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SUPPORTING INFORMATION

Title: The First Catalytic Method for Heck Alkynylation of Unactivated Aryl Bromides (Copper-Free Sonogashira) in an Ionic Liquid: 1 mol-% Palladium/Triphenylphosphane/Pyrrolidine in [BMIM][BF_4] as a Simple, Inexpensive and Recyclable System

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Ref. No.: O200600976

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Experimental Procedures

Generality. All reactions and workup procedures were performed under inert atmosphere of argon using conventional vacuum-line and glasswork techniques. The solids (catalyst and reagents) and the ionic liquid (IL) were degassed under vacuum before use. The organic and organometallic products were received from commercial sources and used without further purification. Chromatography was performed on silica gel (230-400 mesh, Merck Kieselgel 60). GC, GC-MS, and NMR experiments[1-9] were performed in our laboratories on Shimadzu GC-2014, Hewlett-Packard HP-6890 series and Bruker Avance 300, respectively.

Representative catalytic experiment for the Heck alkynylation reaction in [BMIM][BF_4].

The ionic liquid [BMIM][BF_4] was synthesized following the method described in the literature.[10] This IL is also commercially available (see for instance at SOLVIONIC.com). The solid mixture of [Pd(allyl)Cl_2] (6.3 mg, 0.03416 mmol of Pd), triphenylphosphine (26.9 mg, 0.10256 mmol) and 4-bromoacetophenone (680 mg, 3.416 mmol) was degassed for 15 min in a 20 mL Schlenk tube equipped with a magnetic stirrer bar and a reflux condenser. Under argon were added 3 mL of [BMIM][BF_4]. The mixture was then degassed under reduced pressure for another 10 min. The Schlenk tube was heated in an oil bath at 110°C to give an orange solution. To the ionic liquid solution was added, out of the oil bath, 0.35 mL pyrrolidine (292 mg, 4.099 mmol, d = 0.87) then 0.45 mL phenylacetylene (419 mg, 4.099 mmol, d = 0.93). The resulting mixture was heated at 130°C for 2 h under argon. The product was extracted from the ionic liquid phase by the addition of diethylether (six times 5 or 10 mL) and decanting off the ether from the IL phase (GC yield 88%). After evaporation the residue was purified by silica gel chromatography (diethylether/hexane : 1/9) to give 620 mg (isolated yield 82%) of 4-(2-phenylethynyl)acetophenone.

Recycling experiment for the Heck alkynylation reaction in [BMIM][BF_4]. After extraction with diethylether the resulting dark colored ionic liquid was kept under air for several days or weeks

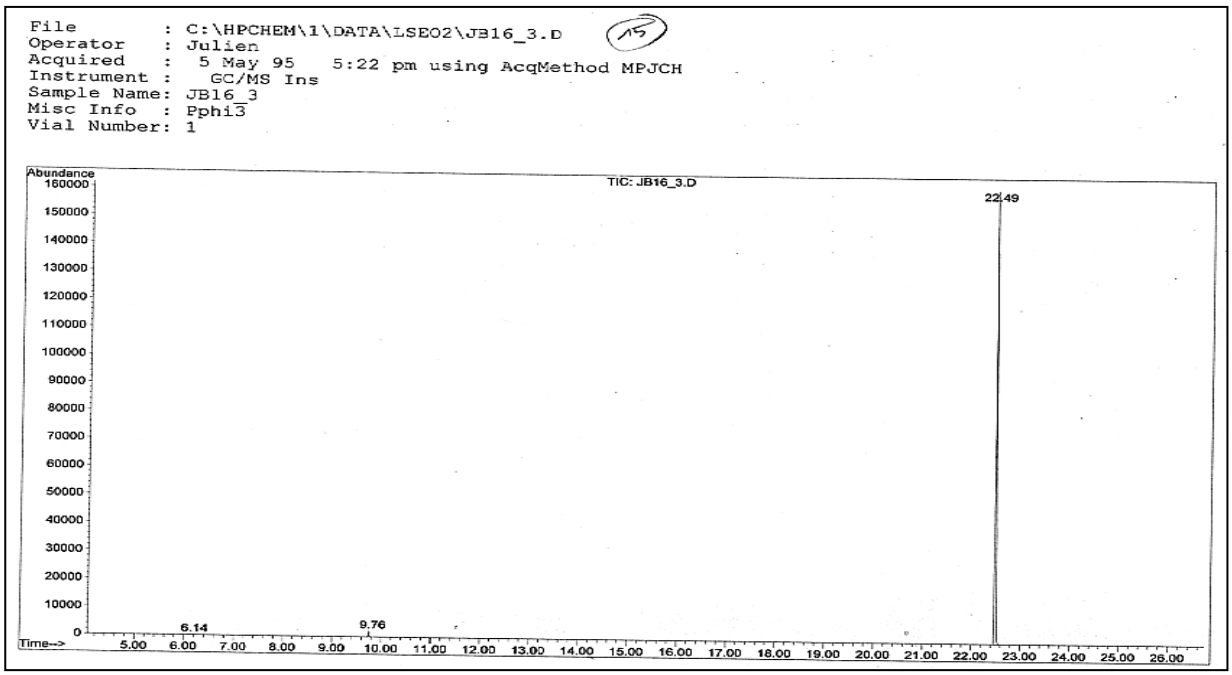
with no particular precaution. The recovered ionic liquid was reused without any pre-treatment (no water washing), but degassed under reduced pressure for 15 min. As phosphine oxide was sometimes detected by GC-MS, the tube was refilled with 26.9 mg triphenylphosphine; the arylhalide was added and the mixture degassed for 15 min. The reaction was carried out and worked-up under the same conditions employed for the first run.

