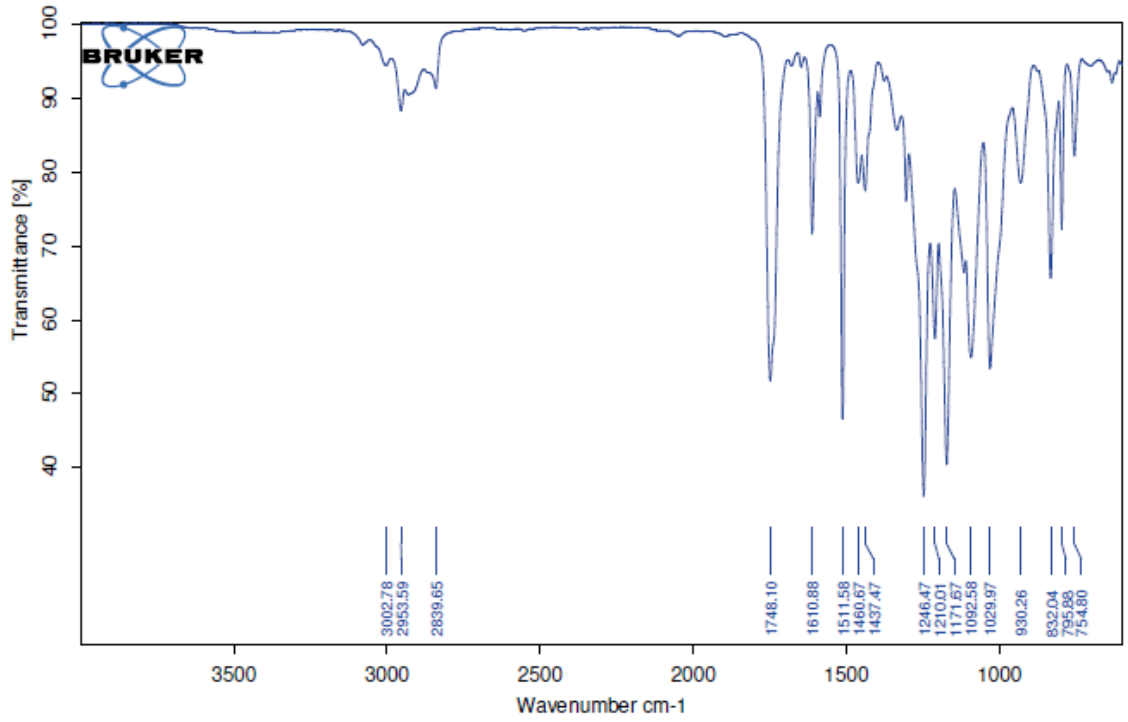
^{1}H NMR (500 MHz, $CDCl_3$) Methyl 2-(allyloxy)-2-(4-methoxyphenyl)acetate **26**



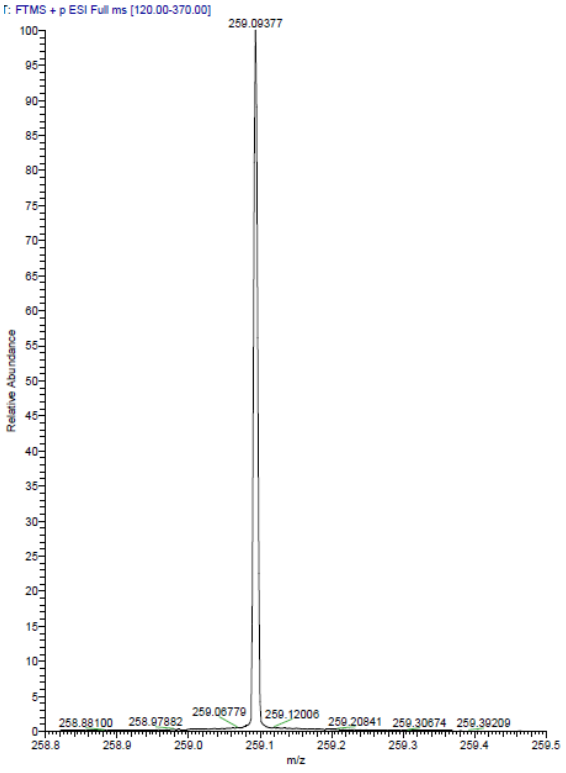
^{13}C NMR (125 MHz, $CDCl_3$) Methyl 2-(allyloxy)-2-(4-methoxyphenyl)acetate **26**



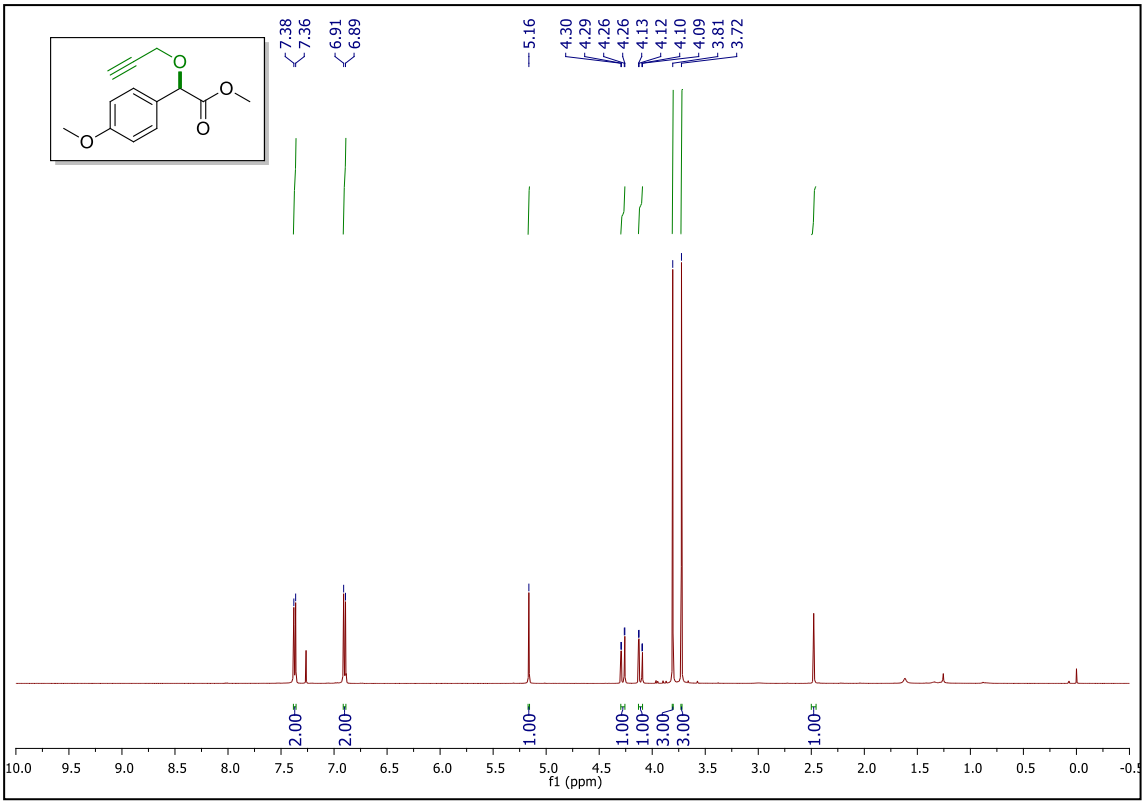
IR Methyl 2-(allyloxy)-2-(4-methoxyphenyl)acetate **26**



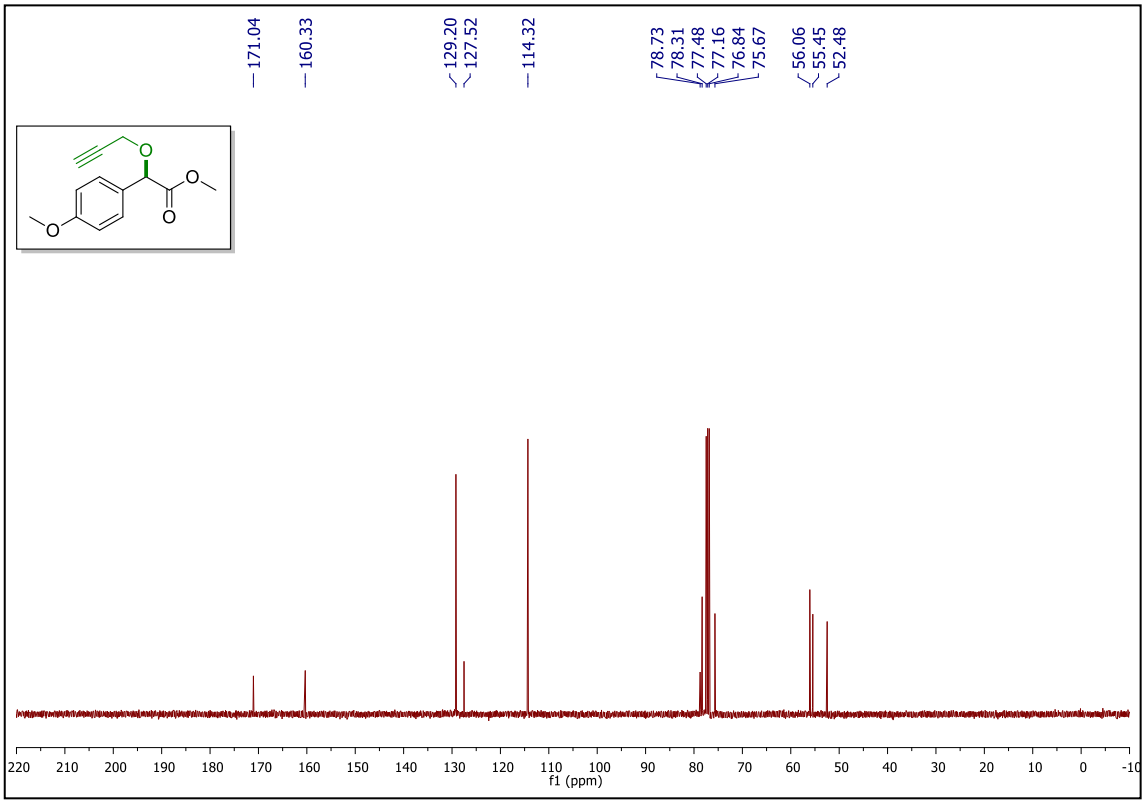
HRMS (ESI-TOF) Methyl 2-(allyloxy)-2-(4-methoxyphenyl)acetate **26**



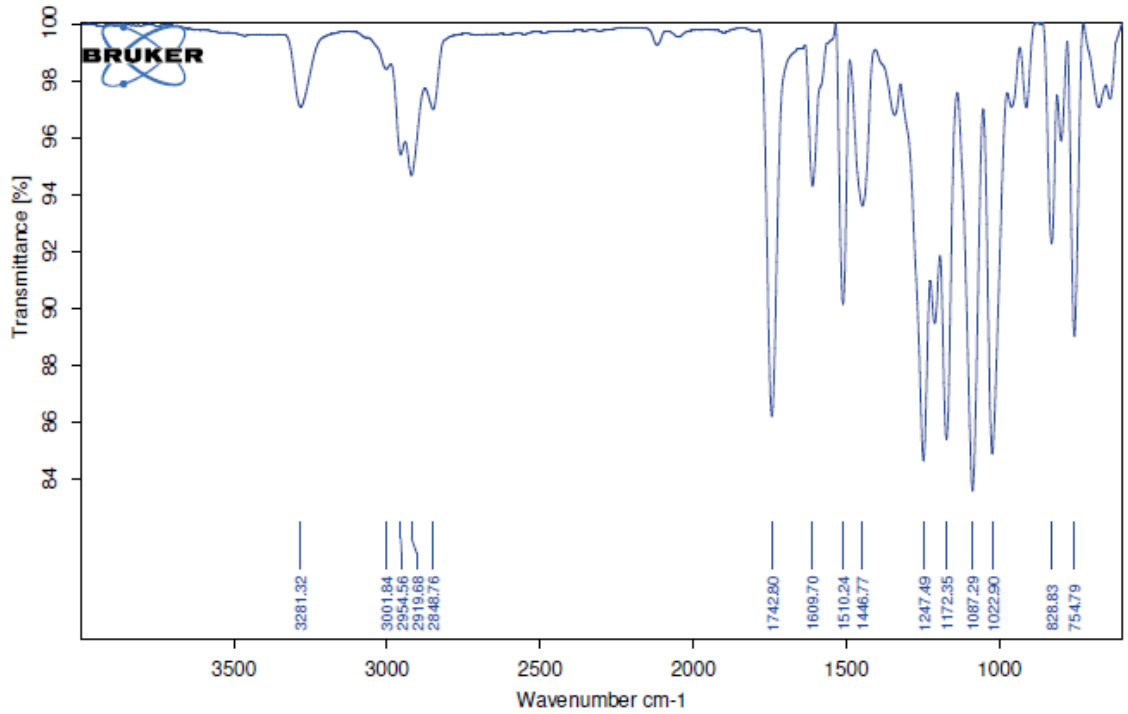
^{1}H NMR (500 MHz, $CDCl_3$) Methyl 2-(4-methoxyphenyl)-2-(prop-2-yn-1-yloxy)acetate **27**



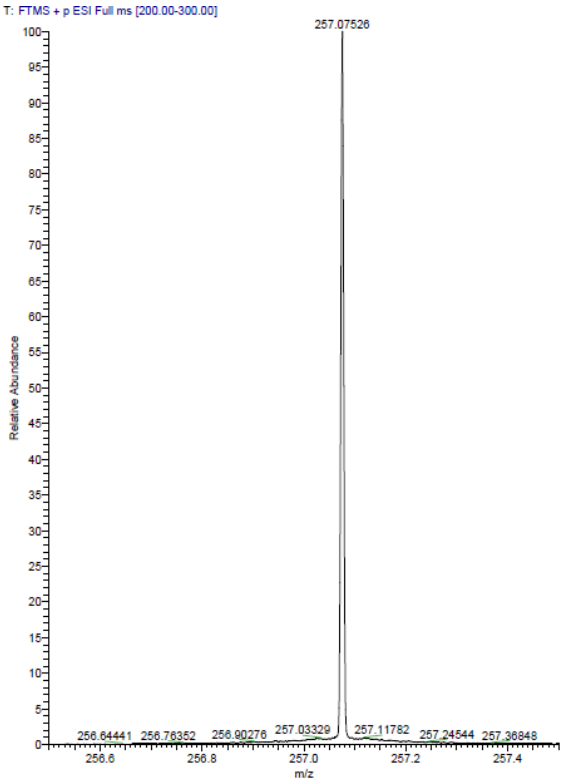
^{13}C NMR (125 MHz, $CDCl_3$) Methyl 2-(4-methoxyphenyl)-2-(prop-2-yn-1-yloxy)acetate **27**



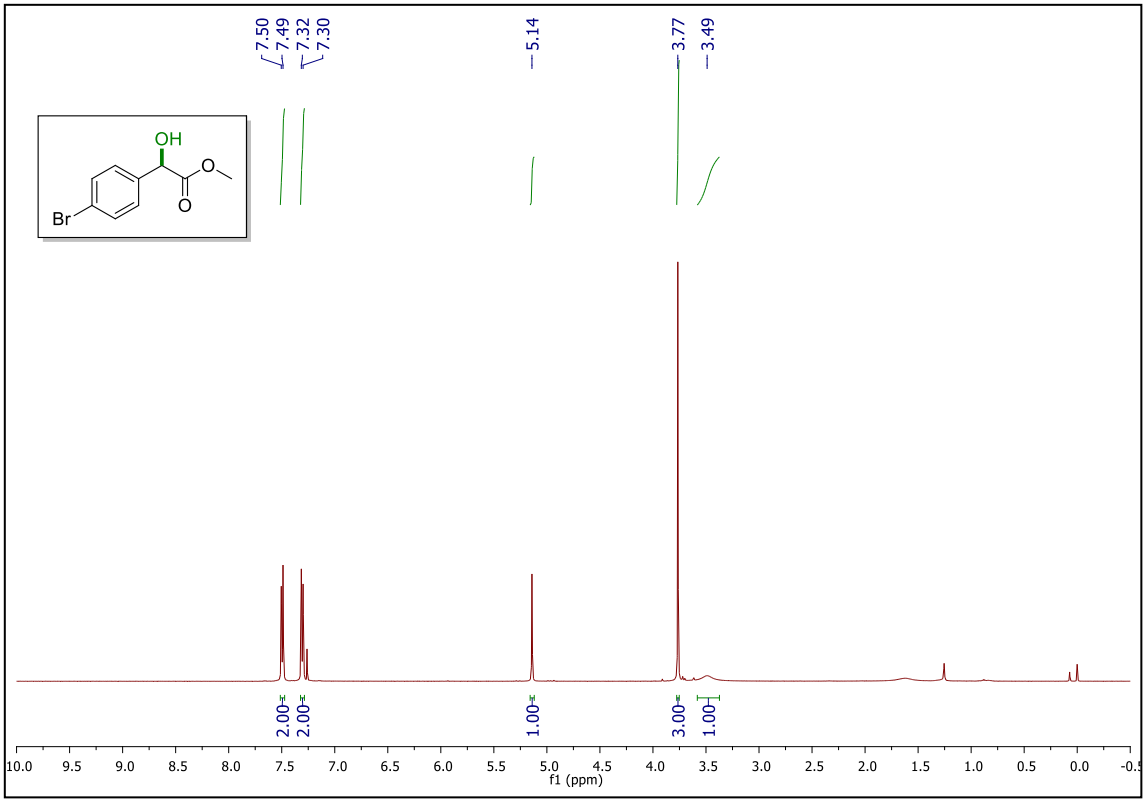
IR Methyl 2-(4-methoxyphenyl)-2-(prop-2-yn-1-yloxy)acetate **27**



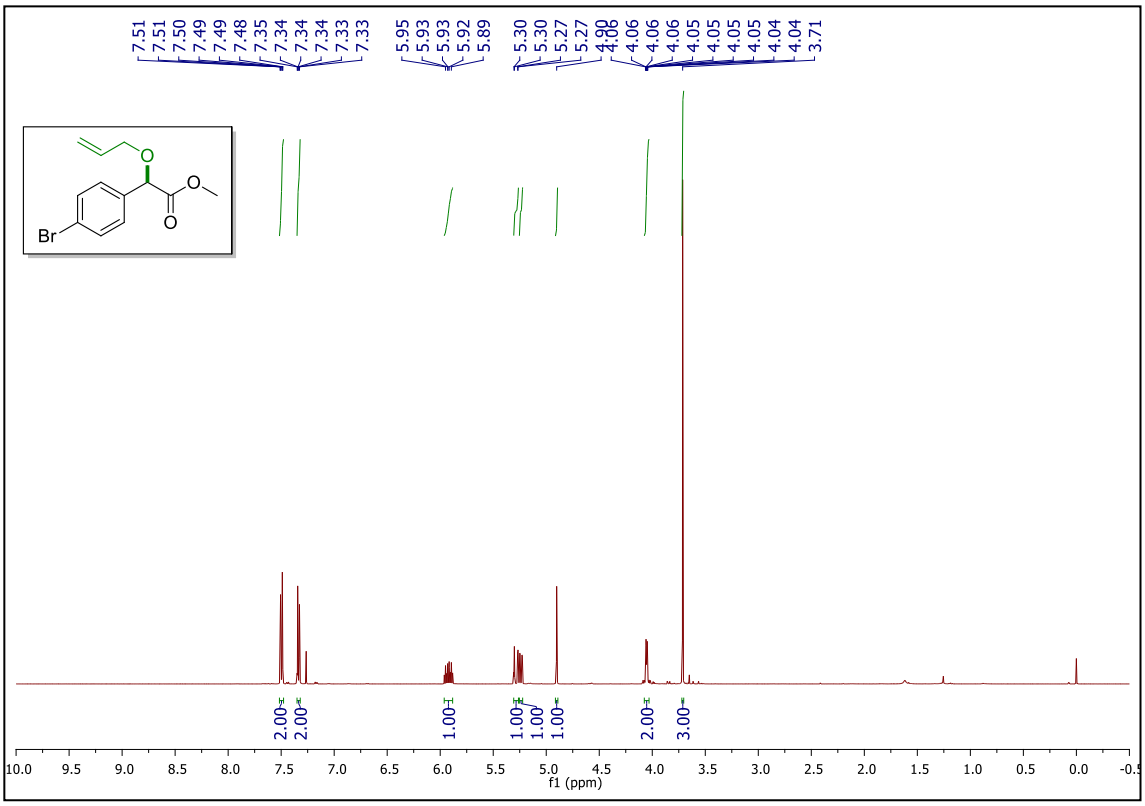
HRMS (ESI-TOF) Methyl 2-(4-methoxyphenyl)-2-(prop-2-yn-1-yloxy)acetate **27**