GC and GC-MS data

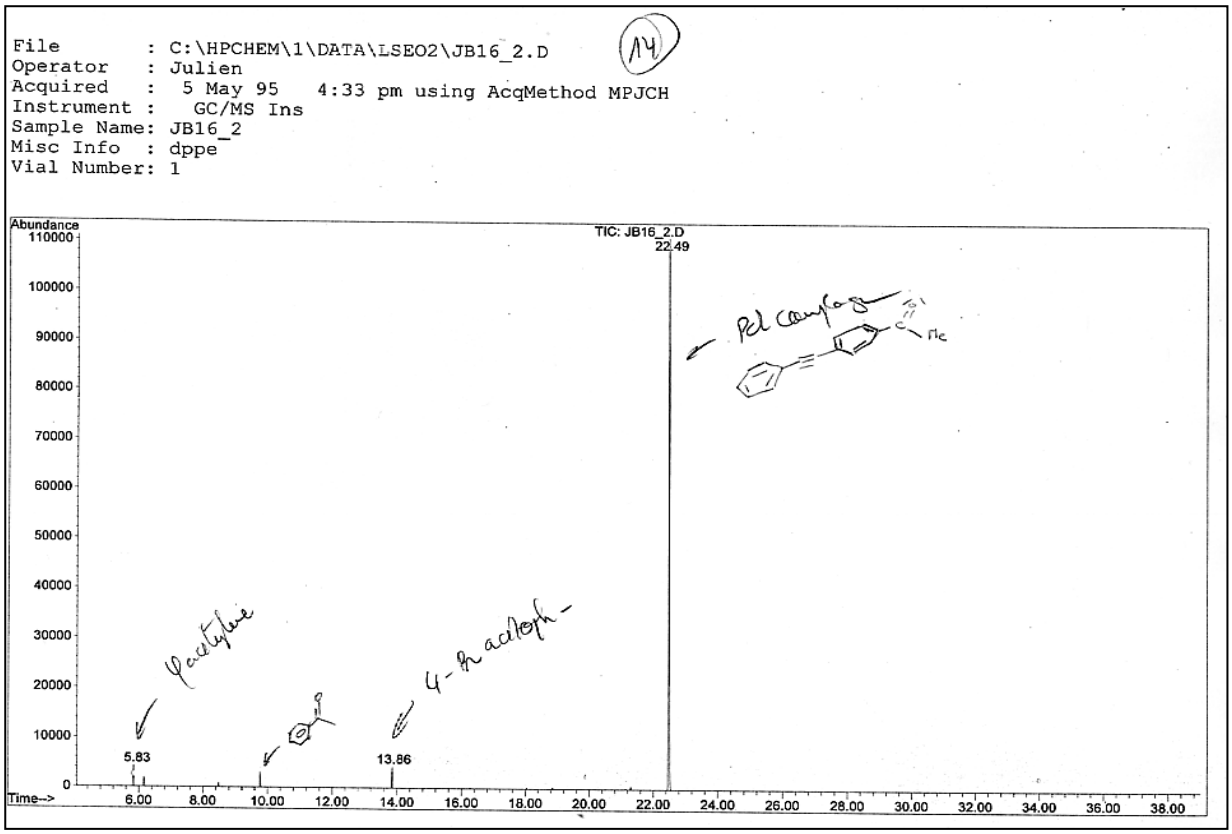
GC and GC-MS experimental conditions. GC yield are based upon external standart calibration from pure starting products and coupling products. The retention time obtained for the reagents and products (see GC and GC/MS chromatogram copy in this supplementary information) were obtained from a Supelco equity-5 capillary column (30m) on a Shimadzu GC-2014, or from a hp-5 capillary column (30m) for the GC-MS; the following program was used in GC-MS and GC for experiments reported in Table 1 to 3: carrier gas He, gas flow 1.3 ml/min (GC-MS); Injector (300°C), oven temperature program: 1 min at 60°C, 20°C/min till 280°C, 5, 10 or 15 min at 280°C, detector FID (300°C) or MSD. A slower heating rate was sometimes used for GC-MS in experiments reported in Table 1, giving longer retention time.

GC chromatogram Table 1, entry 4 and ***Table 2, entry 1***

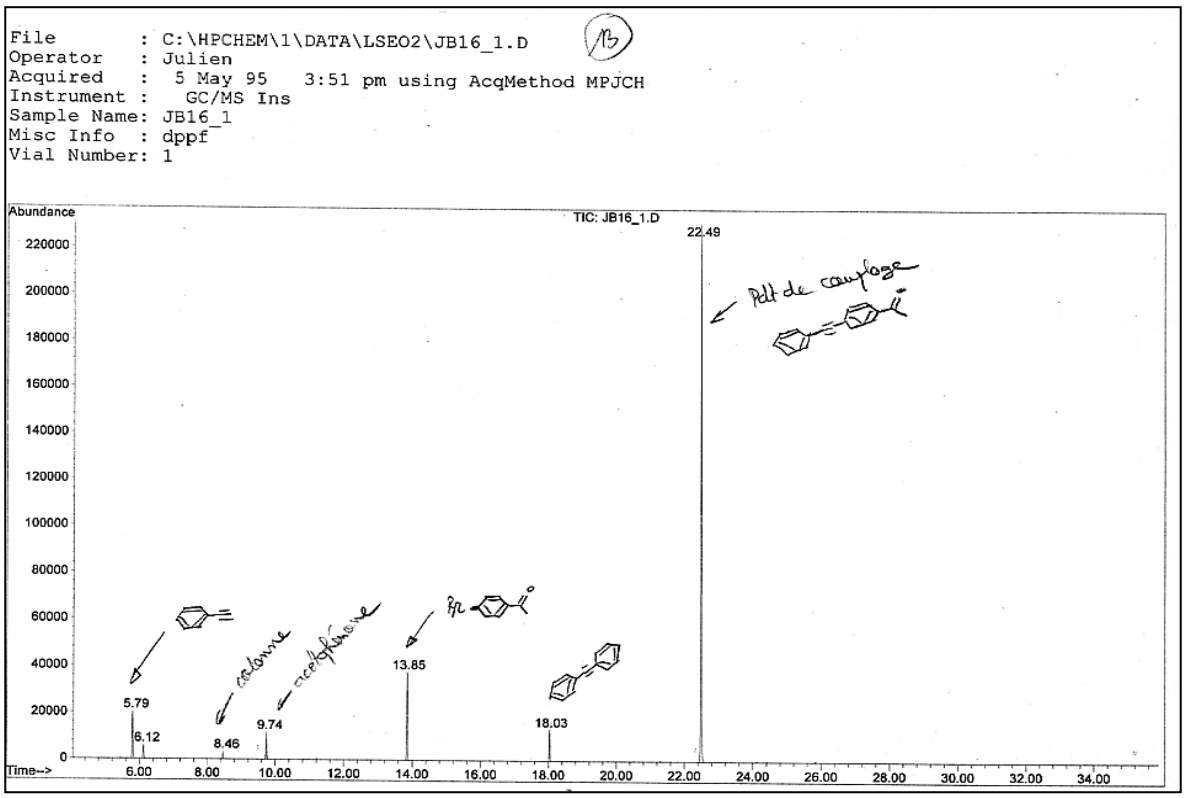
Rt phenylacetylene = 5.83 min
Rt acetophenone = 9.75 min
Rt 4-bromoacetophenone = 13.85 min
Rt 4-(phenylethynyl)acetophenone = 22.49 min



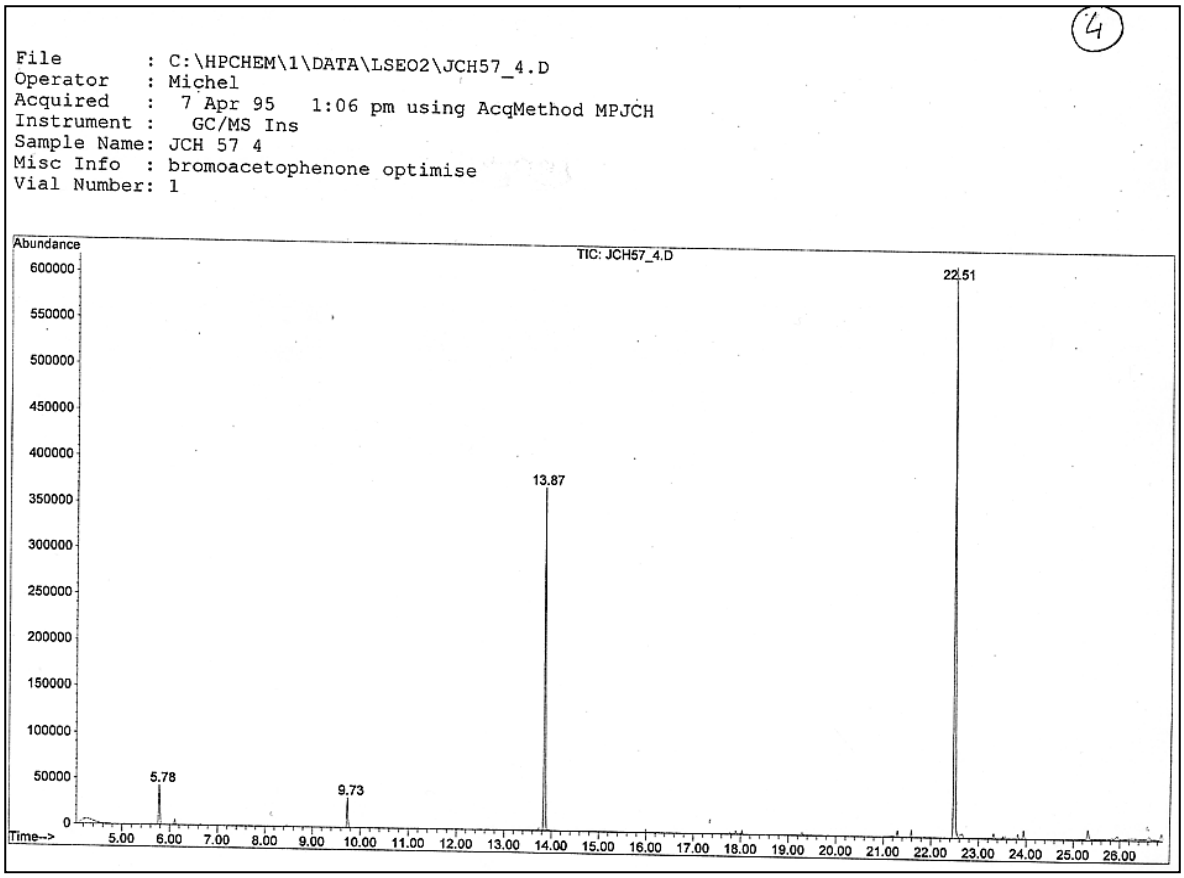
GC chromatogram Table 1, entry 5



GC chromatogram Table 1, entry 6

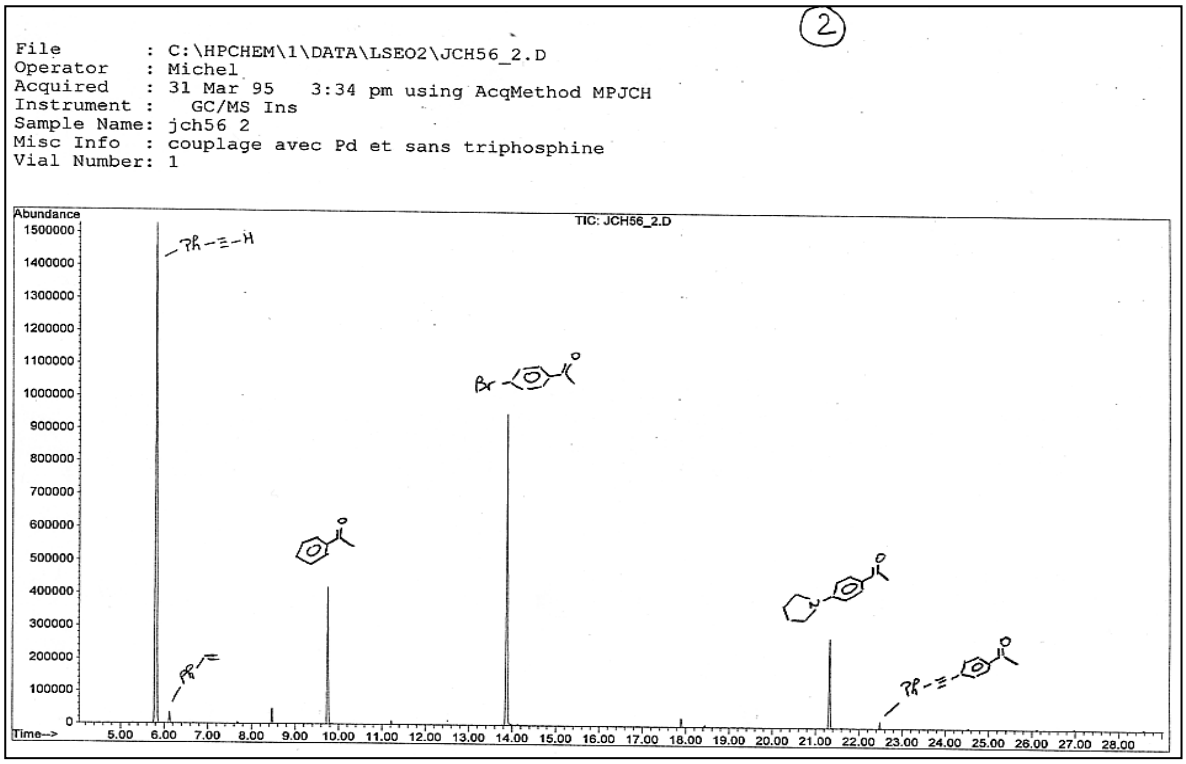


GC chromatogram Table 1, entry 3

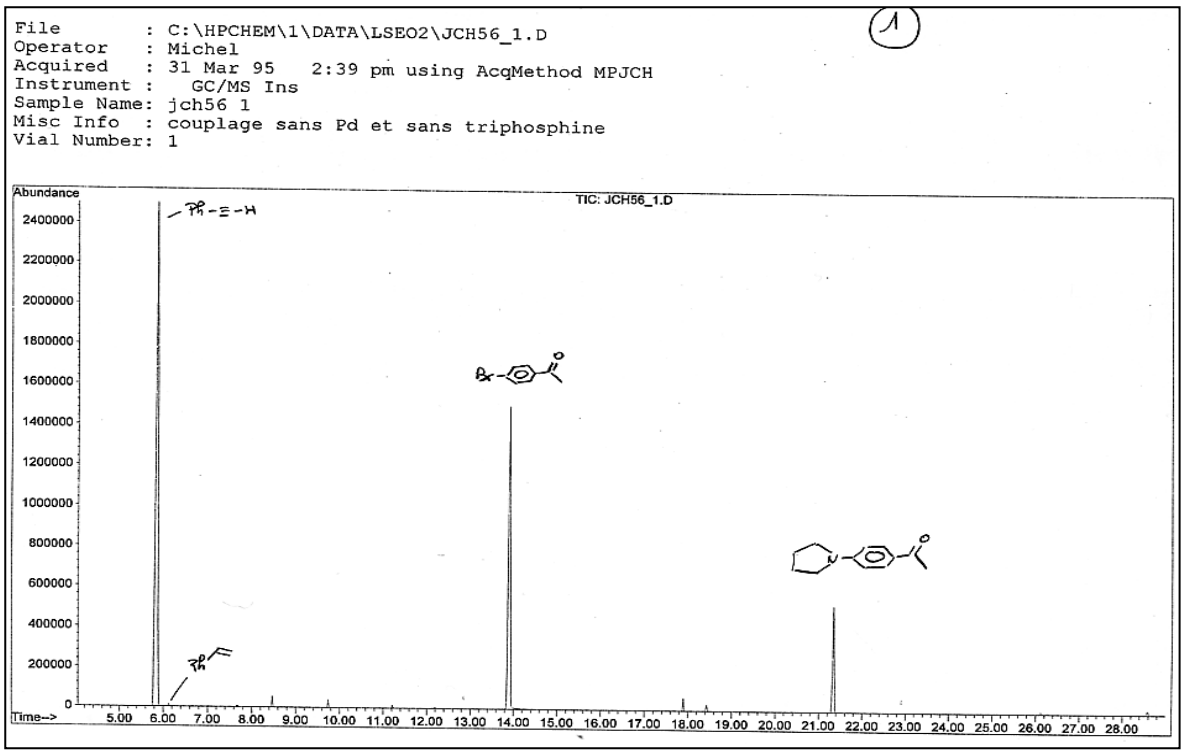