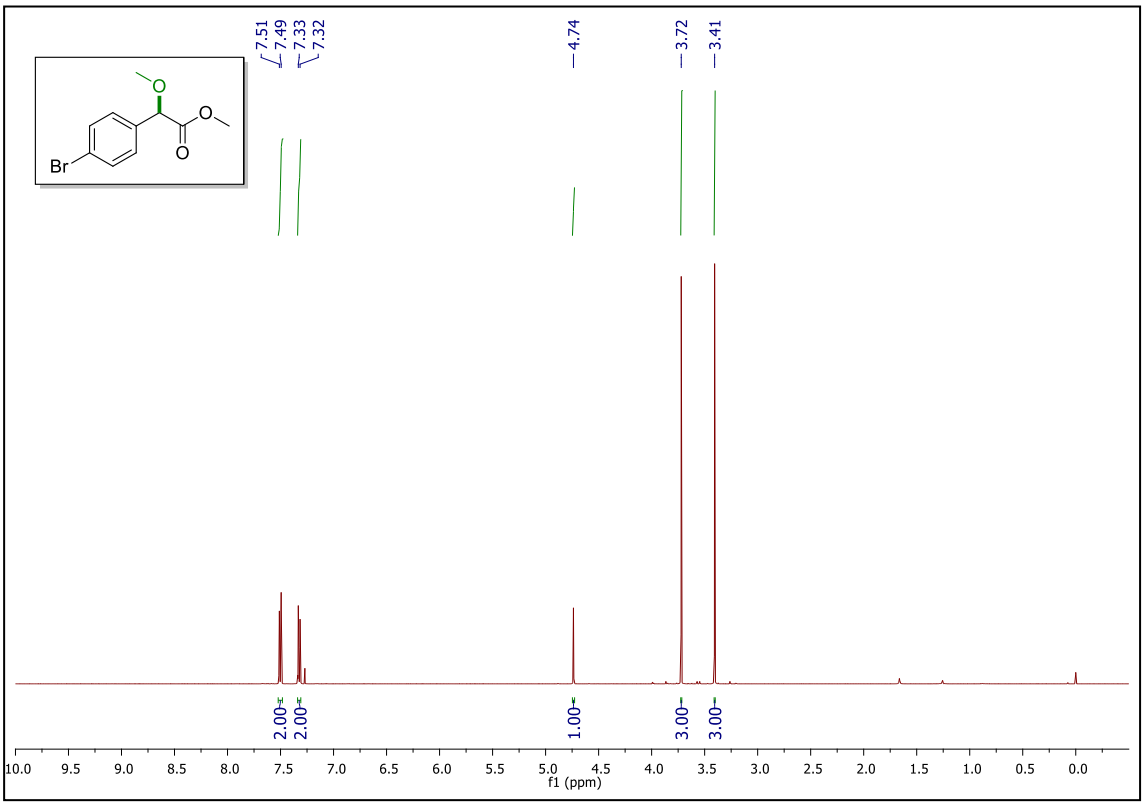
^{1}H NMR (500 MHz, $CDCl_3$) Methyl 2-(4-bromophenyl)-2-hydroxyacetate **28**



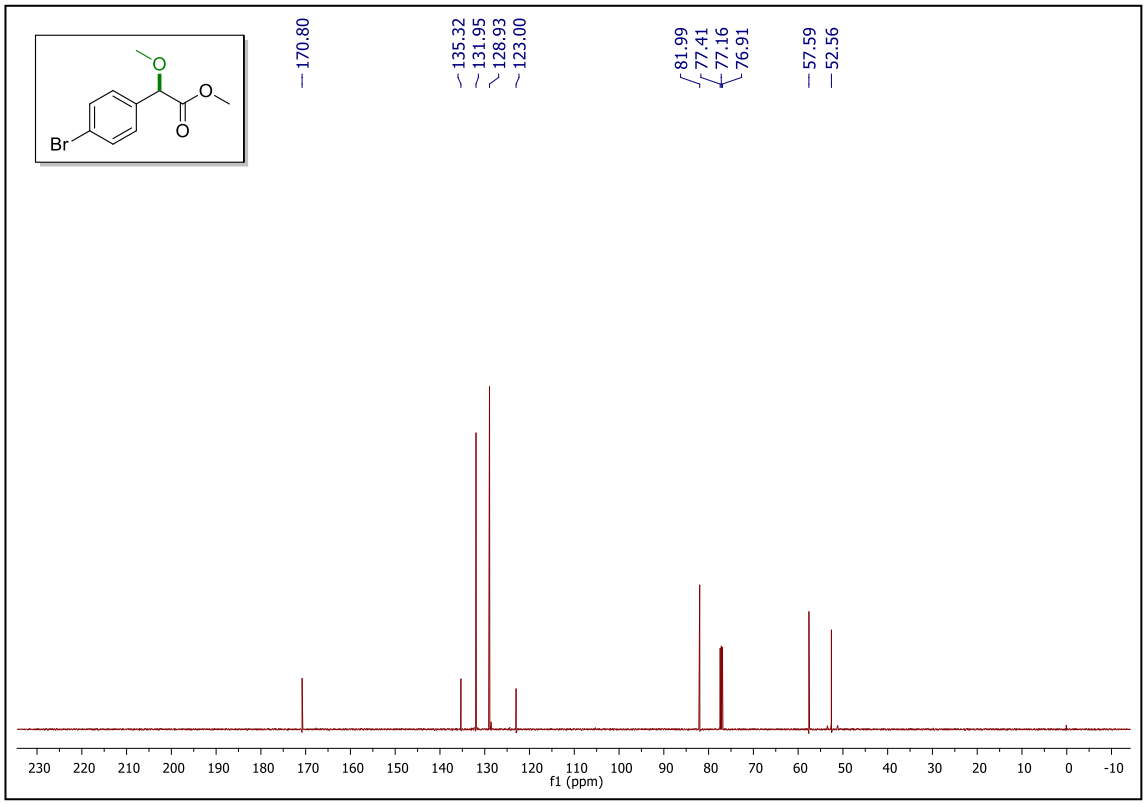
^{1}H NMR (500 MHz, $CDCl_3$) Methyl 2-allyloxy-2-(4-bromophenyl)acetate **29**



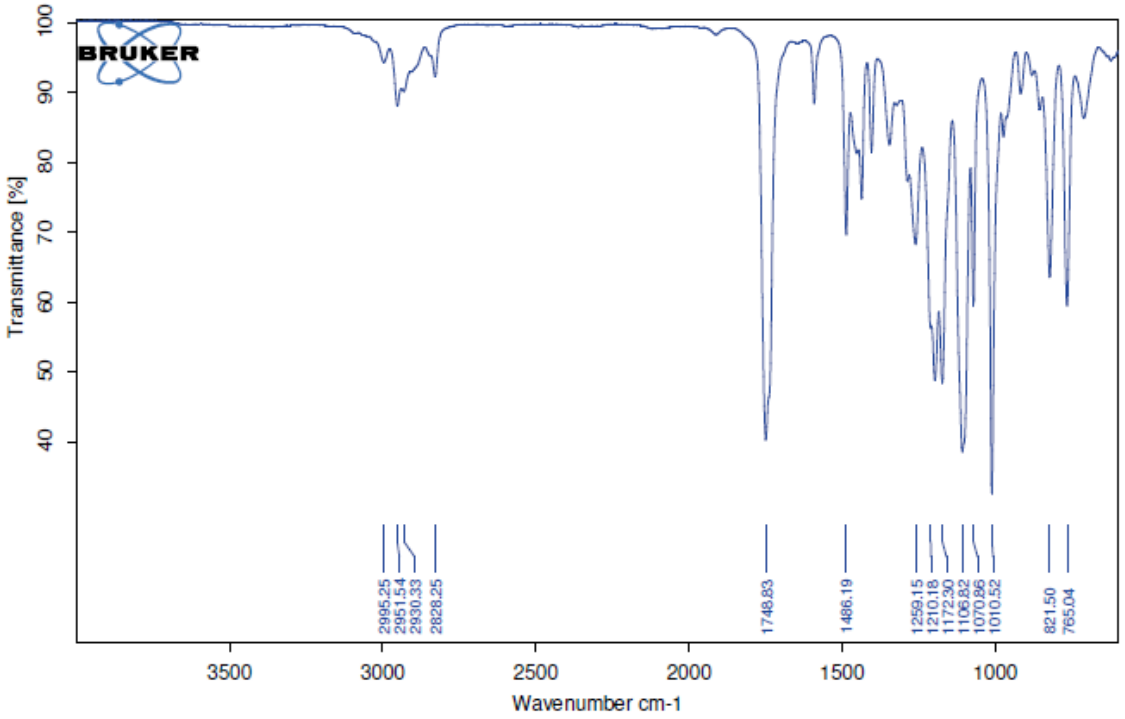
^{1}H NMR (500 MHz, $CDCl_3$) Methyl 2-(4-bromophenyl)-2-methoxyacetate **30**



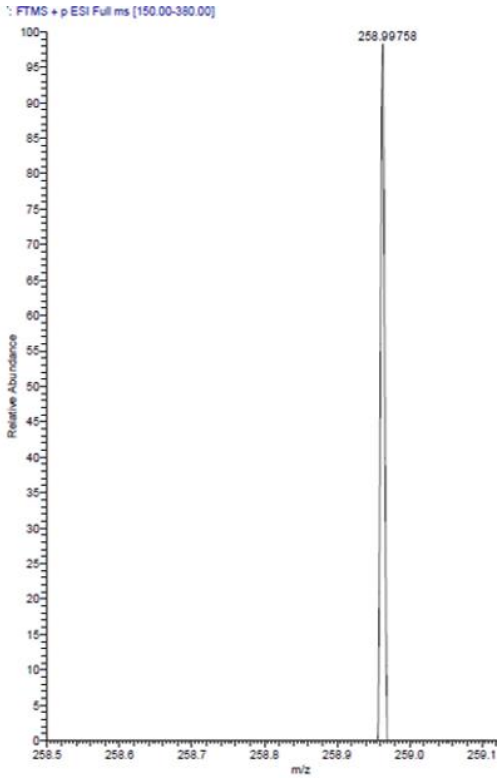
^{13}C NMR (125 MHz, $CDCl_3$) Methyl 2-(4-bromophenyl)-2-methoxyacetate **30**



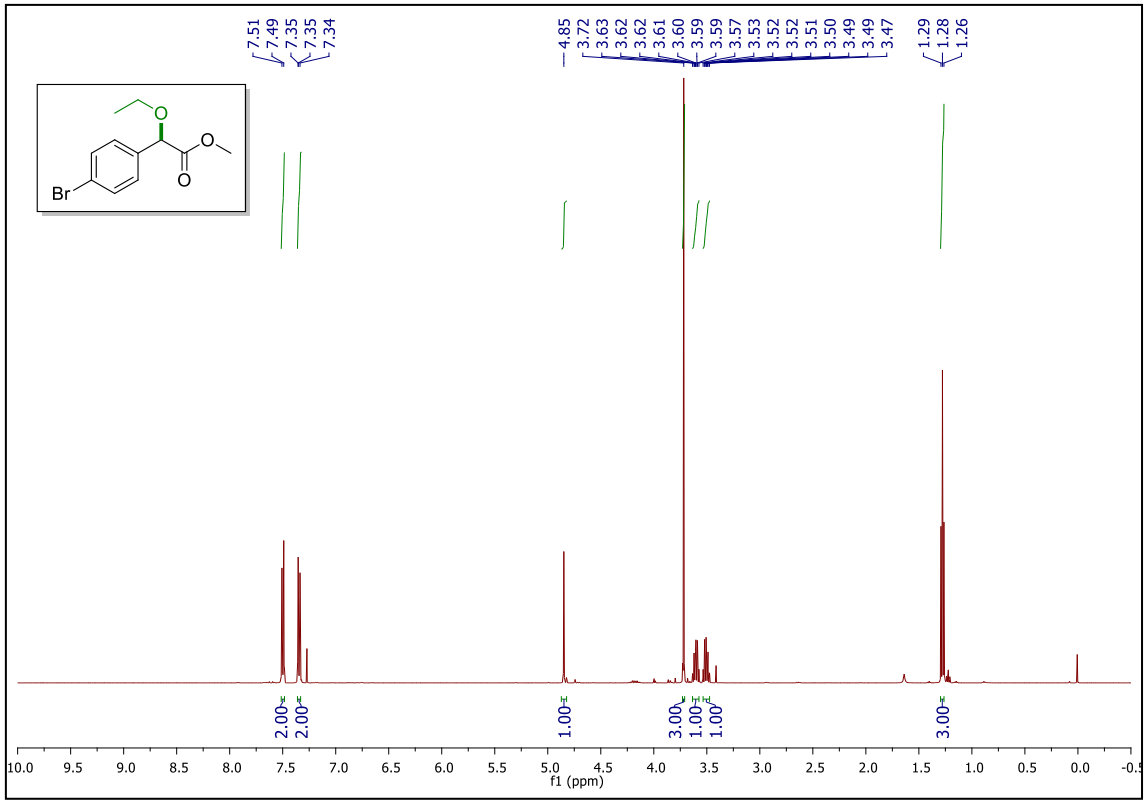
IR Methyl 2-(4-bromophenyl)-2-methoxyacetate **30**



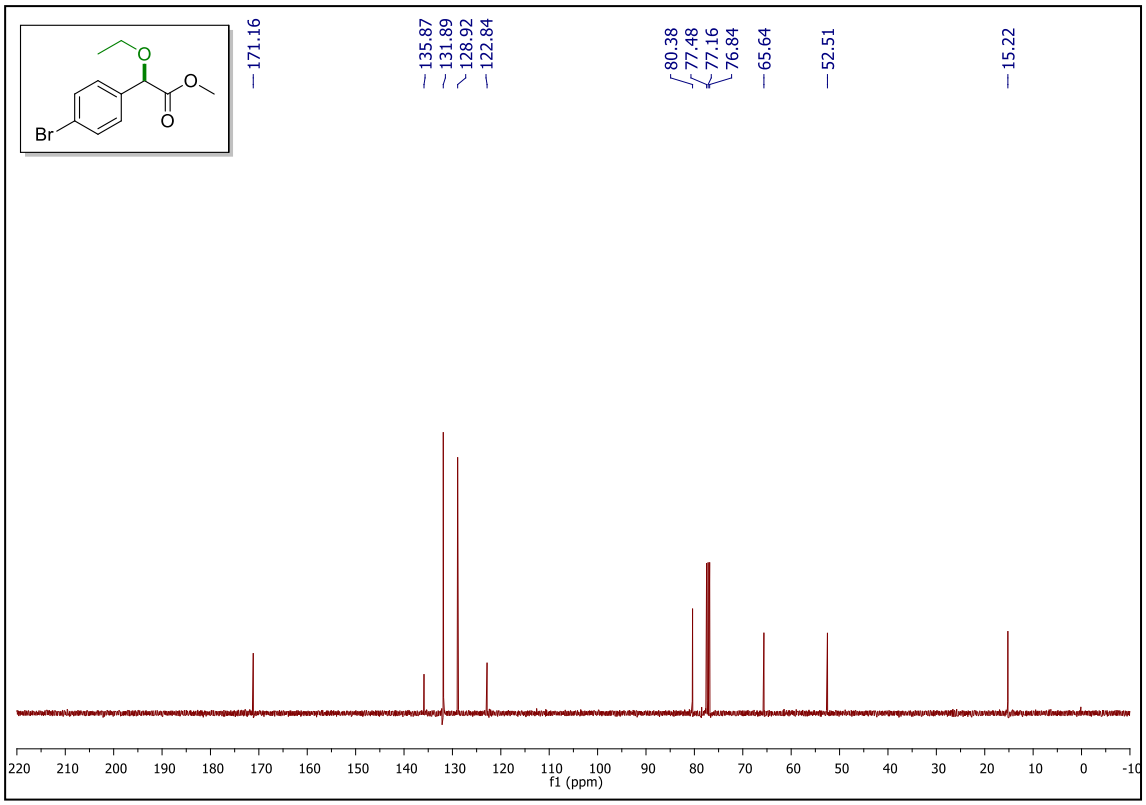
HRMS (ESI-TOF) Methyl 2-(4-bromophenyl)-2-methoxyacetate **30**



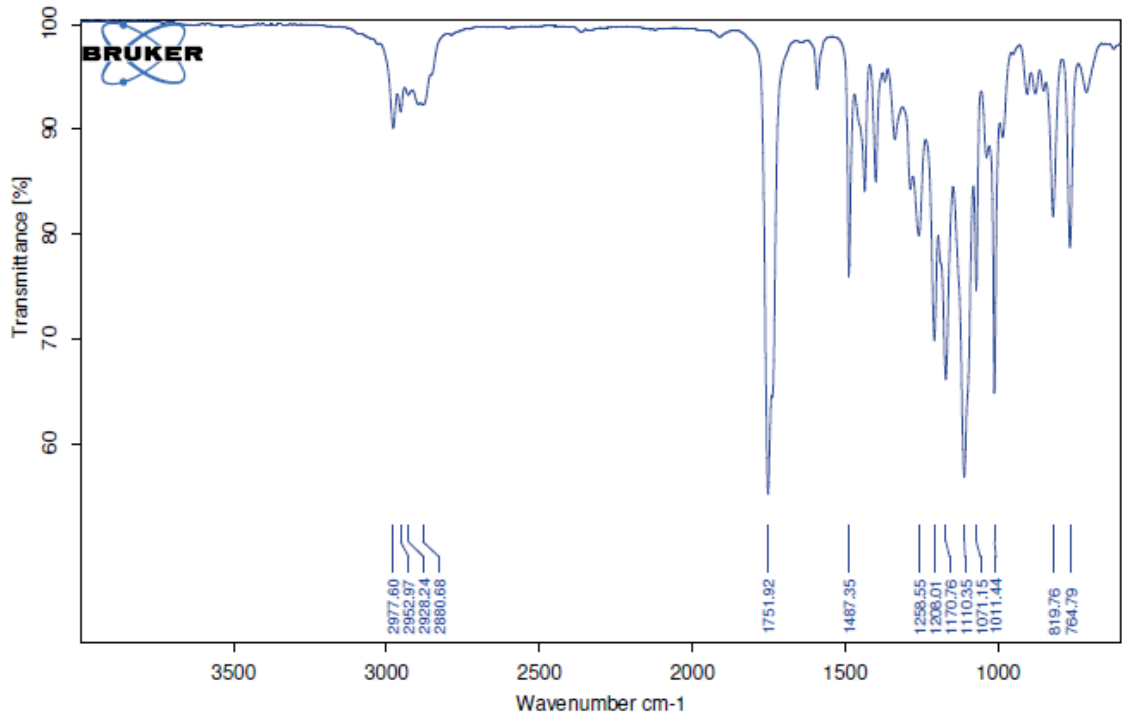
^{1}H NMR (500 MHz, $CDCl_3$) Methyl 2-(4-bromophenyl)-2-methoxyacetate **31**



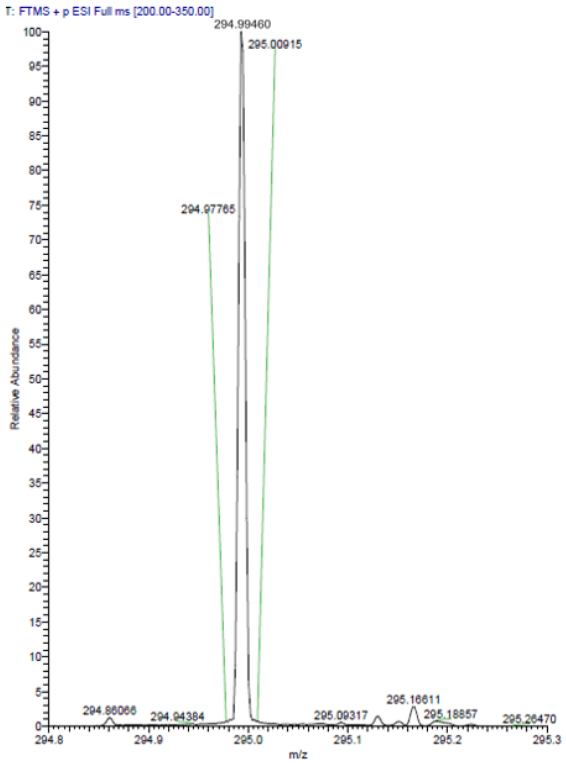
^{13}C NMR (125 MHz, $CDCl_3$) Methyl 2-(4-bromophenyl)-2-ethoxyacetate **31**