GC chromatogram Table 1, entry 2

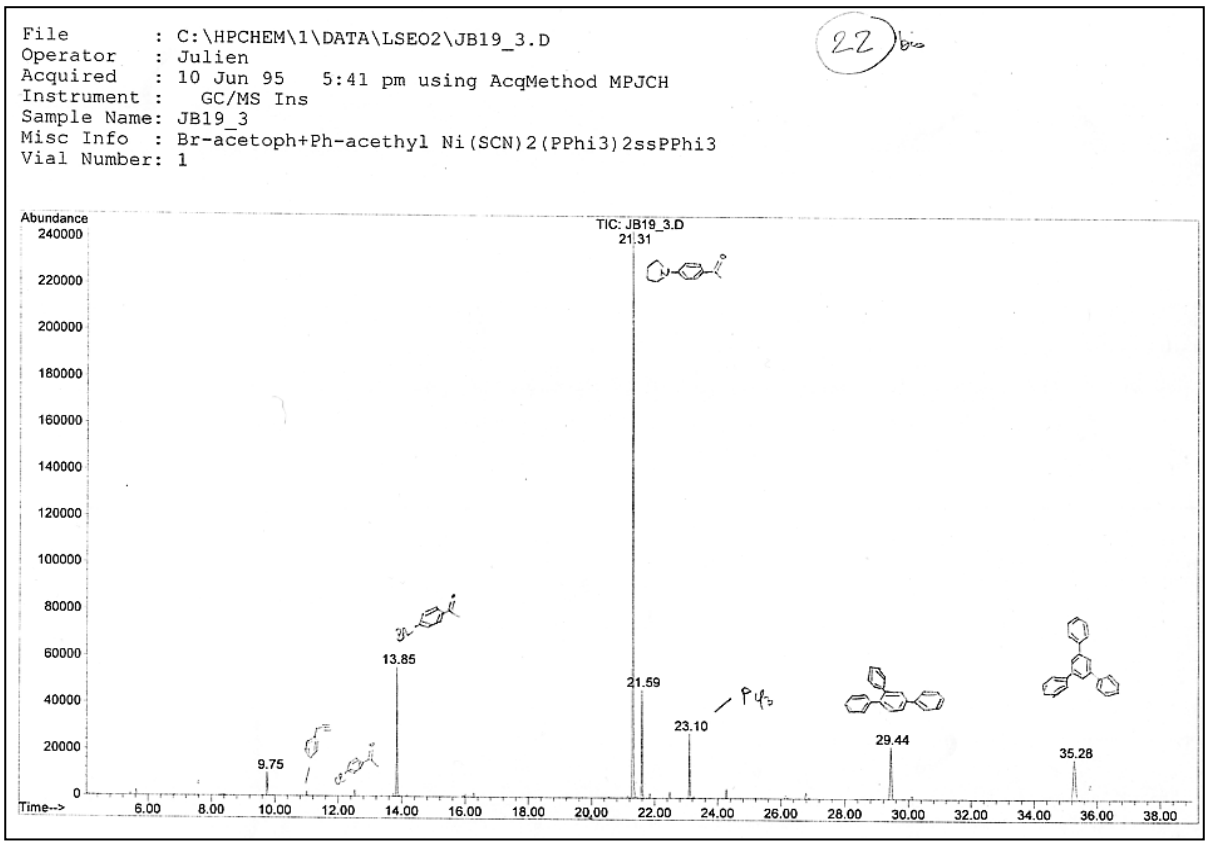
Rt phenylacetylene = 5.83 min
Rt acetophenone = 9.75 min
Rt 4-bromoacetophenone = 13.85 min
Rt 4-(pyrrolidinyl)acetophenone = 21.31 min
Rt 4-(phenylethynyl)acetophenone = 22.49 min



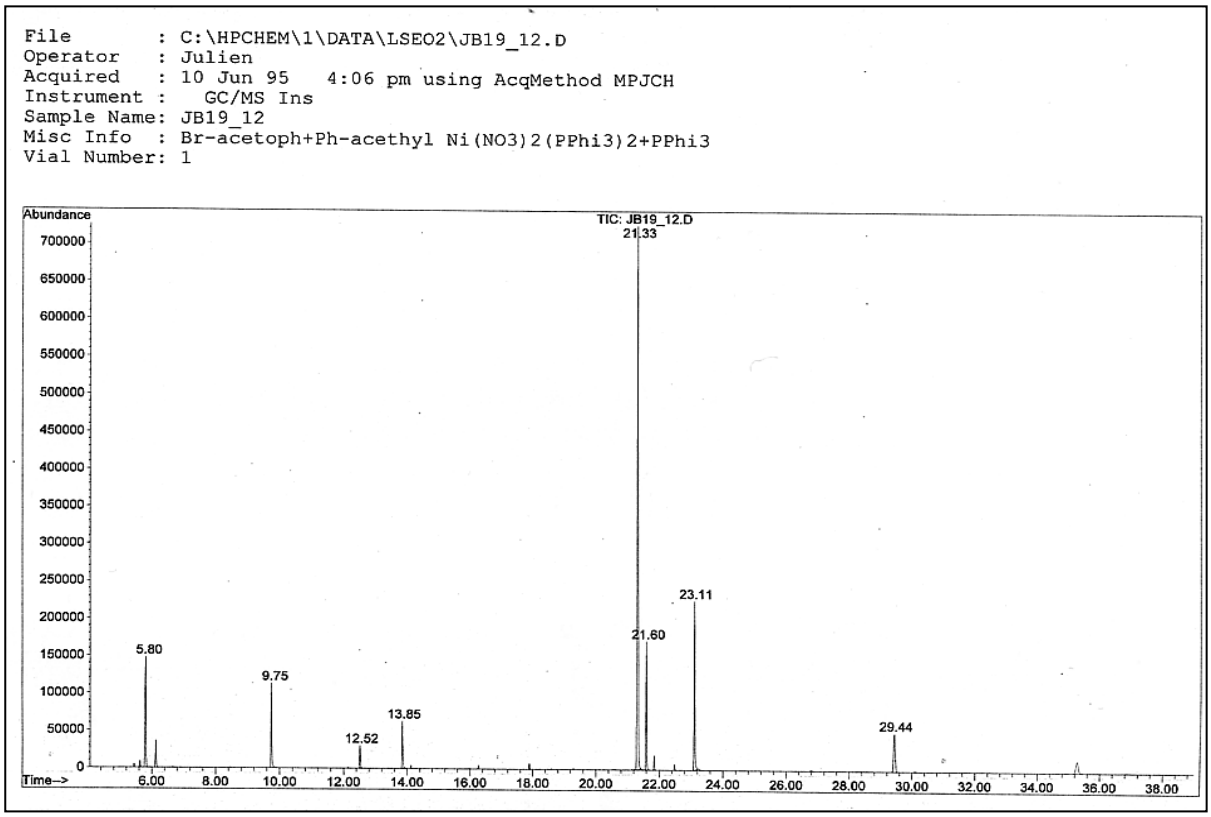
GC chromatogram Table 1, entry 1



GC chromatogram Table 1, entry 10

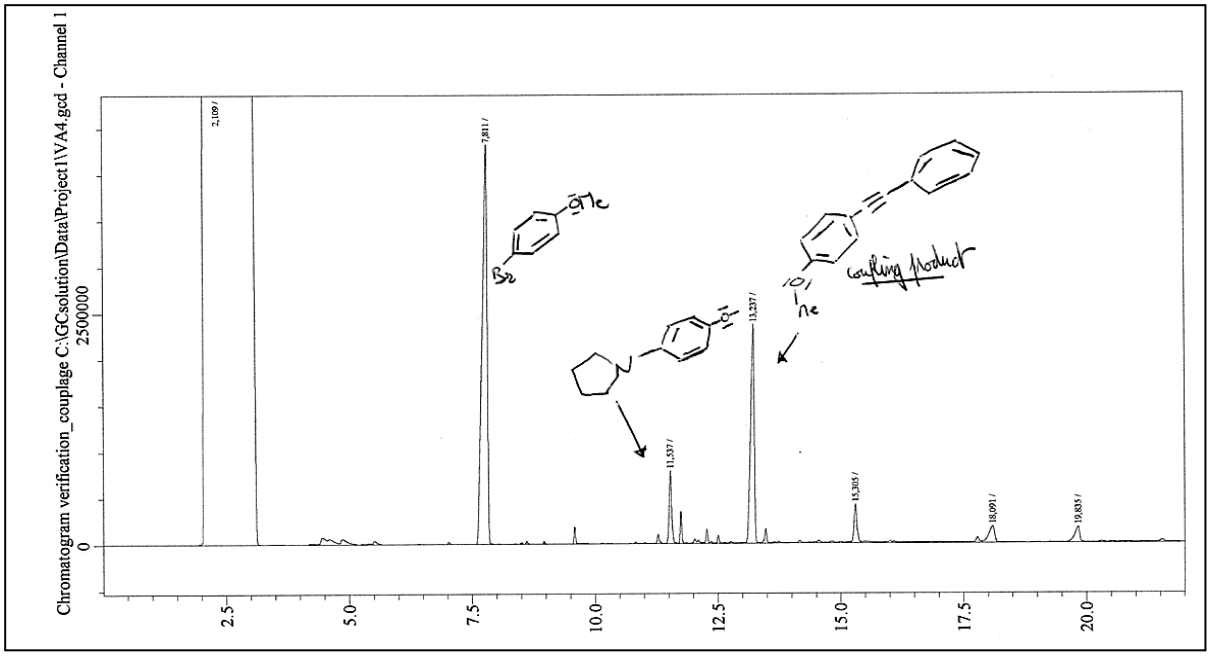


GC chromatogram Table 1, entry 9