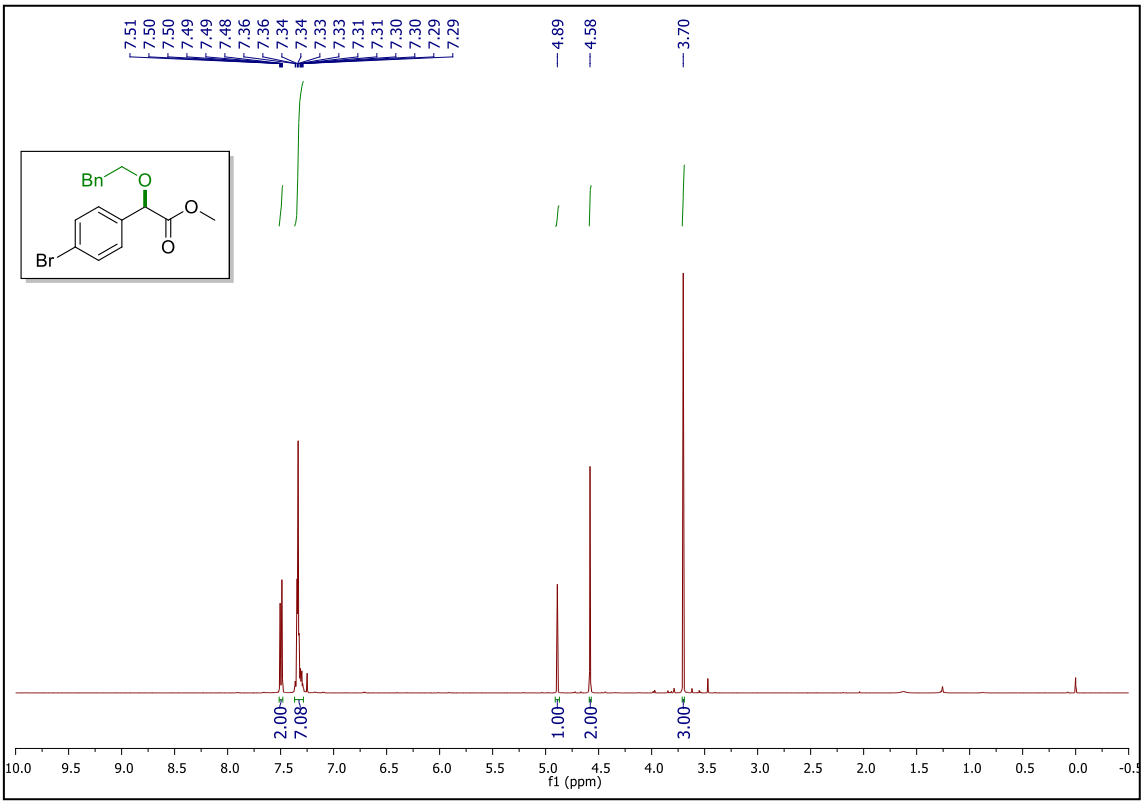
IR Methyl 2-(4-bromophenyl)-2-methoxyacetate **31**



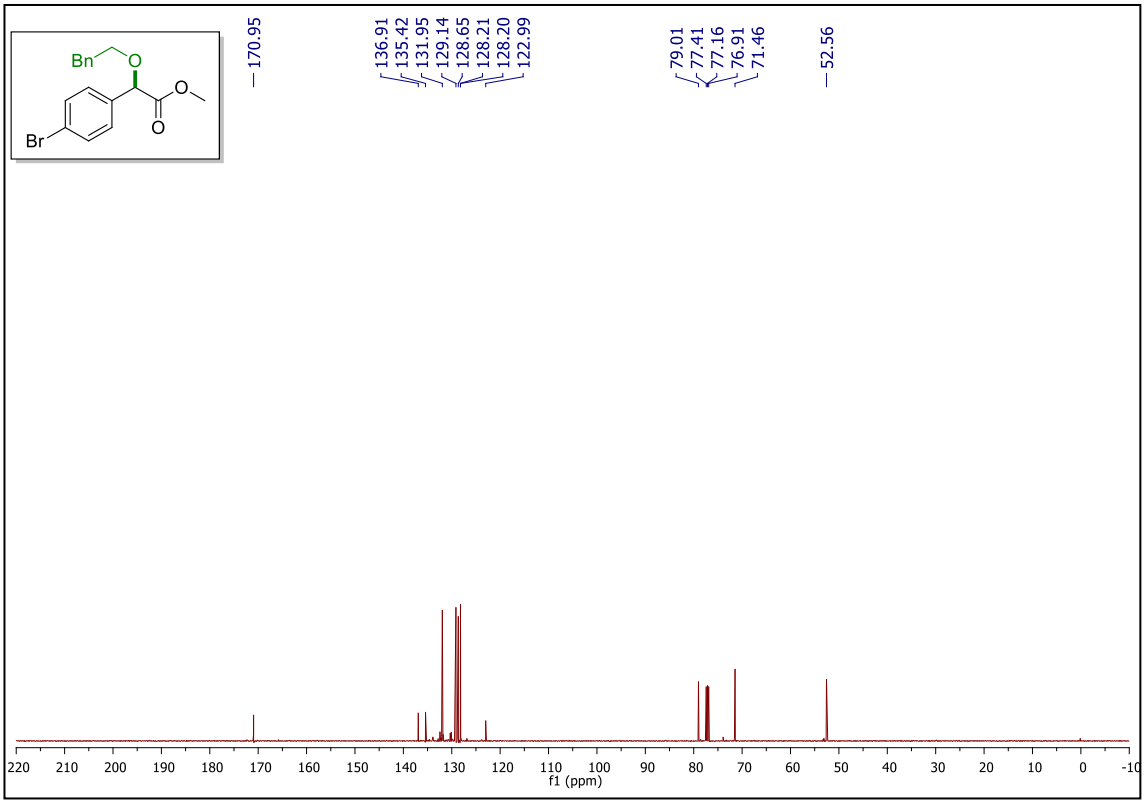
HRMS (ESI-TOF) Methyl 2-(4-bromophenyl)-2-methoxyacetate **31**



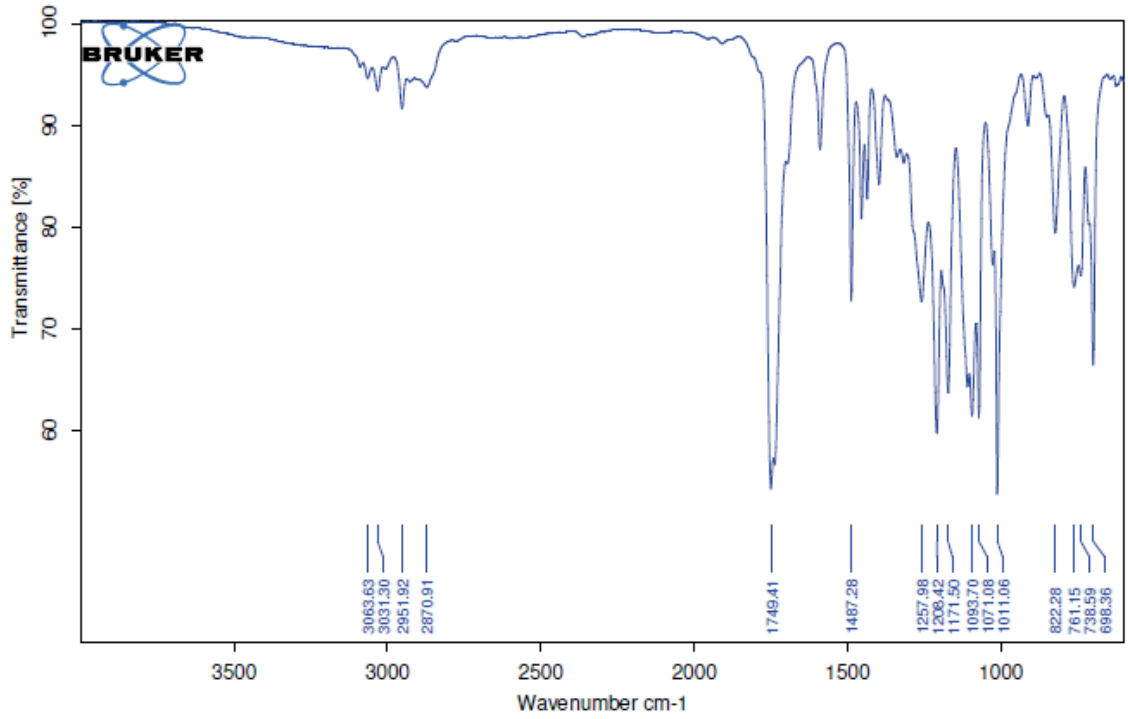
^{1}H NMR (500 MHz, $CDCl_3$) Methyl 2-(4-bromophenyl)-2-phenethoxyacetate **32**



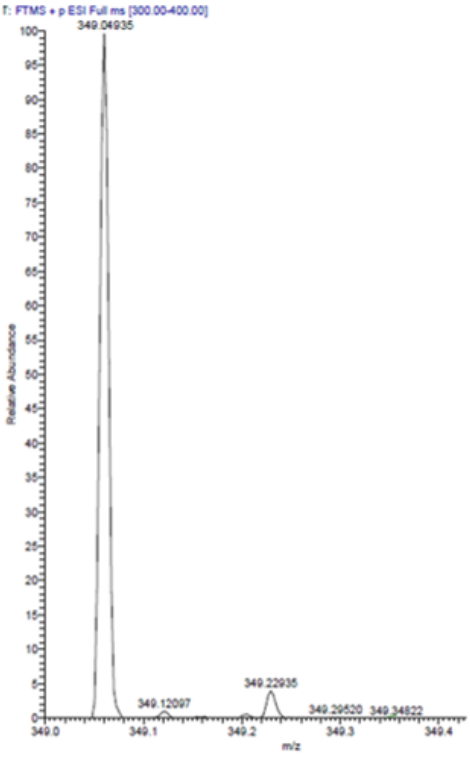
^{13}C NMR (125 MHz, $CDCl_3$) Methyl 2-(4-bromophenyl)-2-phenethoxyacetate **32**



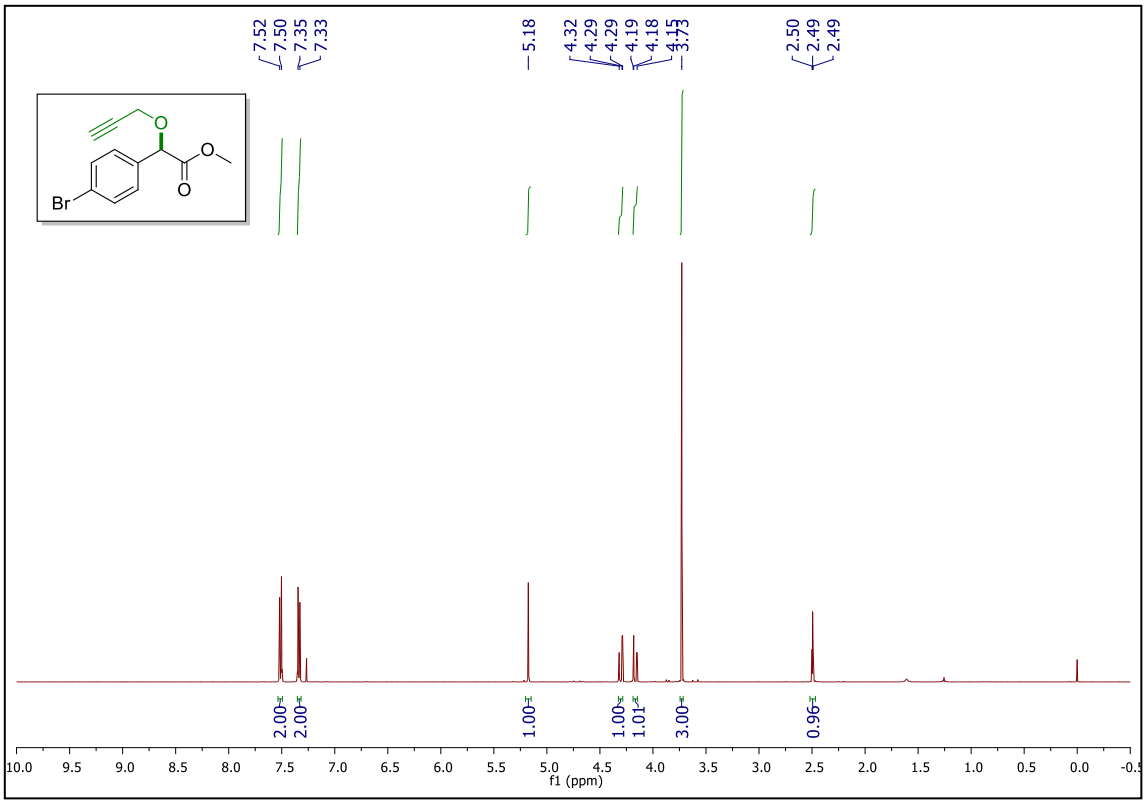
IR Methyl 2-(4-bromophenyl)-2-phenethoxyacetate **32**



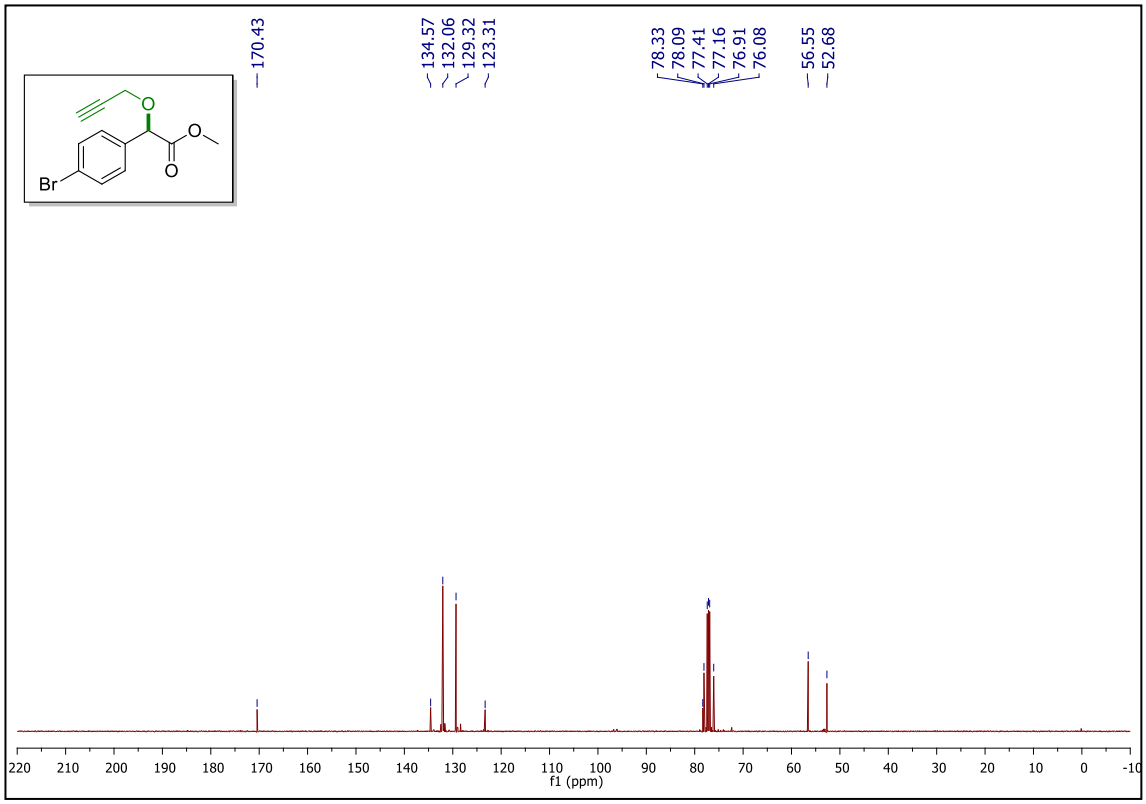
HRMS (ESI-TOF) Methyl 2-(4-bromophenyl)-2-phenethoxyacetate **32**



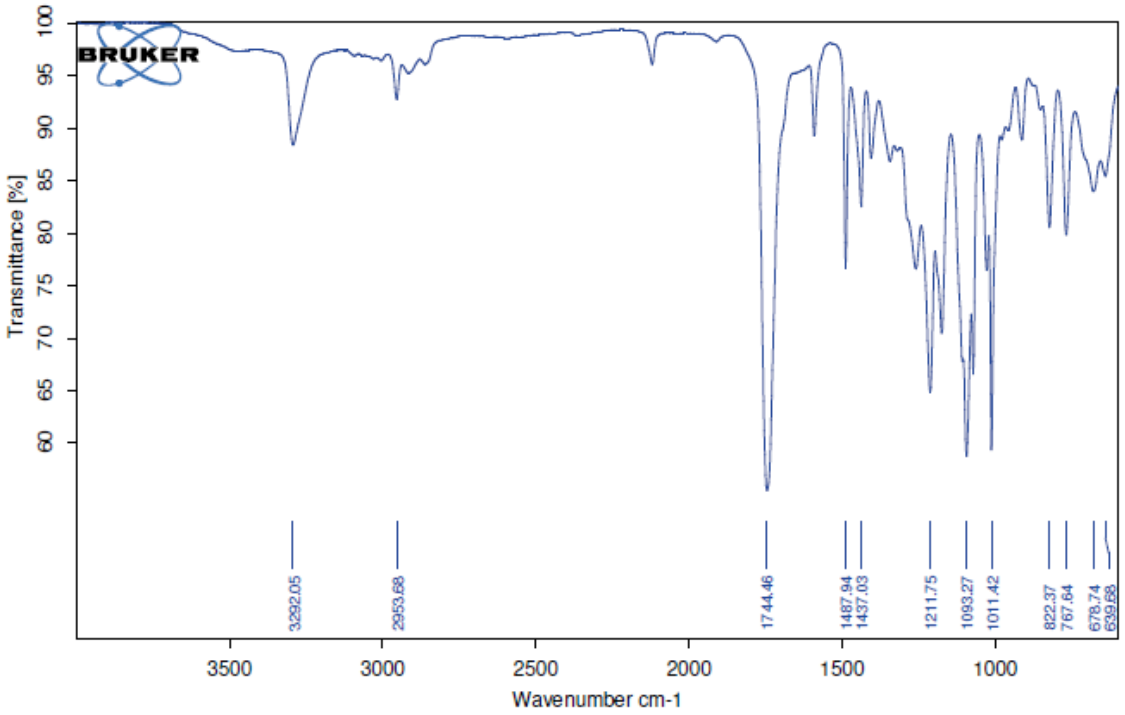
^{1}H NMR (500 MHz, $CDCl_3$) Methyl 2-(4-bromophenyl)-2-(prop-2-yn-1-yloxy)acetate **33**



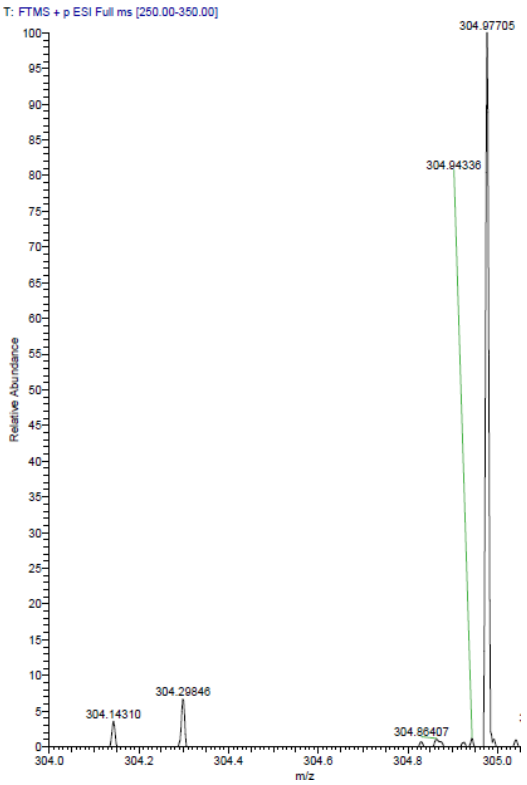
^{13}C NMR (125 MHz, $CDCl_3$) Methyl 2-(4-bromophenyl)-2-(prop-2-yn-1-yloxy)acetate **33**