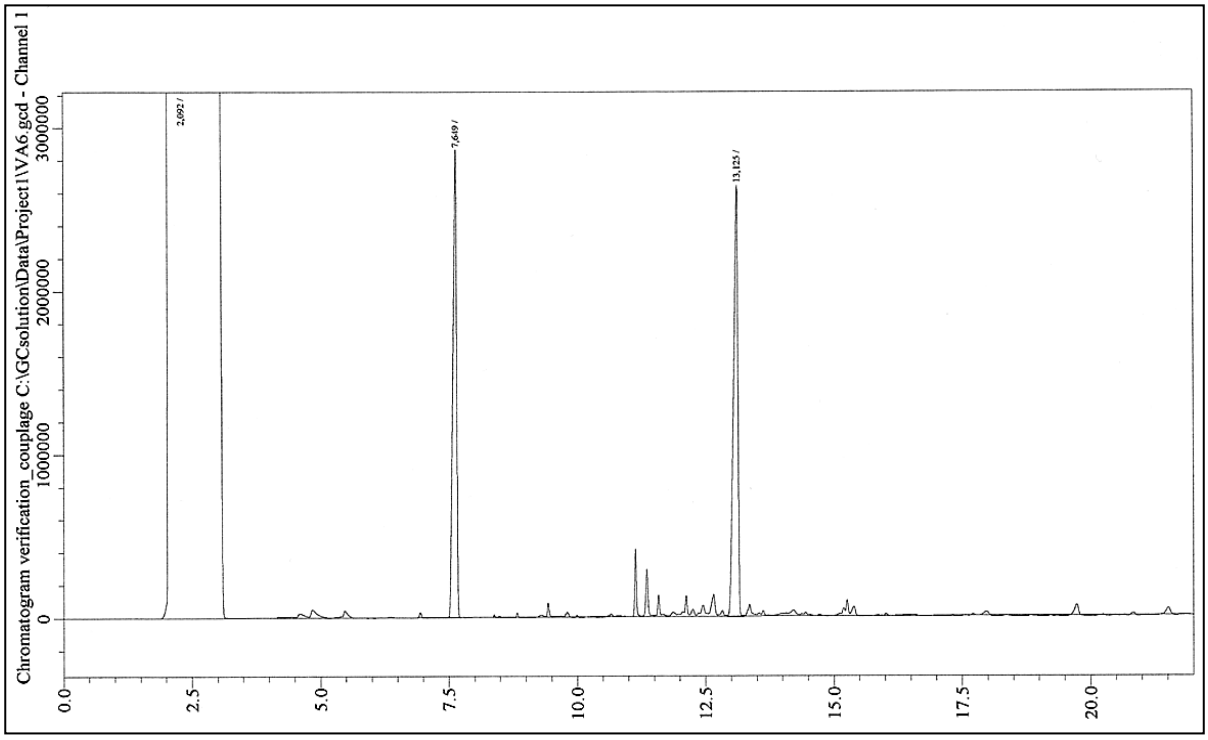


GC chromatogram Table 1, entry 11

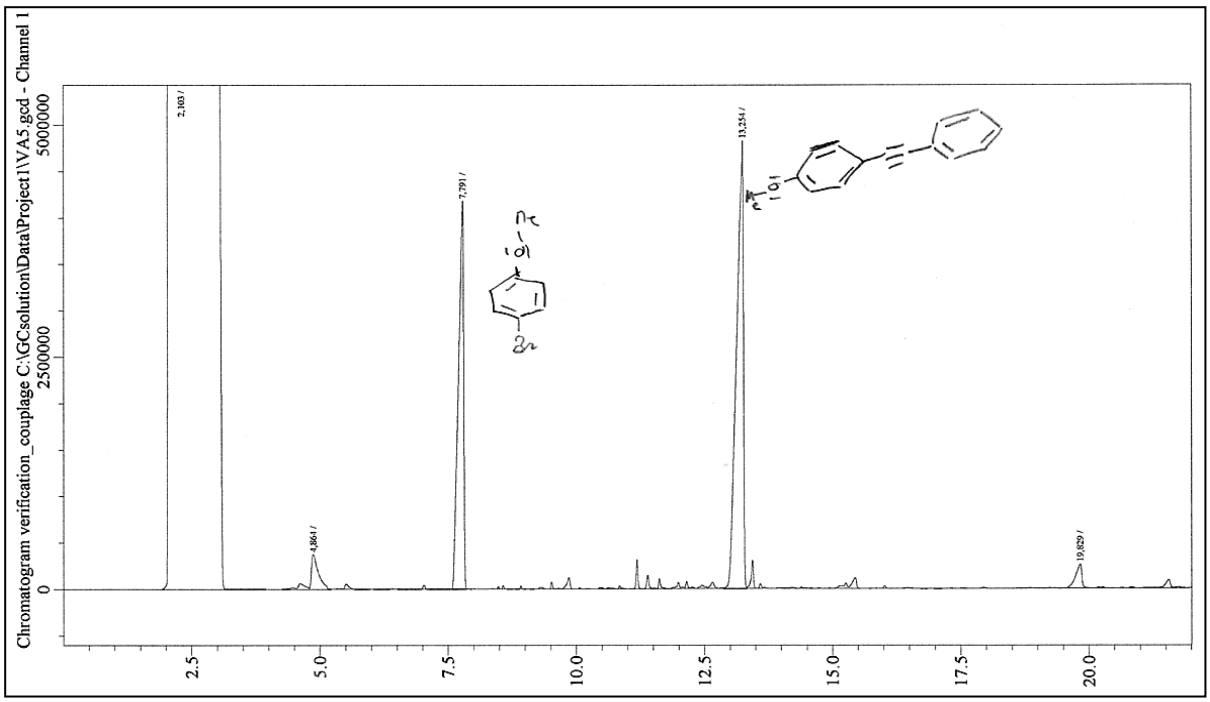
Rt 4-bromoanisole = 7.80 min
Rt 4-(pyrrolidinyl)anisole = 11.5 min
Rt 4-(phenylethynyl)anisole = 13.20 min