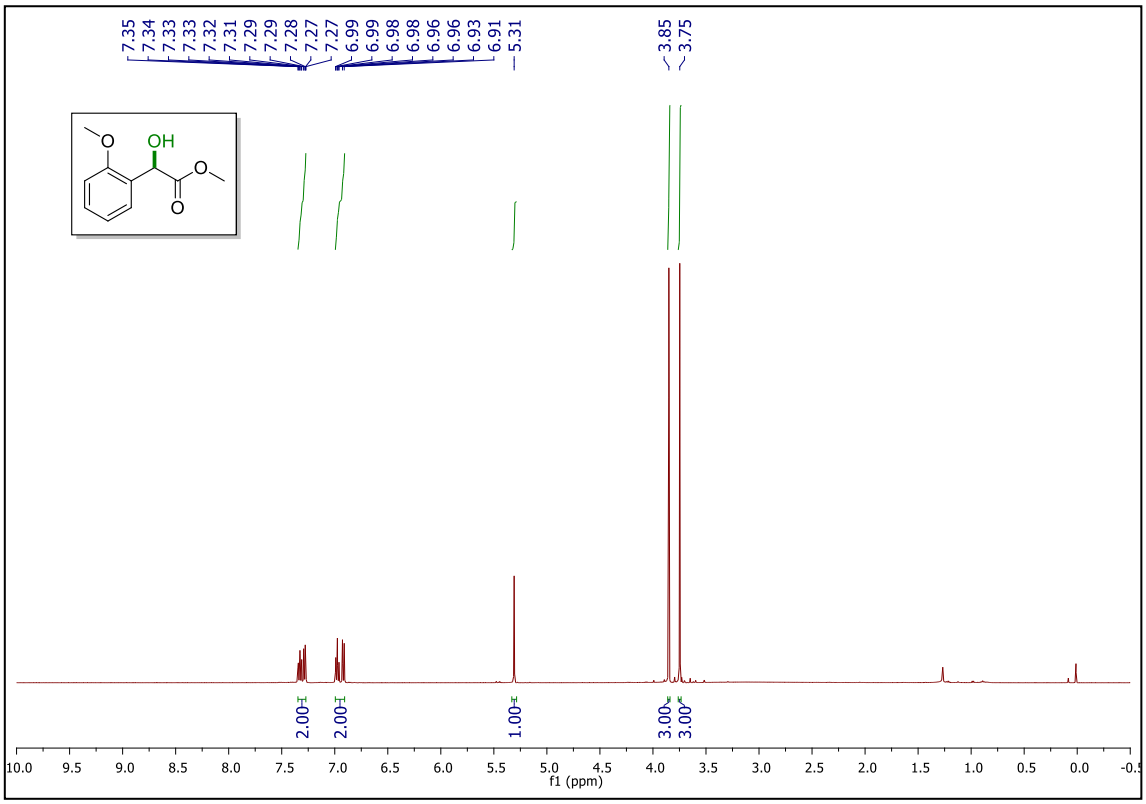
IR Methyl 2-(4-bromophenyl)-2-(prop-2-yn-1-yloxy)acetate **33**



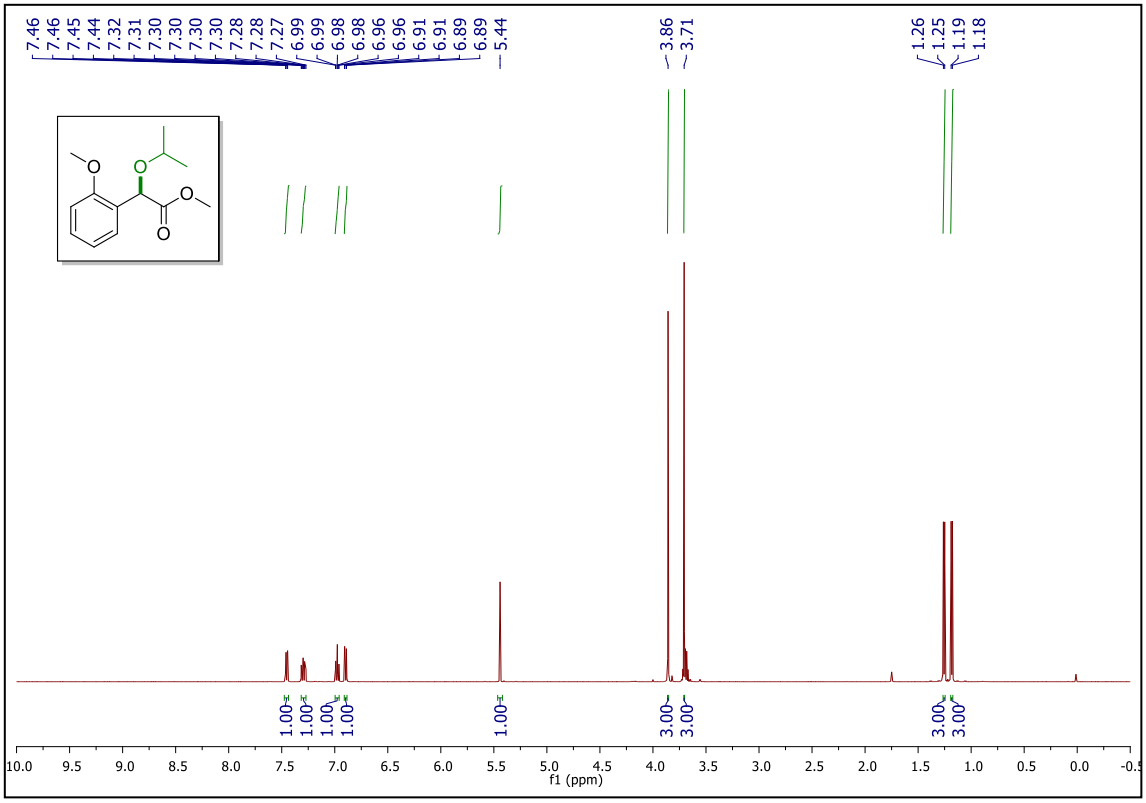
HRMS (ESI-TOF) Methyl 2-(4-bromophenyl)-2-(prop-2-yn-1-yloxy)acetate **33**



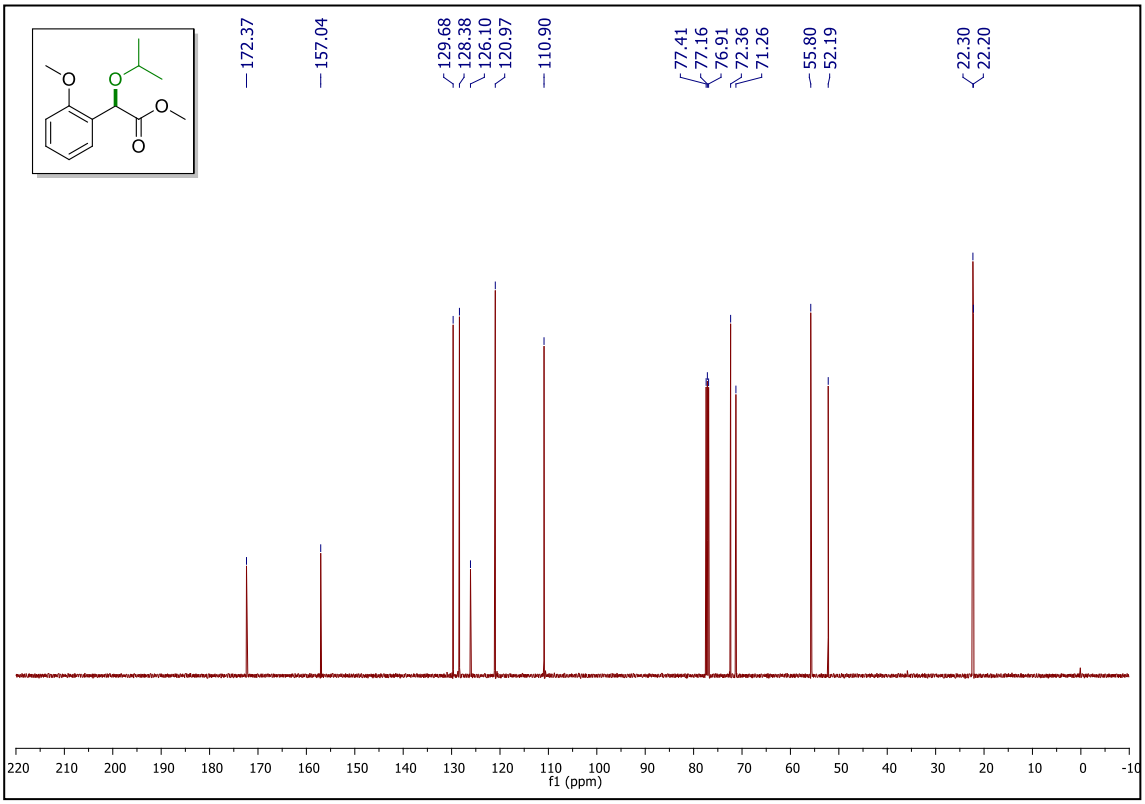
^{1}H NMR (500 MHz, $CDCl_3$) Methyl 2-hydroxy-2-(2-methoxyphenyl)acetate **34**



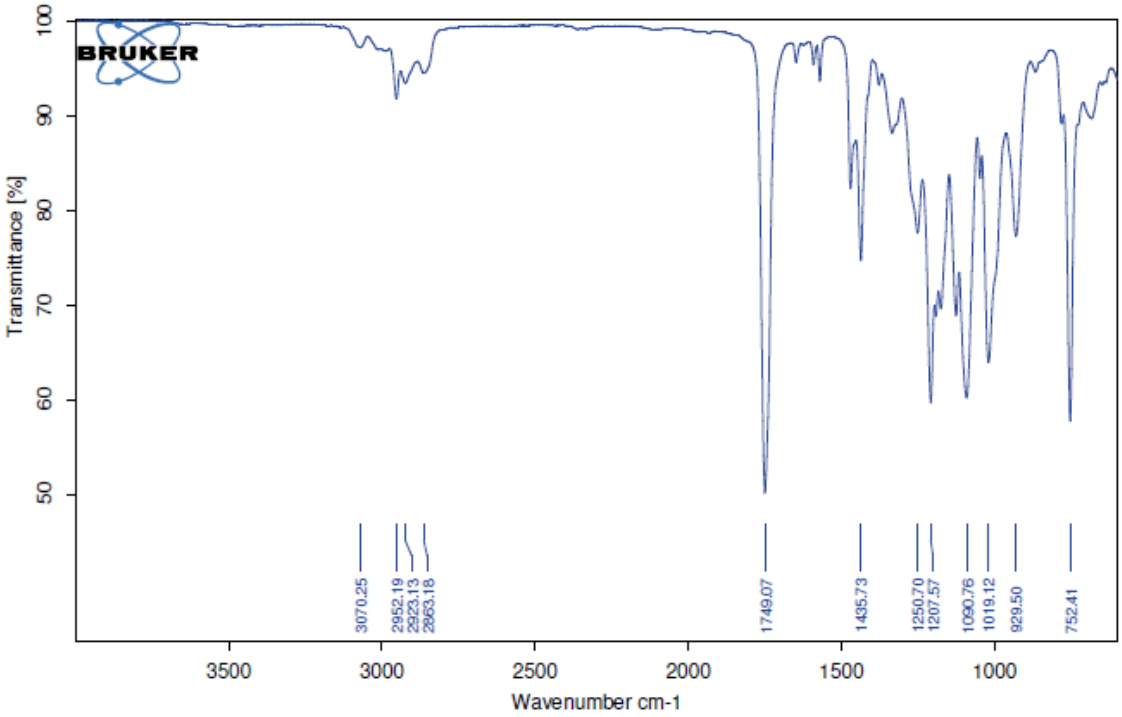
^{1}H NMR (500 MHz, $CDCl_3$) Methyl 2-isopropoxy-2-(2-methoxyphenyl)acetate **35**



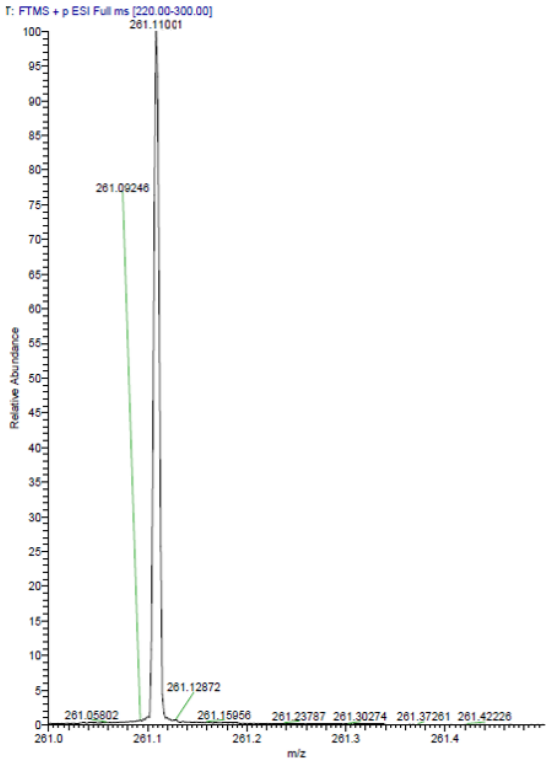
^{13}C NMR (125 MHz, $CDCl_3$) Methyl 2-isopropoxy-2-(2-methoxyphenyl)acetate **35**



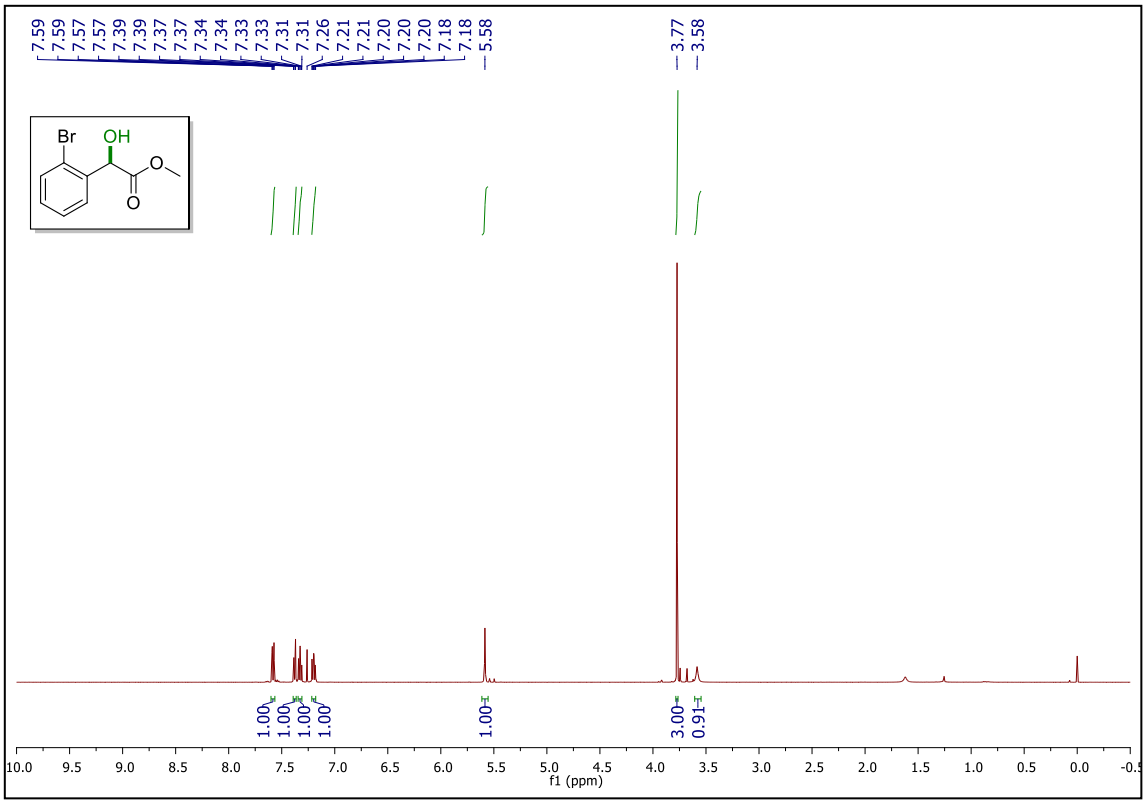
IR Methyl 2-isopropoxy-2-(2-methoxyphenyl)acetate **35**



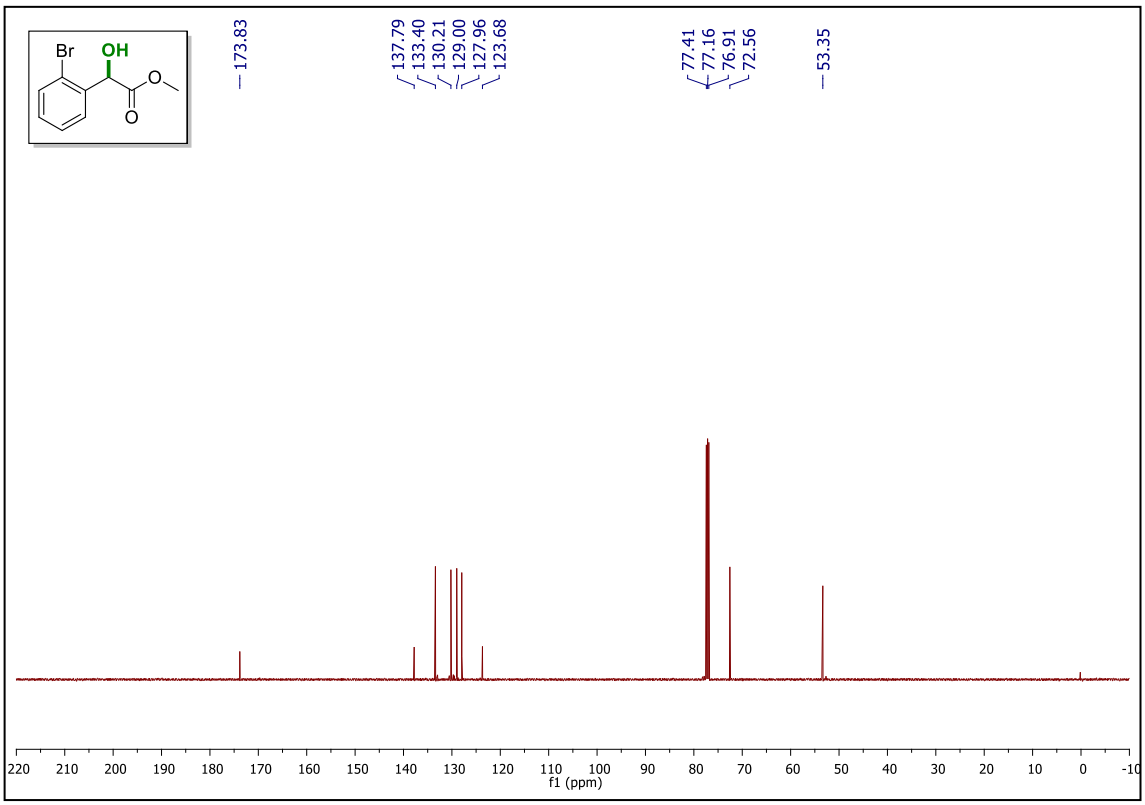
HRMS (ESI-TOF) Methyl 2-isopropoxy-2-(2-methoxyphenyl)acetate **35**



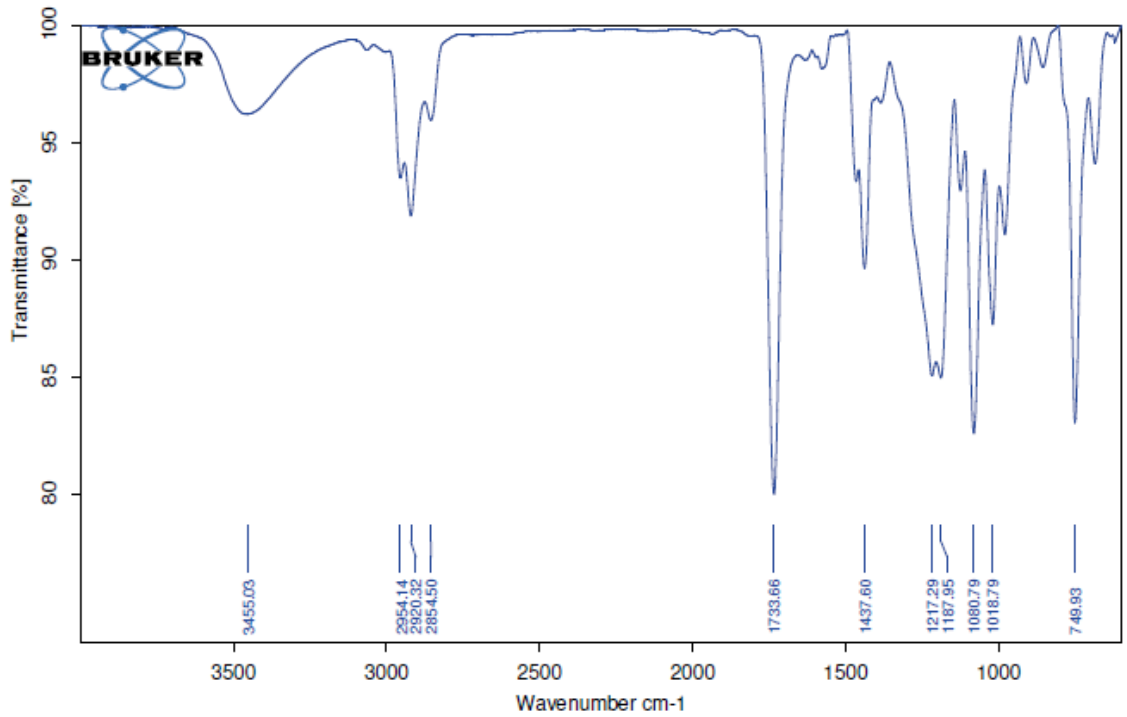
^{1}H NMR (500 MHz, $CDCl_3$) Methyl 2-(2-bromophenyl)-2-hydroxyacetate **36**



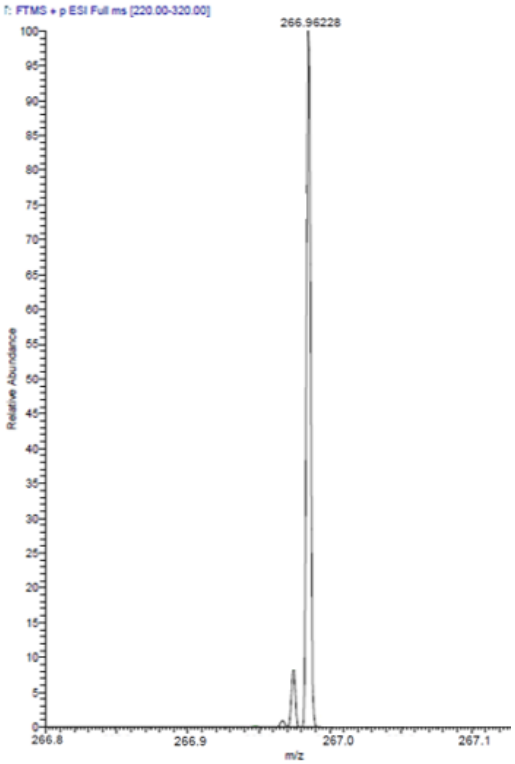
^{13}C NMR (125 MHz, $CDCl_3$) Methyl 2-(2-bromophenyl)-2-hydroxyacetate **36**



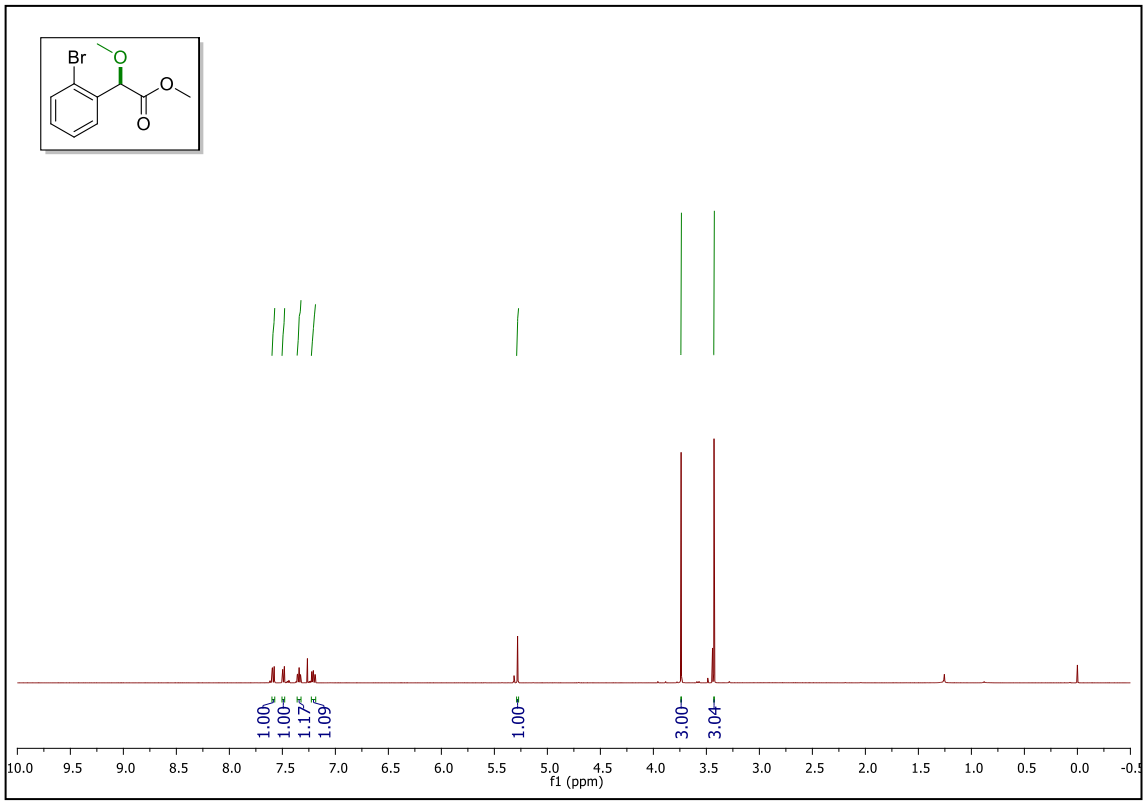
IR Methyl 2-(2-bromophenyl)-2-hydroxyacetate **36**



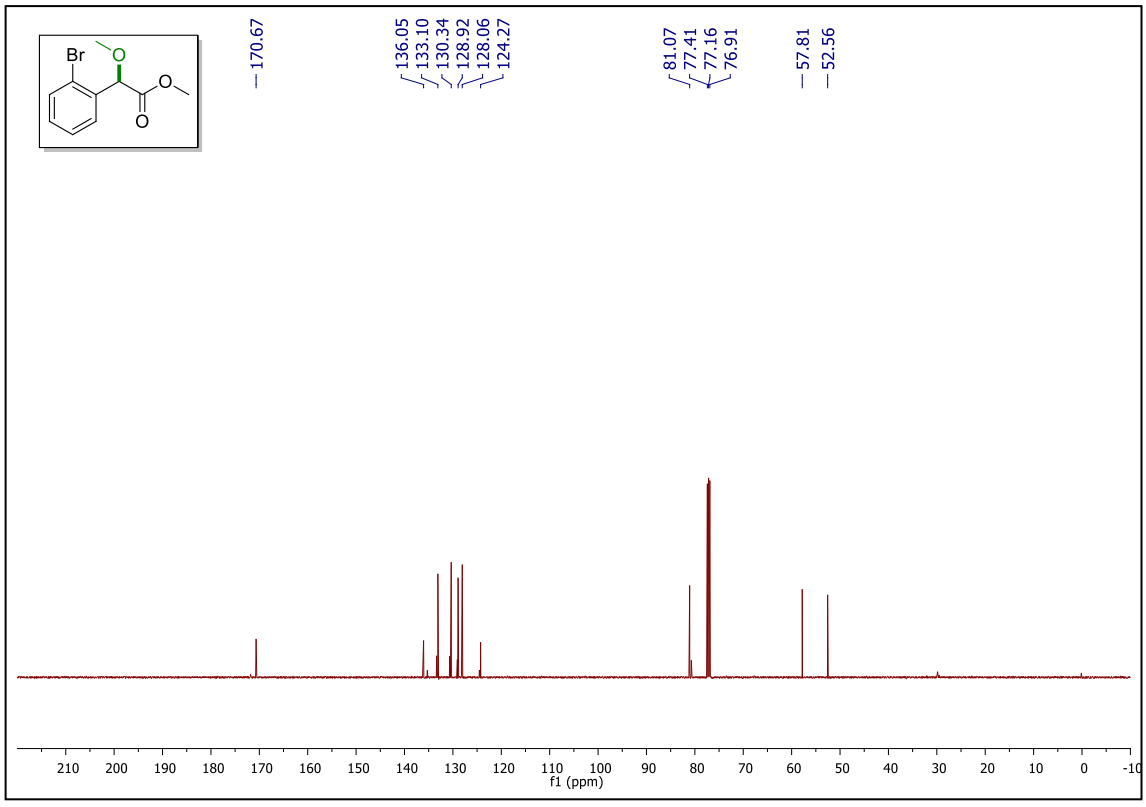
HRMS (ESI-TOF) Methyl 2-(2-bromophenyl)-2-hydroxyacetate **36**



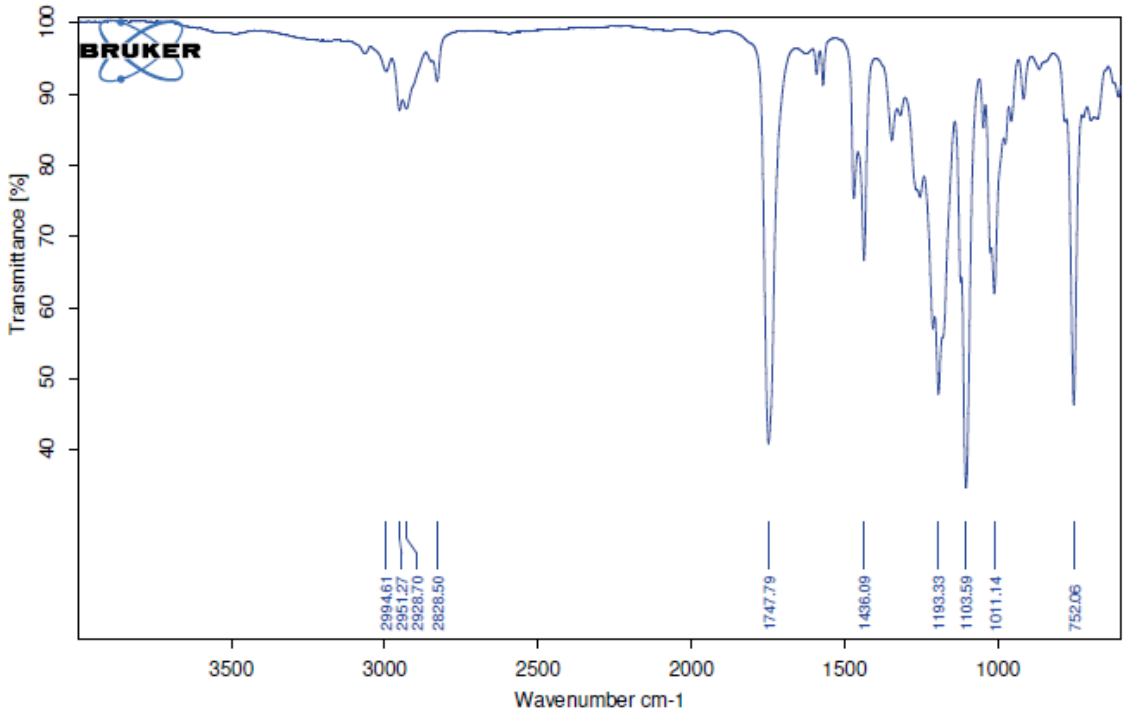
^{1}H NMR (500 MHz, $CDCl_3$) Methyl 2-(2-bromophenyl)-2-methoxyacetate **37**



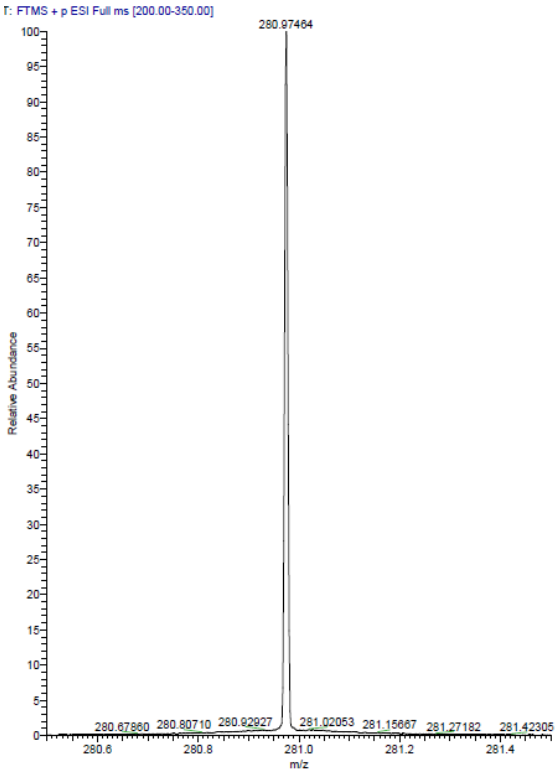
^{13}C NMR (125 MHz, $CDCl_3$) Methyl 2-(2-bromophenyl)-2-methoxyacetate **37**



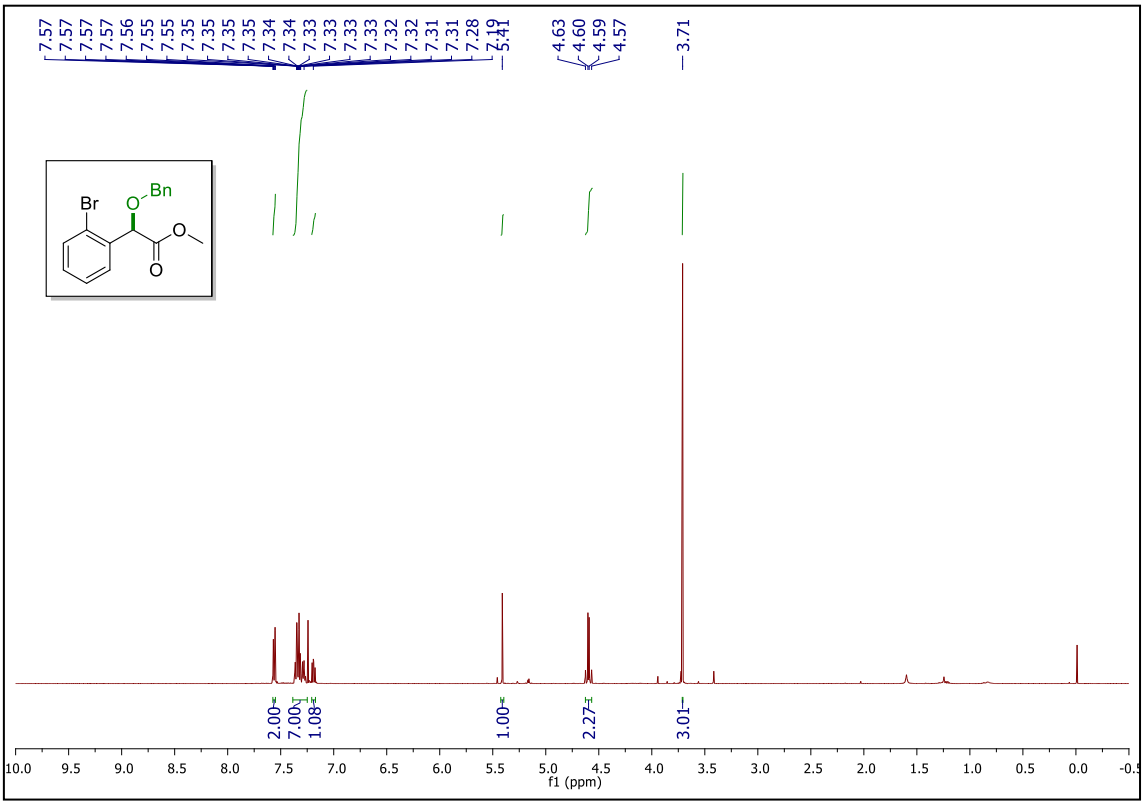
IR Methyl 2-(2-bromophenyl)-2-methoxyacetate **37**



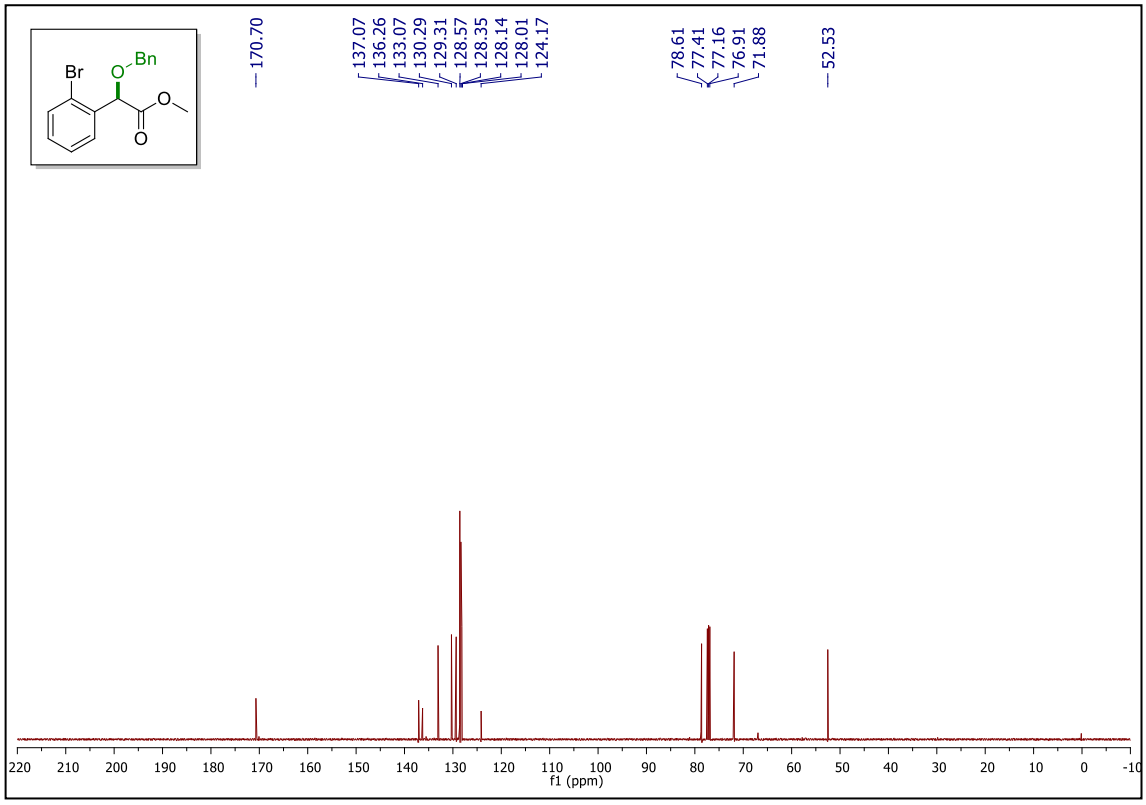
HRMS (ESI-TOF) Methyl 2-(2-bromophenyl)-2-methoxyacetate **37**



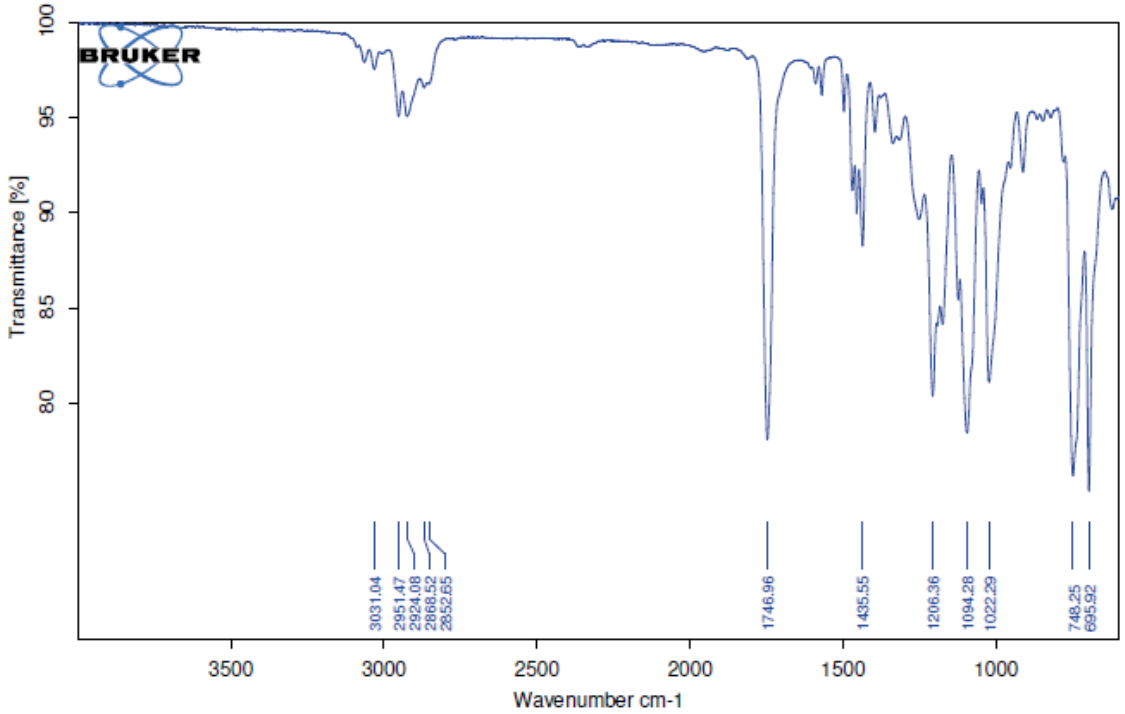
^{1}H NMR (500 MHz, $CDCl_3$) Methyl 2-(benzyloxy)-2-(2-bromophenyl)acetate **38**