GC chromatogram Table 1, entry 14

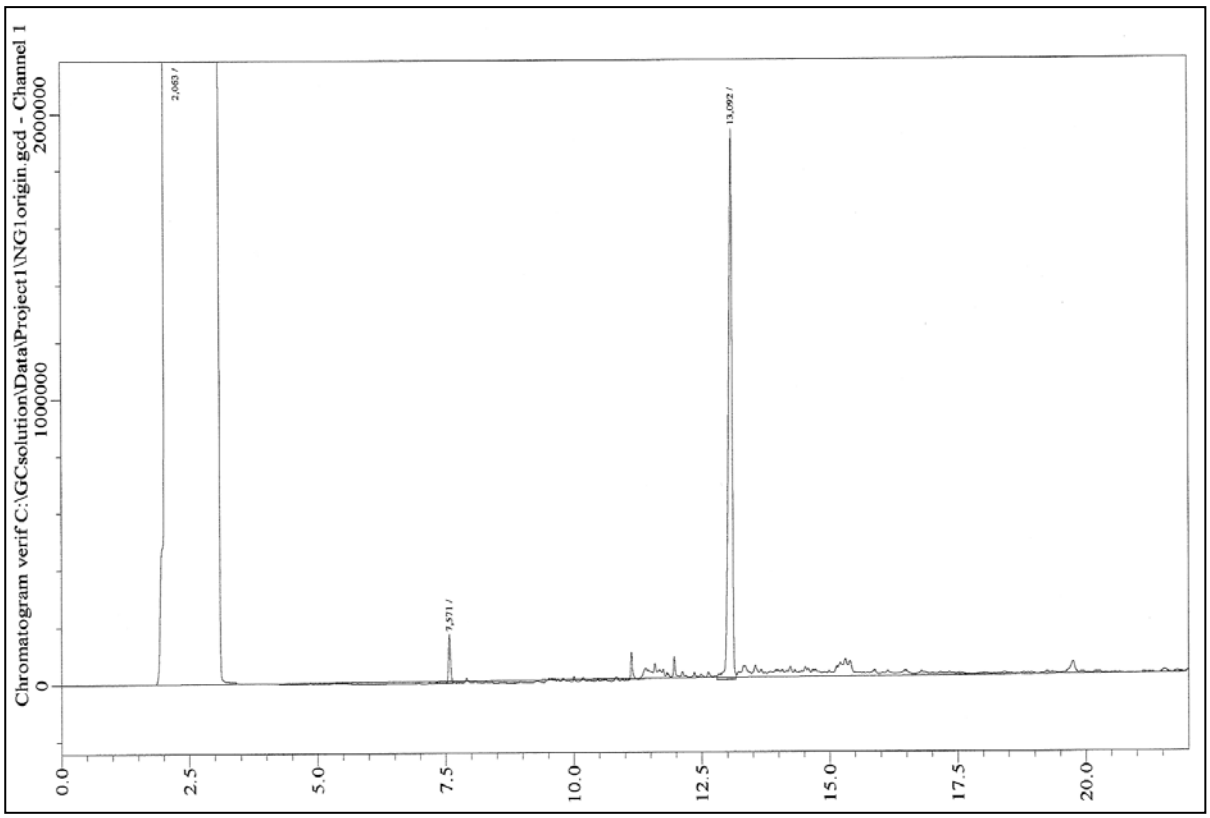


GC chromatogram Table 1, entry 12



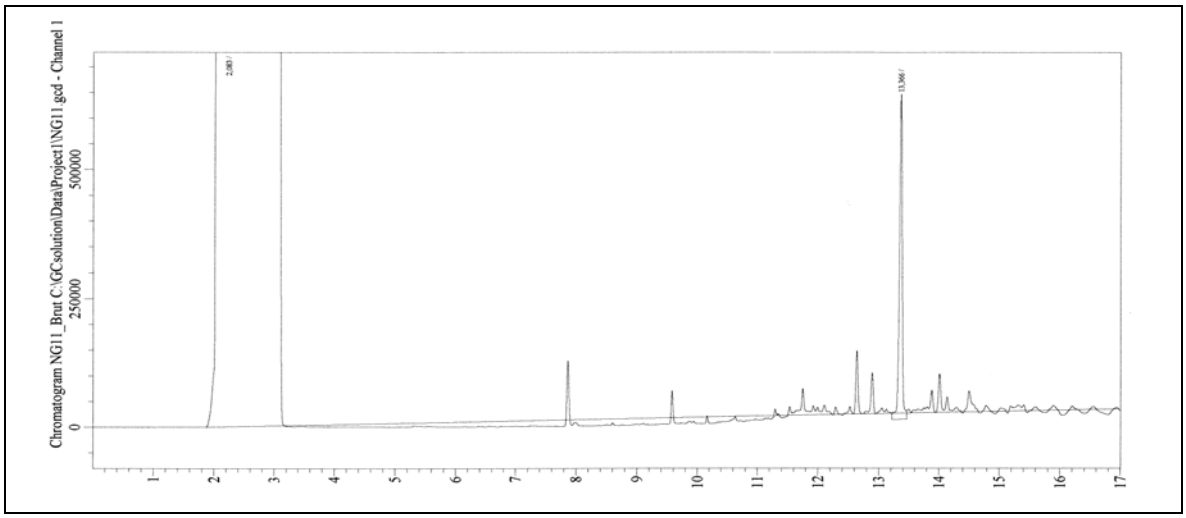
GC chromatogram ***Table 2, entry 5***

Rt 4-bromoanisole = 7.60 min
Rt 4-(phenylethynyl)anisole = 13.10 min



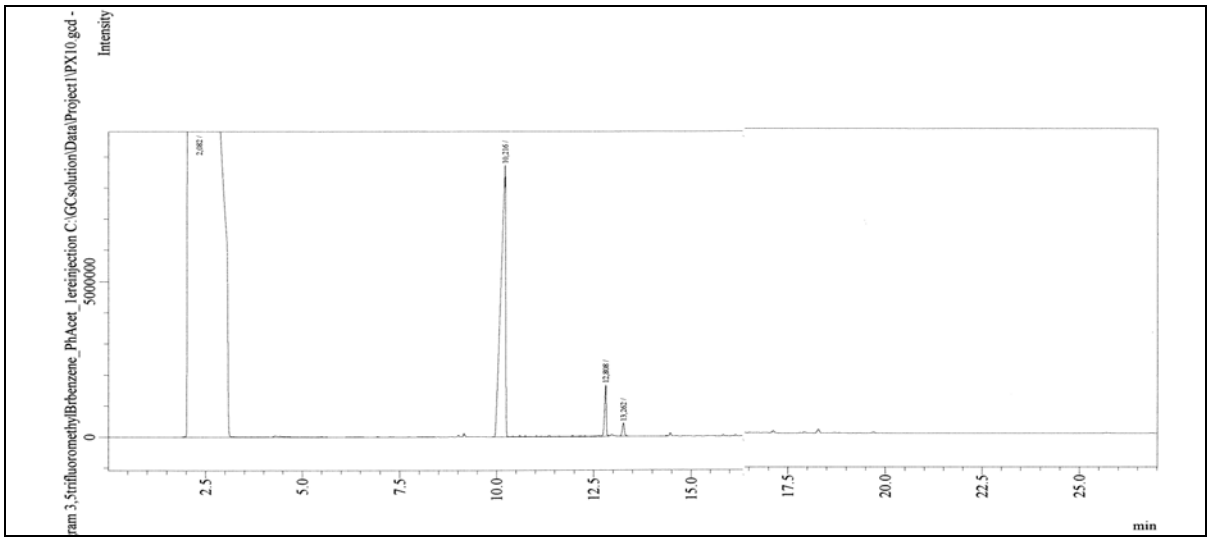
GC chromatogram Table 2, entry 2

Rt bromobenzonitrile = 8.12 min
Rt bis(benzonitrile) = 12.638
Rt 4-(phenylethynyl)benzonitrile = 13.37 min
Rt 4-(pyrrolidinyl)benzonitrile = 12.89