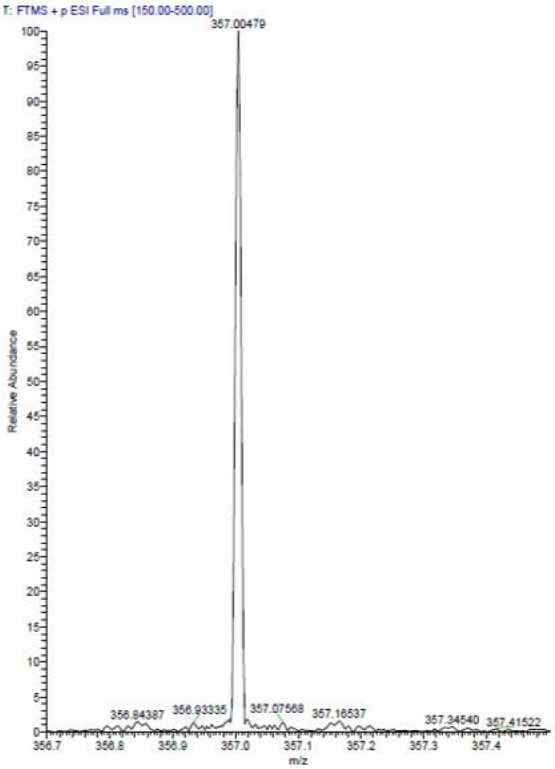
^{13}C NMR (125 MHz, $CDCl_3$) Methyl 2-(benzyloxy)-2-(2-bromophenyl)acetate **38**



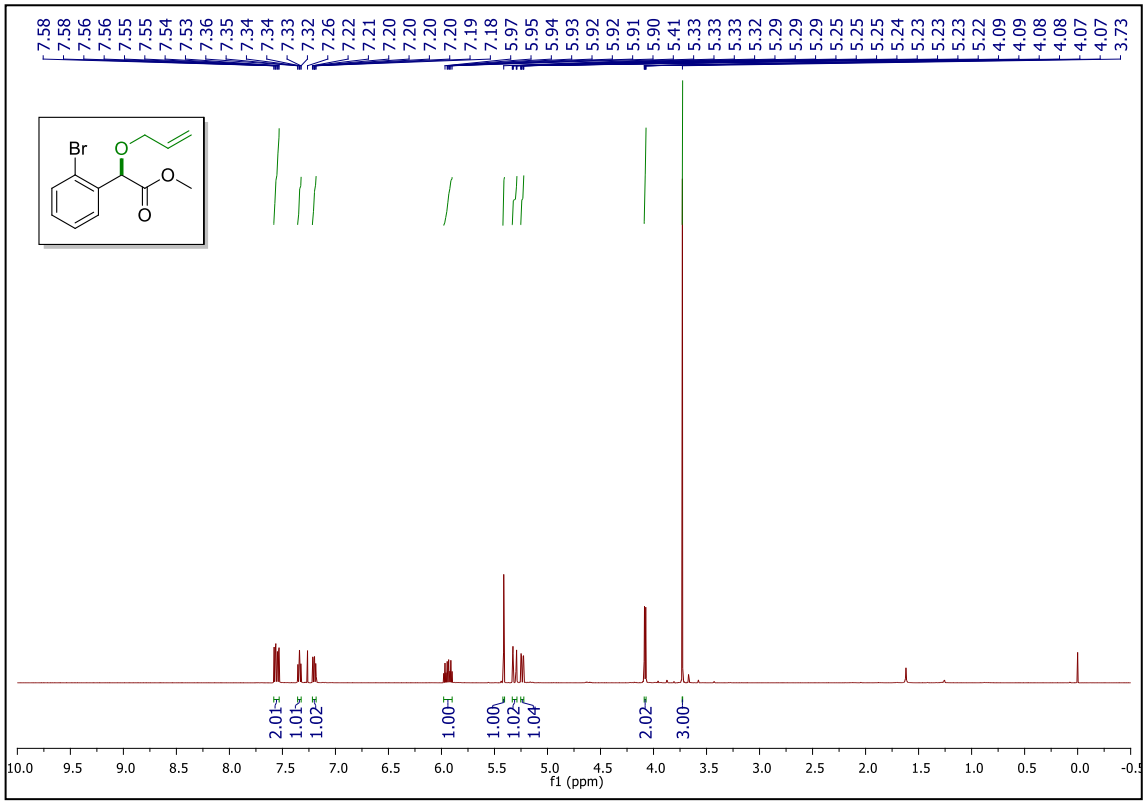
IR Methyl 2-(benzyloxy)-2-(2-bromophenyl)acetate **38**



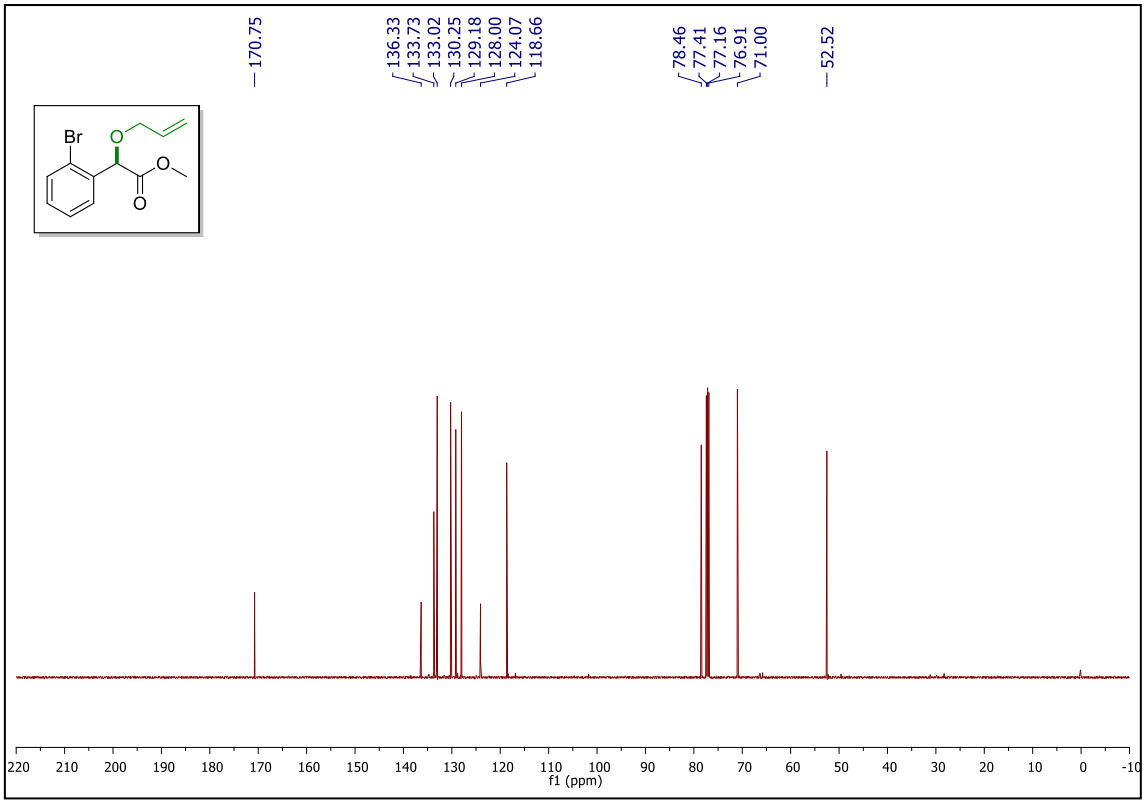
HRMS (ESI-TOF) Methyl 2-(benzyloxy)-2-(2-bromophenyl)acetate **38**



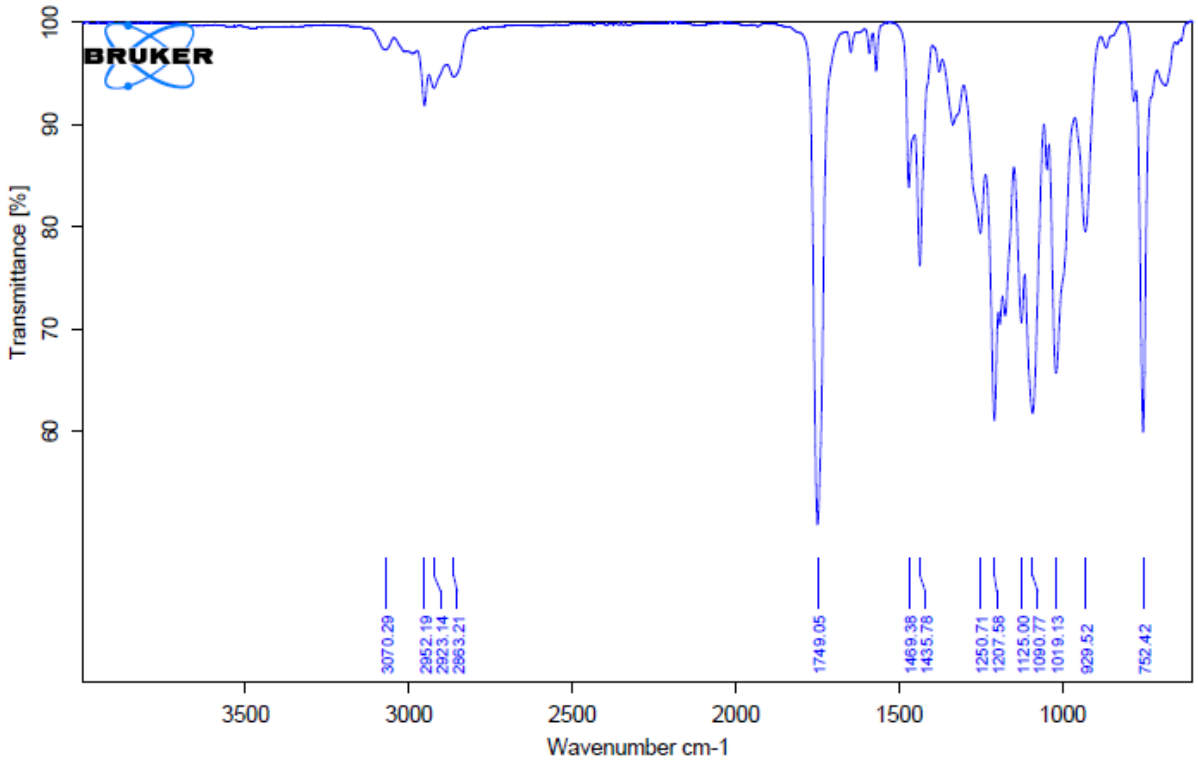
^{1}H NMR (500 MHz, $CDCl_3$) Methyl 2-(allyloxy)-2-(2-bromophenyl)acetate **39**



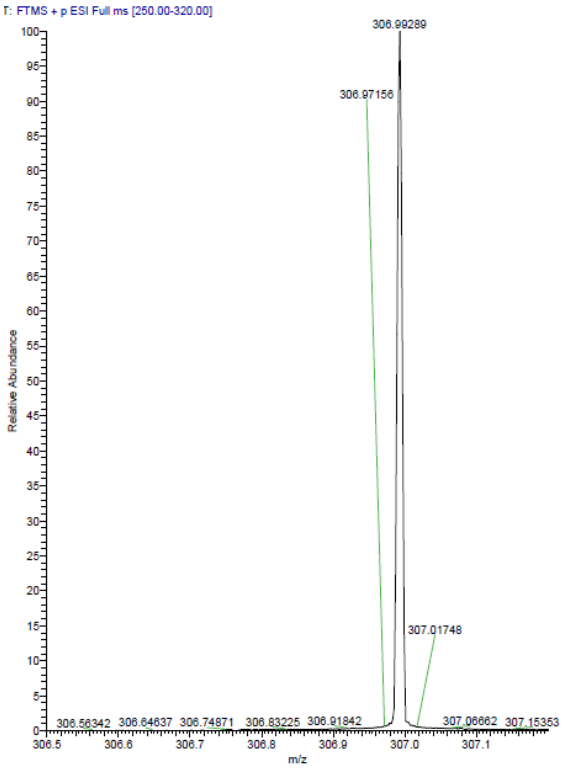
^{13}C NMR (125 MHz, $CDCl_3$) Methyl 2-(allyloxy)-2-(2-bromophenyl)acetate **39**



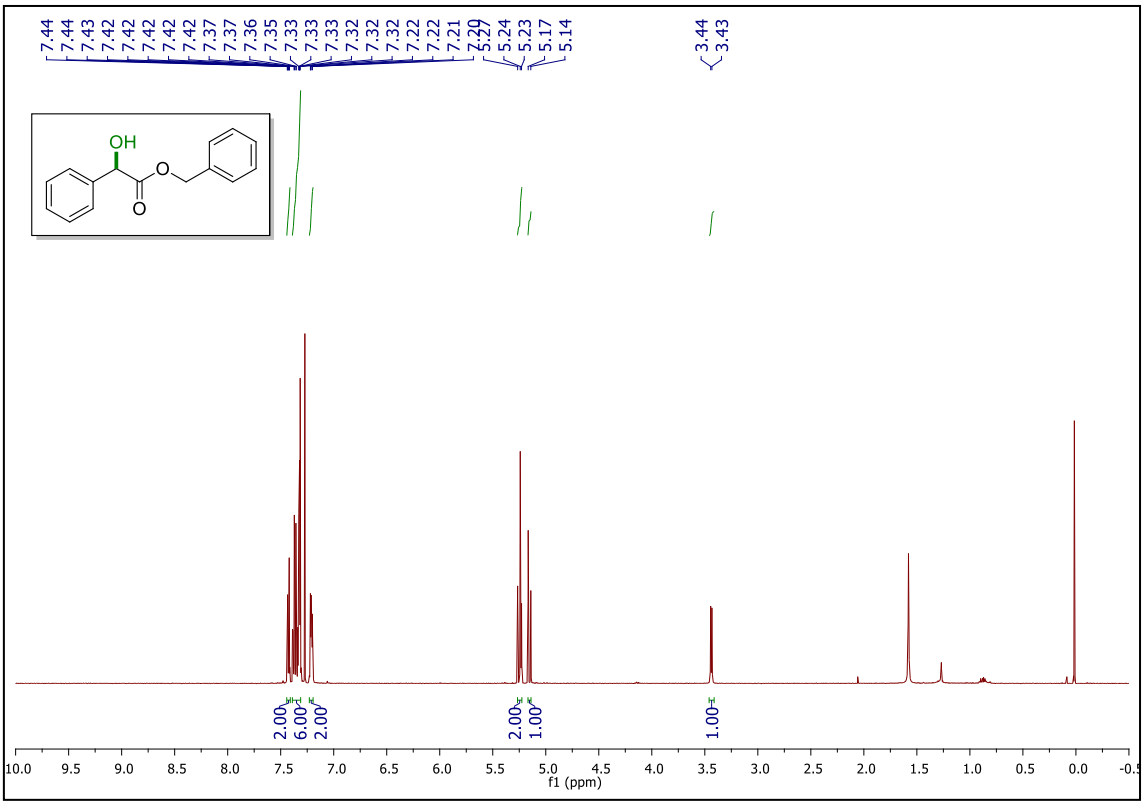
IR Methyl 2-(allyloxy)-2-(2-bromophenyl)acetate **39**



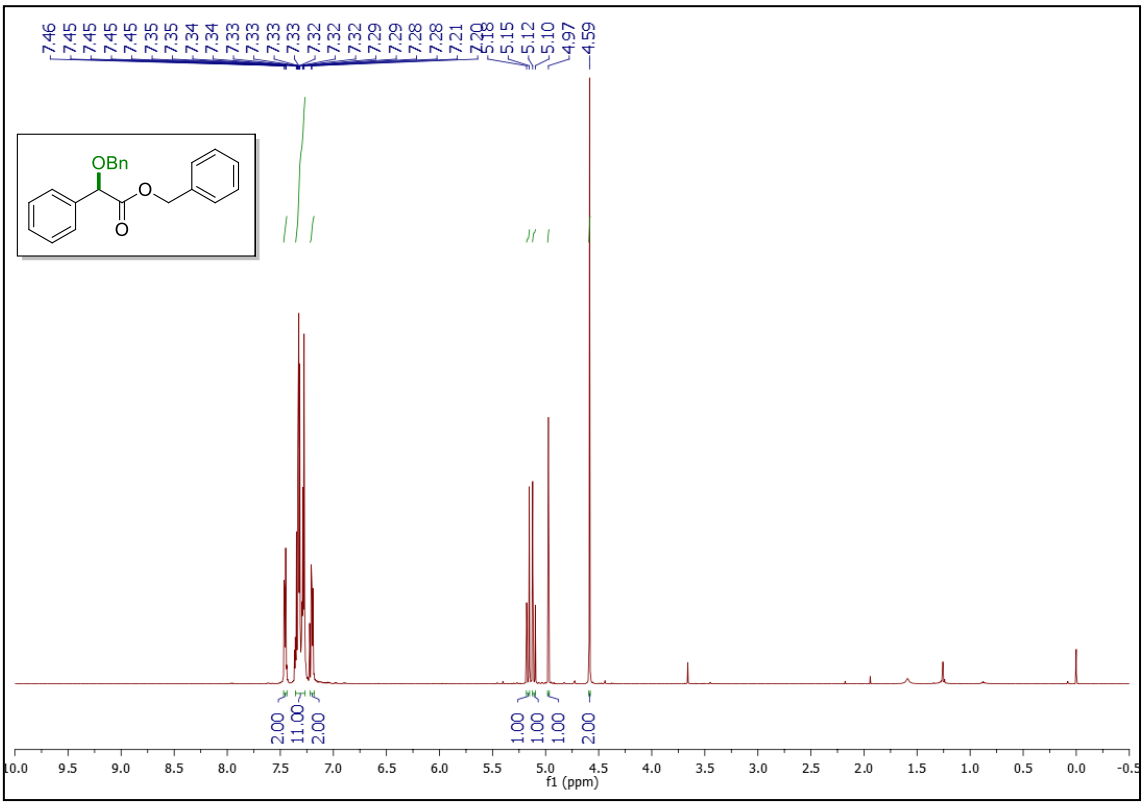
HRMS (ESI-TOF) Methyl 2-(allyloxy)-2-(2-bromophenyl)acetate **39**



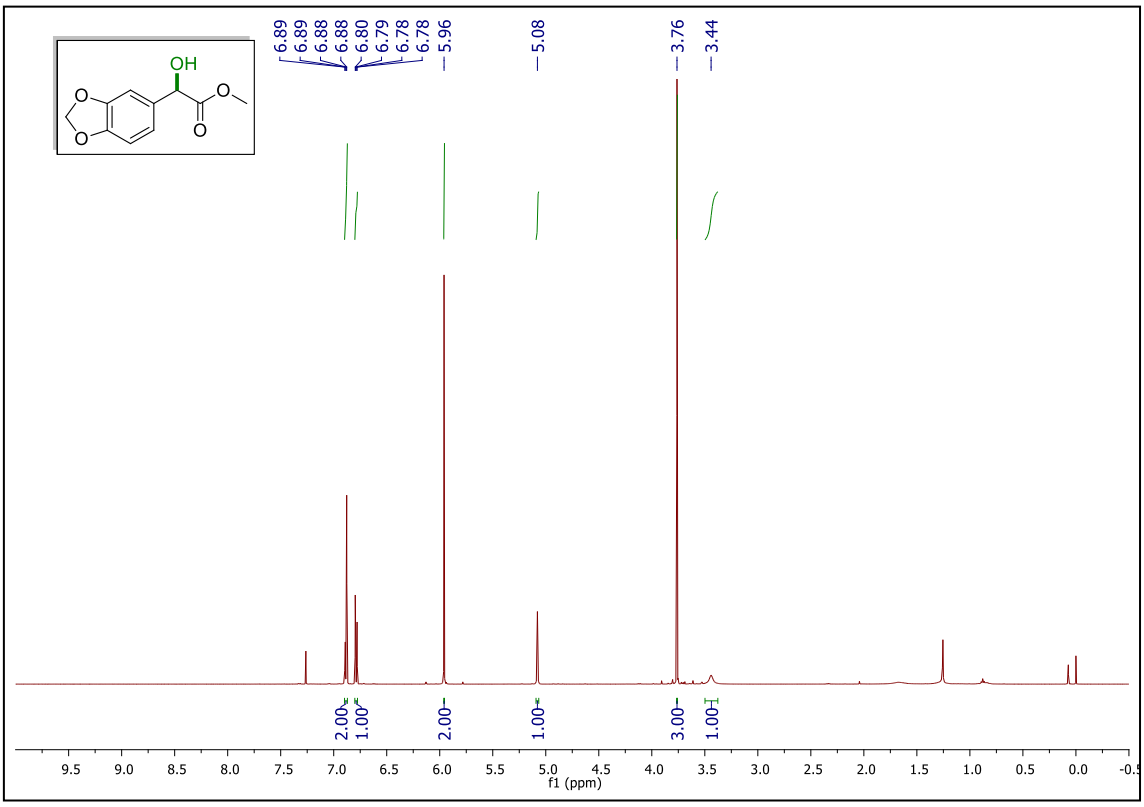
^{1}H NMR (500 MHz, $CDCl_3$) Benzyl 2-hydroxy-2-phenylacetate **40**



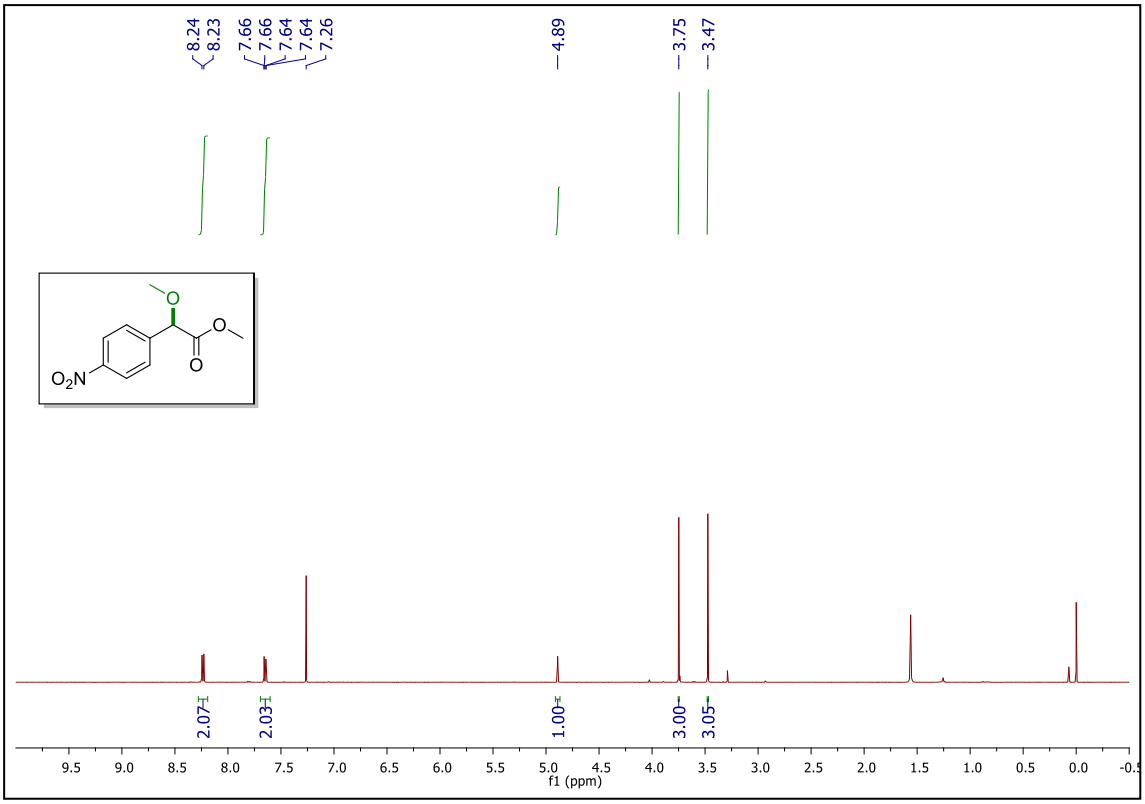
^{1}H NMR (500 MHz, $CDCl_3$) Benzyl 2-benzyloxy-2-phenylacetate **41**



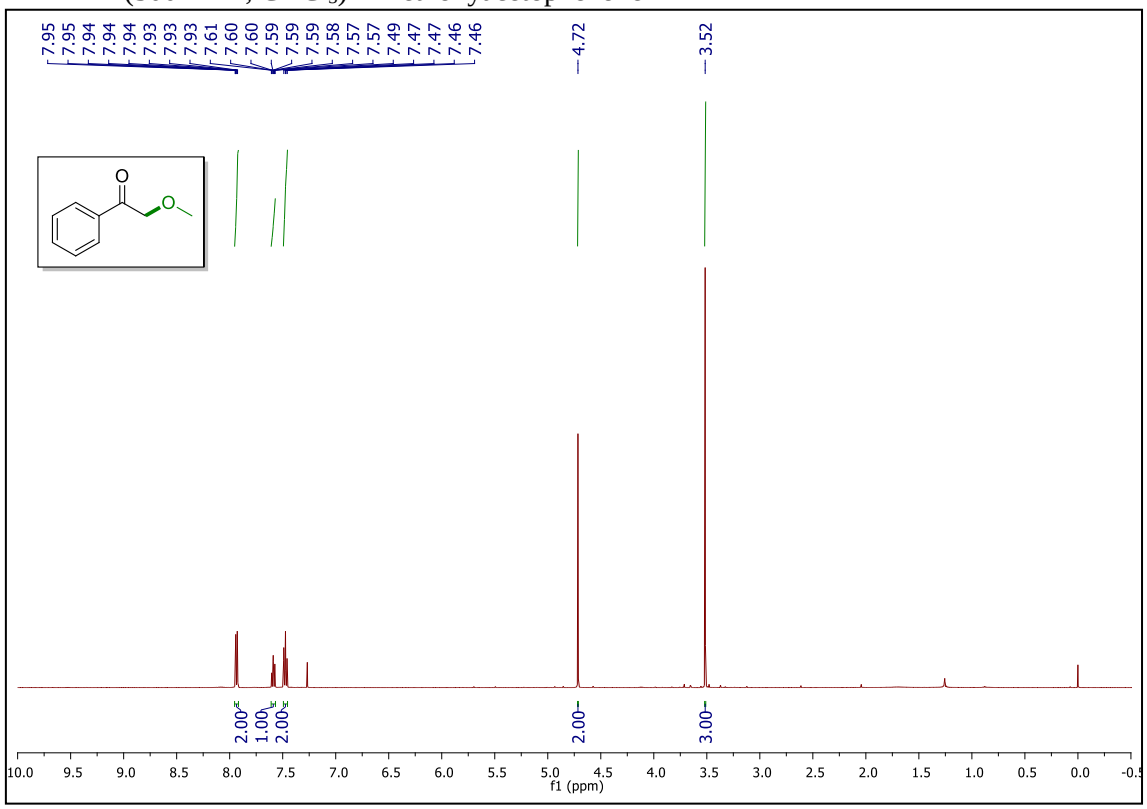
^{1}H NMR (500 MHz, $CDCl_3$) Methyl 2-(benzo[d][1,3]dioxol-5-yl)-2-methoxyacetate **42**



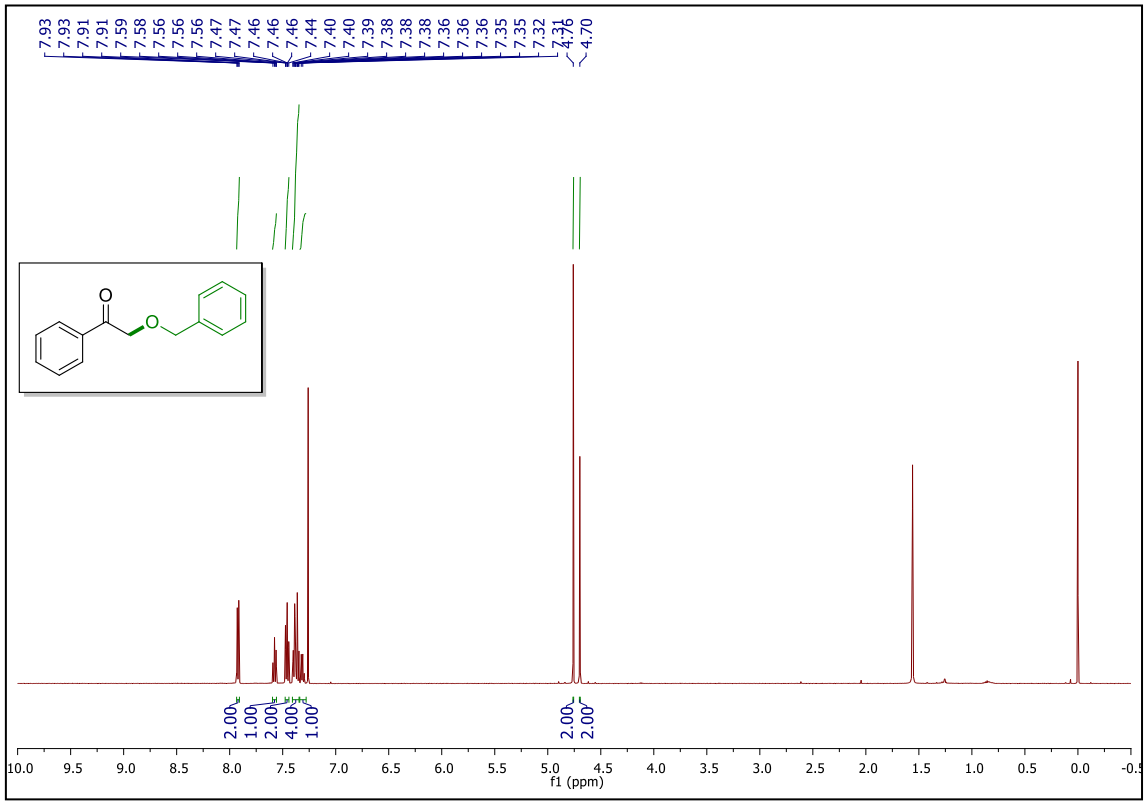
^{1}H NMR (500 MHz, $CDCl_3$) methyl 2-methoxy-2-(4-nitrophenyl)acetate **43**



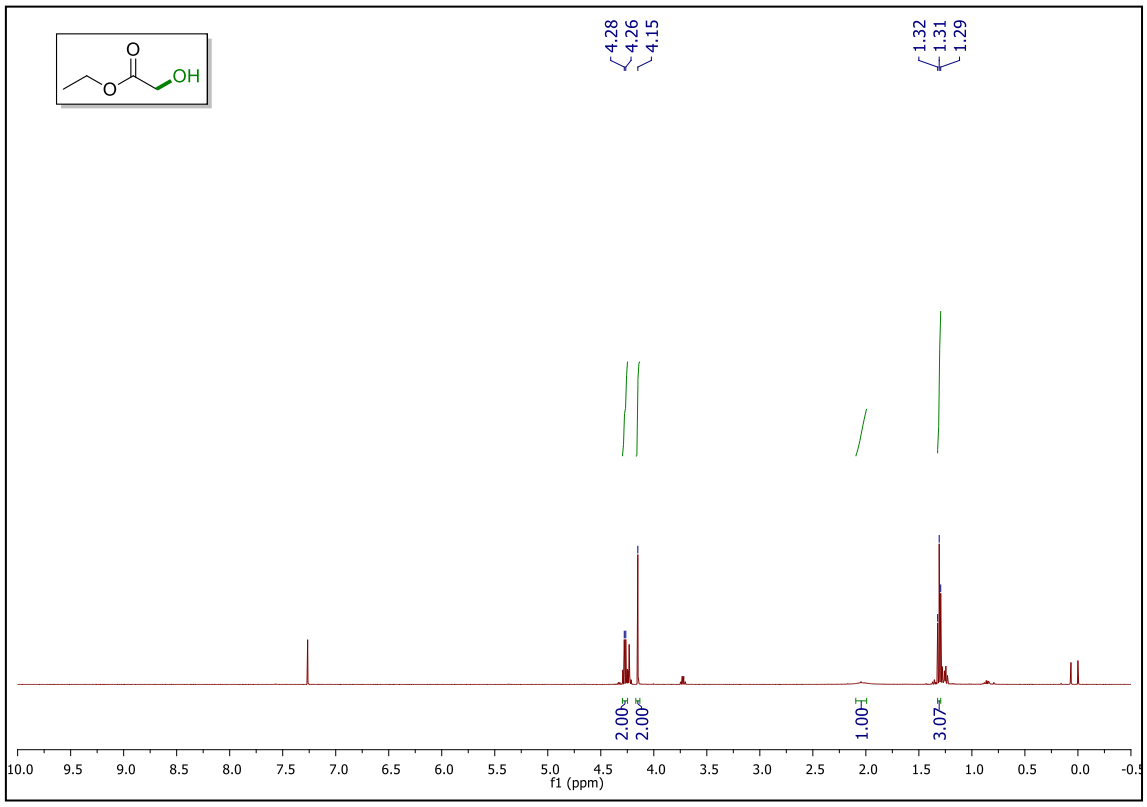
^{1}H NMR (500 MHz, $CDCl_3$) 2-methoxyacetophenone **44**



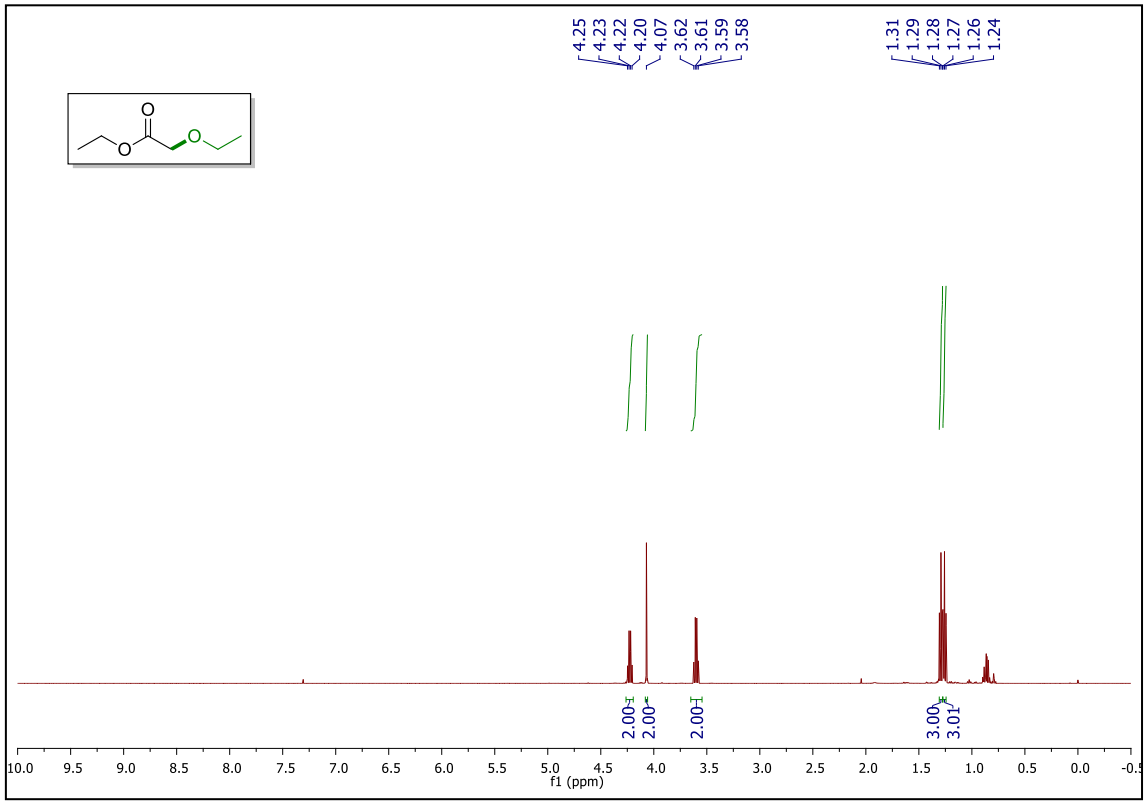
^{1}H NMR (500 MHz, $CDCl_3$) 2-(benzyloxy)-1-phenylethan-1-one **45**



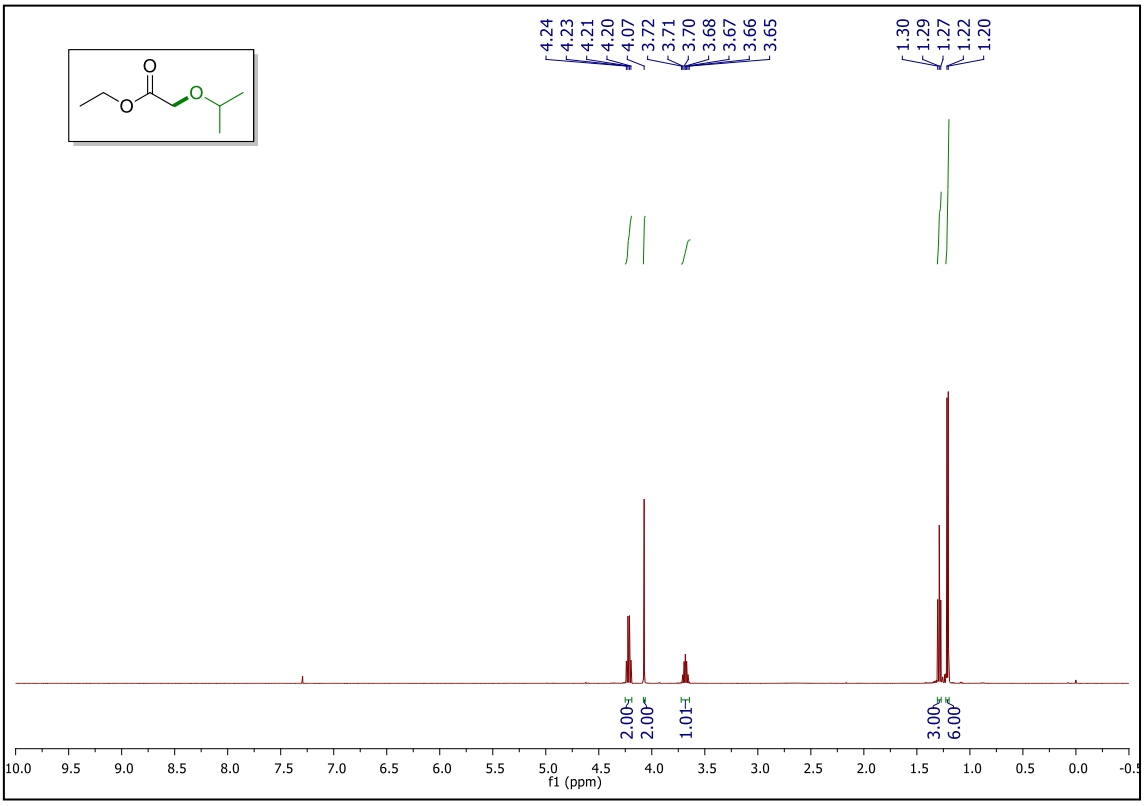
^{1}H NMR (500 MHz, $CDCl_3$) Ethyl 2-hydroxyacetate **46**



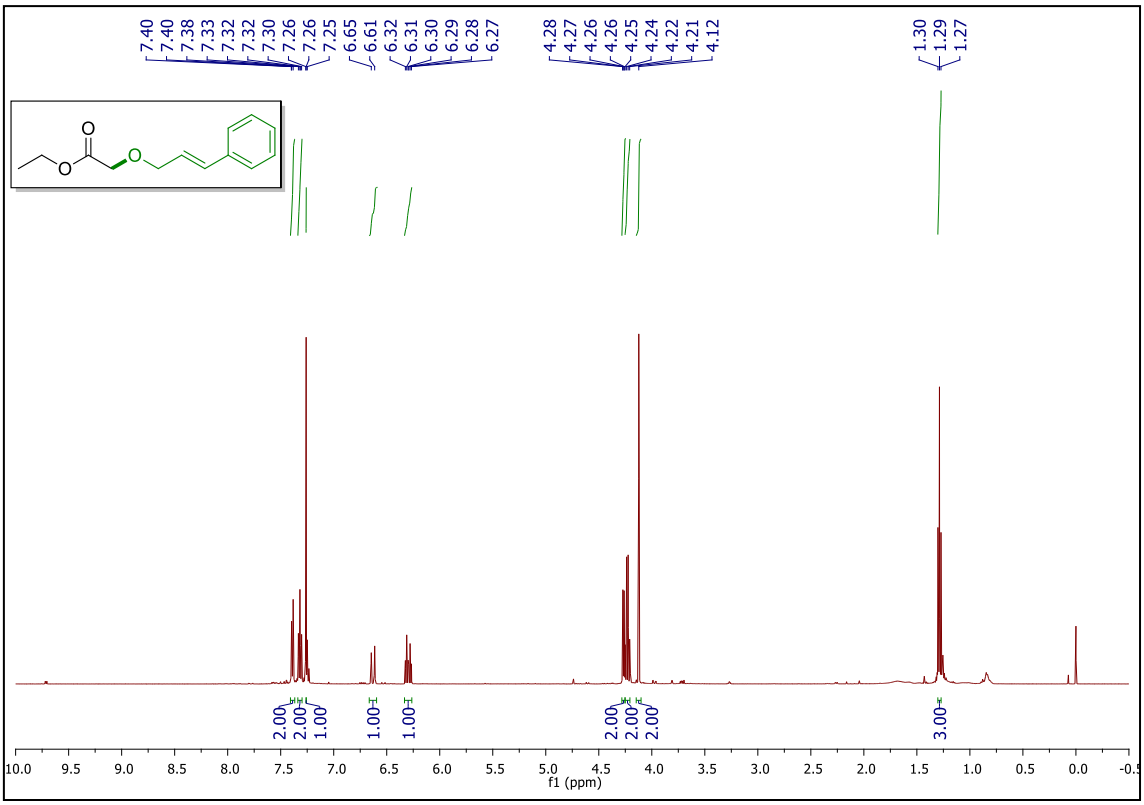
^{1}H NMR (500 MHz, $CDCl_3$) Ethyl 2-methoxyacetate **47**



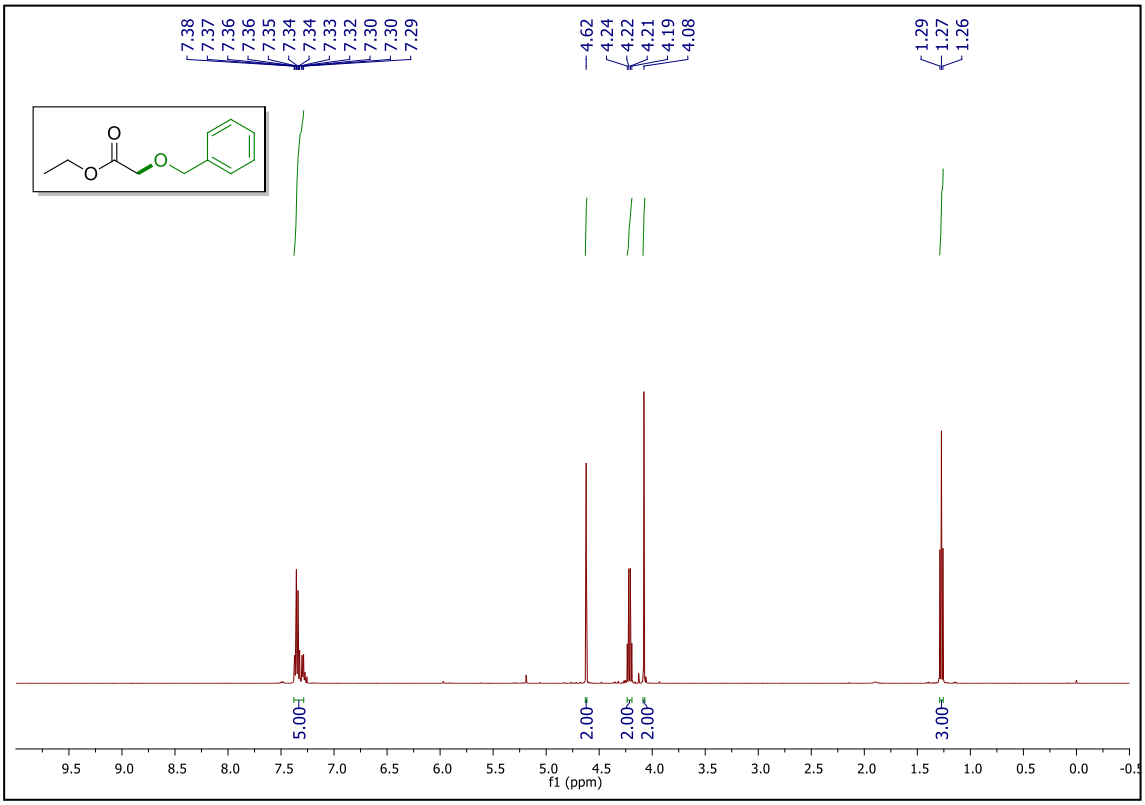
^{1}H NMR (500 MHz, $CDCl_3$) Ethyl isopropoxyacetate **48**



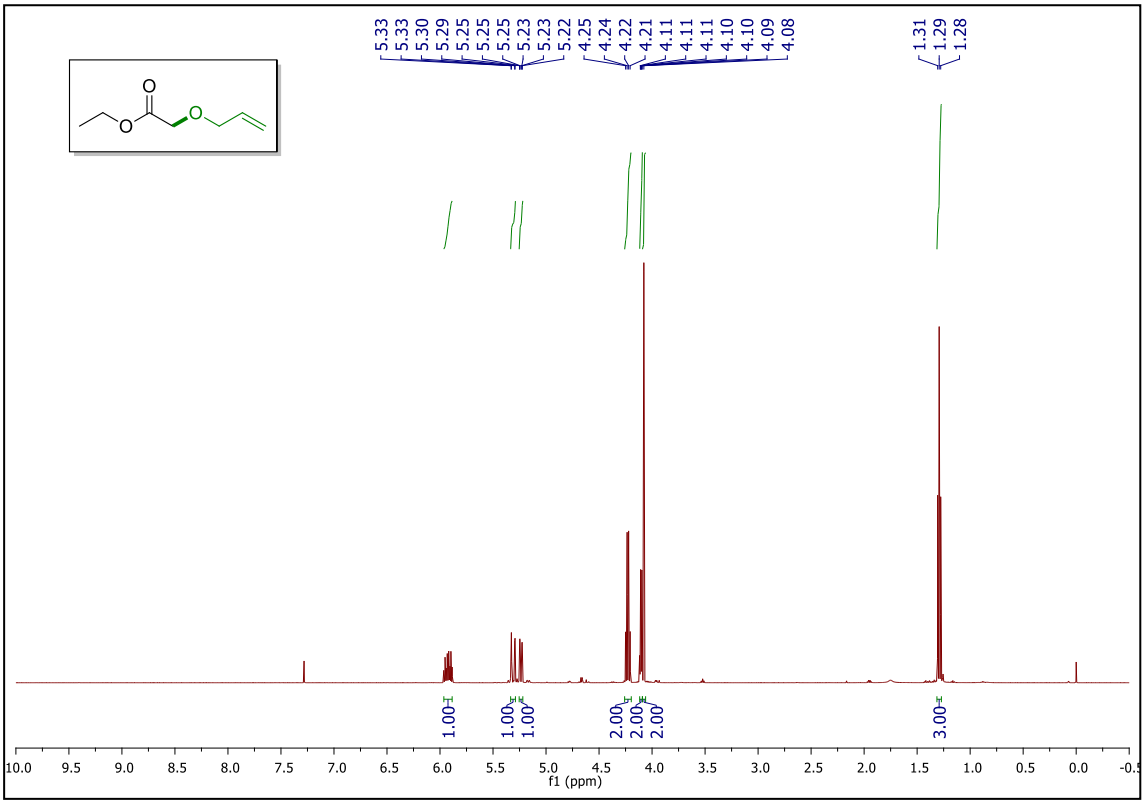
^{1}H NMR (500 MHz, $CDCl_3$) Ethyl (E)-(3-phenylallyloxy)acetate **49**



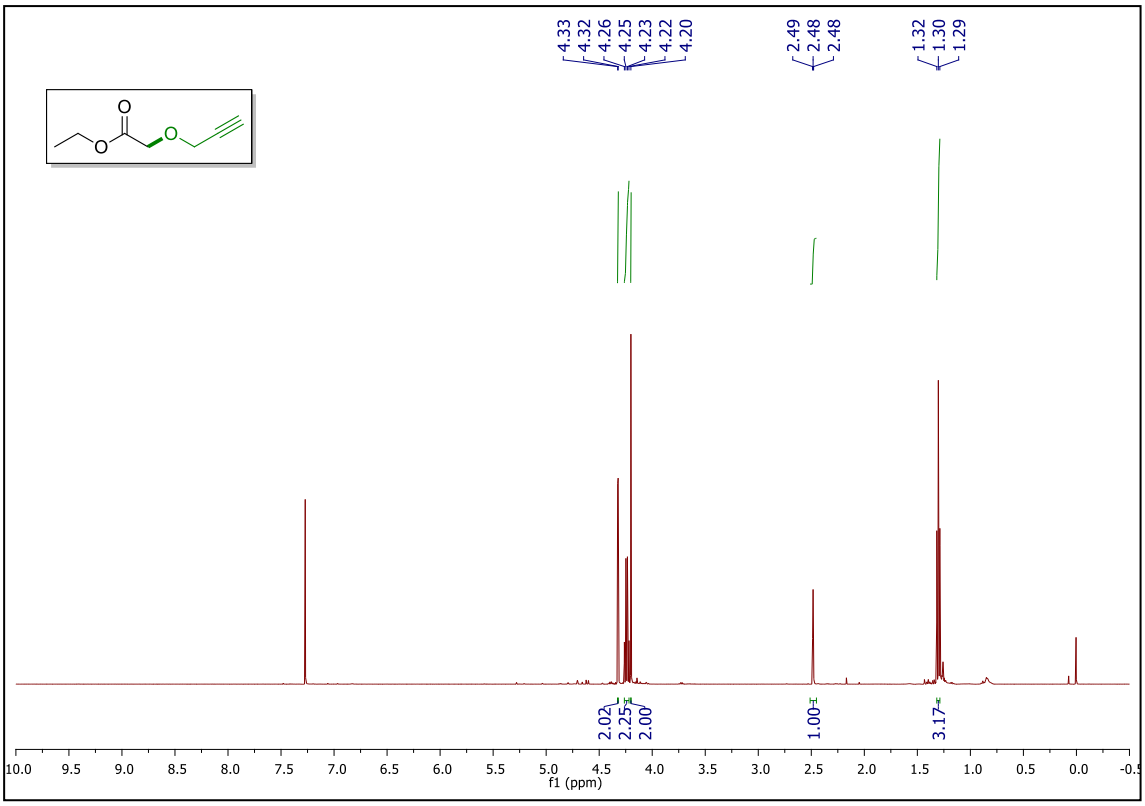
^{1}H NMR (500 MHz, $CDCl_3$) Ethyl benzyloxyacetate **50**



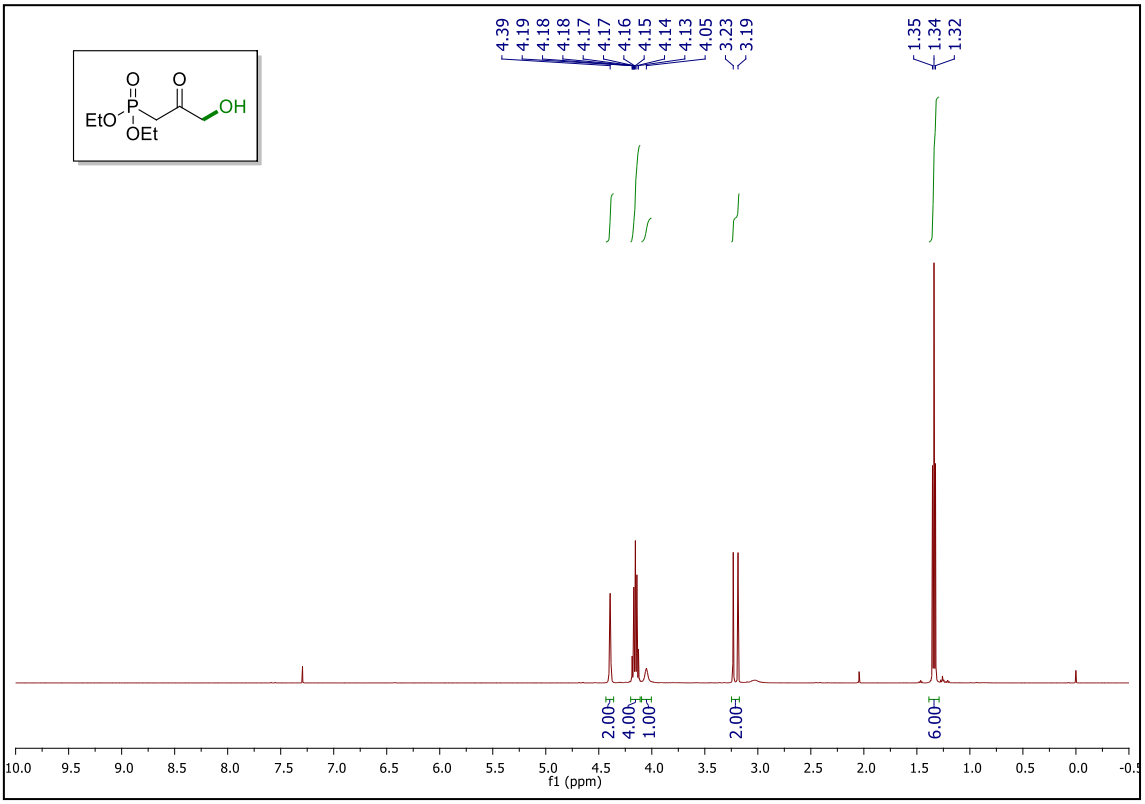
^{1}H NMR (500 MHz, $CDCl_3$) 2-(Allyloxy)ethyl acetate **51**



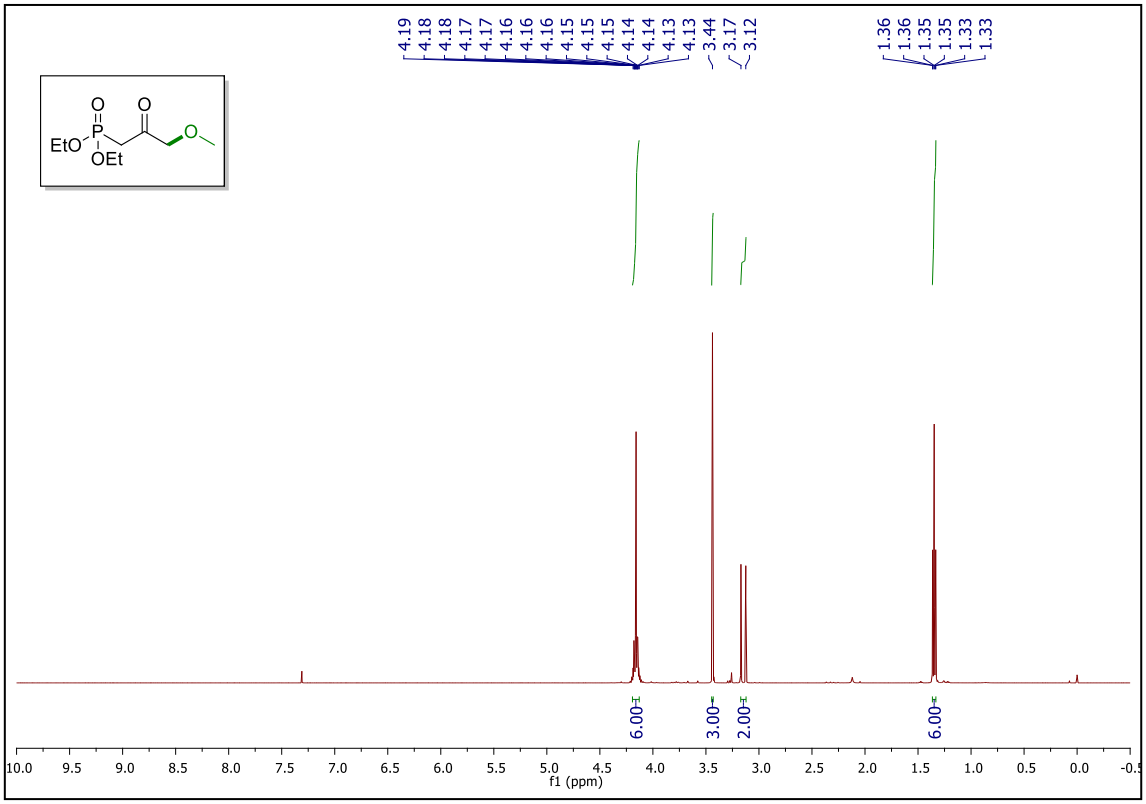
^{1}H NMR (500 MHz, $CDCl_3$) Ethyl 2-(prop-2-yn-1-yloxy)acetate **52**

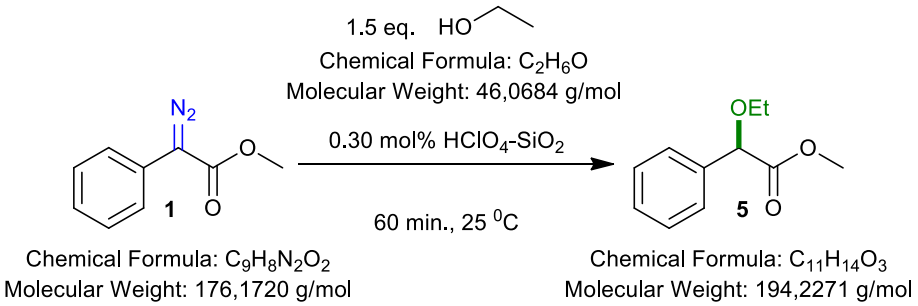


^{1}H NMR (500 MHz, $CDCl_3$) Hydroxy-3 oxo-2 propylphosphonate de diethyle **53**



^{1}H NMR (500 MHz, $CDCl_3$) Diethyl 3-methoxy-2-oxopropylphosphonate **54**





1 0.3 mmol = 52.85 mg

Alcohol 0.45 mmol = 20.73 mg

$HClO_4$-SiO_2 0.3 mol% = 6.42 mg

Purification:

The reaction was filtered with sintered glass disc using 1 mL of ethyl acetate.

Yield of **5**: 54.2 mg = 93%

Metrics calculation

Atom economy (AE):

Atom Economy calculation, introduced in 1991 by Trost, estimates the amount of reagents (substrates, solvents, catalysts) that will be incorporated into the final desired product.

$$AE = \frac{m.w.\ of\ product\ \mathbf{5}}{m.w.\ of\ \mathbf{1} + m.w.\ alcohol}$$

$$AE = \frac{194.22}{176.17+46.06} \times 100$$

Atom economy (AE): **87.39%**

Ref. 1: B. M. Trost, *Science*, 1991, **254**, 1471.

Carbon efficiency (CE):

The CE metric estimate the percentage of carbon in the reagents used in the process that remain in the final desired product.

$$CE = \frac{Amount\ of\ carbon\ in\ product}{Total\ carbon\ present\ in\ reactants} \times 100$$

$$CE = \frac{11 \times 0.279\ mmol}{(0.30\ mmol \times 9) + (0.45\ mmol \times 2)} \times 100$$

Carbon efficiency (CE): **85.25%**

Ref. 2: A. D. Curzons, D. J. C. Constable, D. N. Mortimer and V. L. Cunningham, *Green Chem.*, 2001, **3**, 1–6.

Reaction mass efficiency (RME):

The RME considers the mass of product divided by total mass of reactants stoichiometric. That metric also offers a better and easy way of identification of the best or the worst reactions that have influence on whole industrial process or synthesis.

RME = $\frac{Mass\ of\ product\ \mathbf{5}}{Mass\ of\ \mathbf{1} + Mass\ of\ alcohol}$ x 100

RME = $\frac{54.2}{52.85+20.73}$ x 100

Reaction mass efficiency (RME) = **73.66%**

Ref. 2: A. D. Curzons, D. J. C. Constable, D. N. Mortimer and V. L. Cunningham, *Green Chem.*, 2001, **3**, 1–6.

Mass intensity (MI):

Mass intensity considers the yield, stoichiometry, the solvent, and the reagent used in the reaction mixture using the total mass in a process divided by the mass of product.

(MI) = $\frac{Total\ mass\ used\ in\ a\ process\ or\ process\ step\ (\mathrm{kg})}{Mass\ of\ product\ \mathbf{5}\ (\mathrm{kg})}$

(MI) = $\frac{52.85+20.73+6.42+897}{54.2}$

Mass intensity (MI) = **18 kg/kg**

Ref. 2: A. D. Curzons, D. J. C. Constable, D. N. Mortimer and V. L. Cunningham, *Green Chem.*, 2001, **3**, 1–6.

Mass productivity (MP):

This metric express mass intensity as its reciprocal and making it a percentage.

(MP) = $\frac{1}{Mass\ intensify}$ x 100

(MP) = $\frac{1}{18}$ x 100

Mass productivity (MP) = **5.5%**

Ref. 2: A. D. Curzons, D. J. C. Constable, D. N. Mortimer and V. L. Cunningham, *Green Chem.*, 2001, **3**, 1–6.

E factor:

E-factor is defined by comparison of waste produced for a given quantity of product. The ideal value is zero.

E factor = $\frac{Total\ waste\ (\mathrm{kg})}{kg\ product\ \mathbf{5}}$

E factor = $\frac{6.42+897+6.91}{54.2}$

E factor = **16.8**

E factor can also be defined as MI – 1.

Ref. 3: R. A. Sheldon, *Chem. Ind. (London)*, 1992, 903–906; R. A. Sheldon, *Chem. Ind. (London)*, 1997, 12–15.