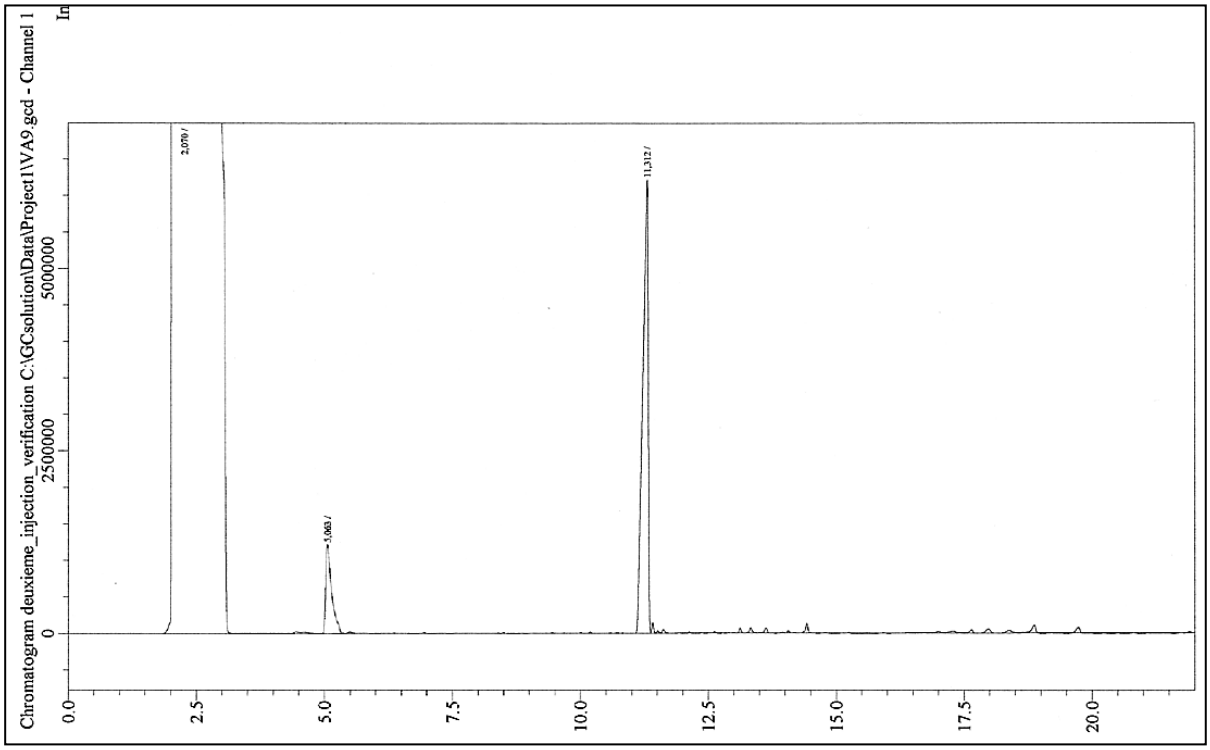
GC chromatogram Table 2, entry 3

Rt 3,5-(Trifluoromethyl)bromobenzene = 4.29 min
Rt Phenyl-(3,5-bis(trifluoromethyl)phenyl)acetylene. = 10.21 min



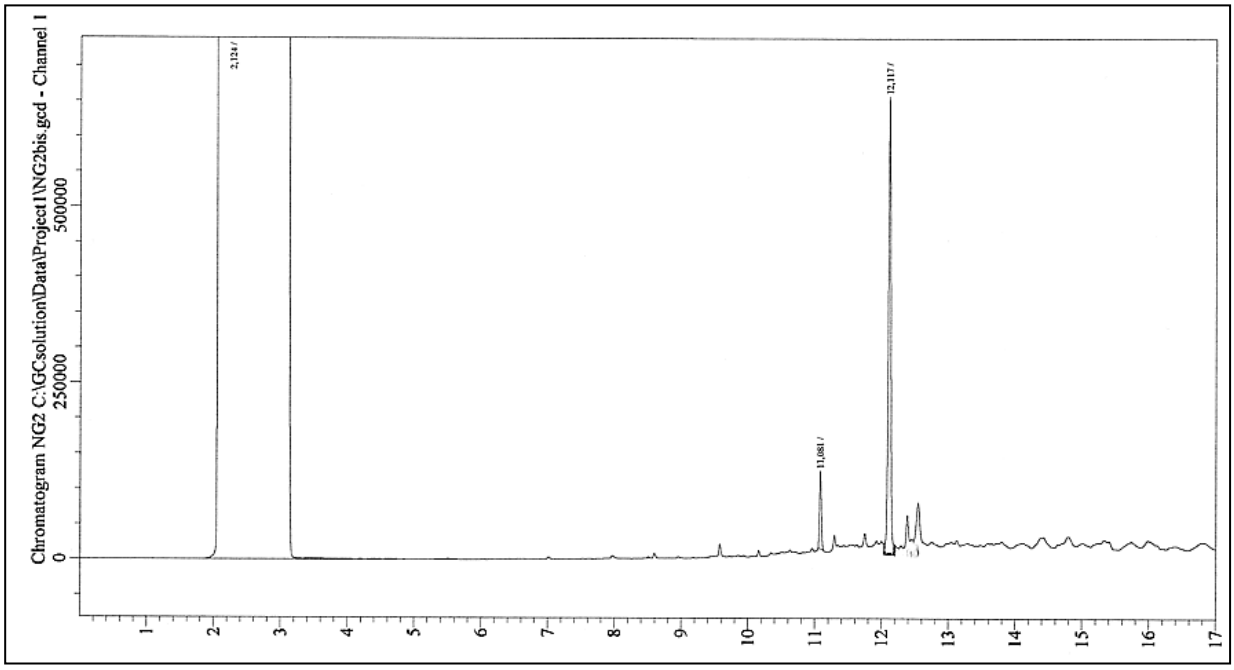
GC chromatogram Table 2, entry 4

Rt bromobenzene = 5.06 min
Rt diphenylacetylene = 11.30 min



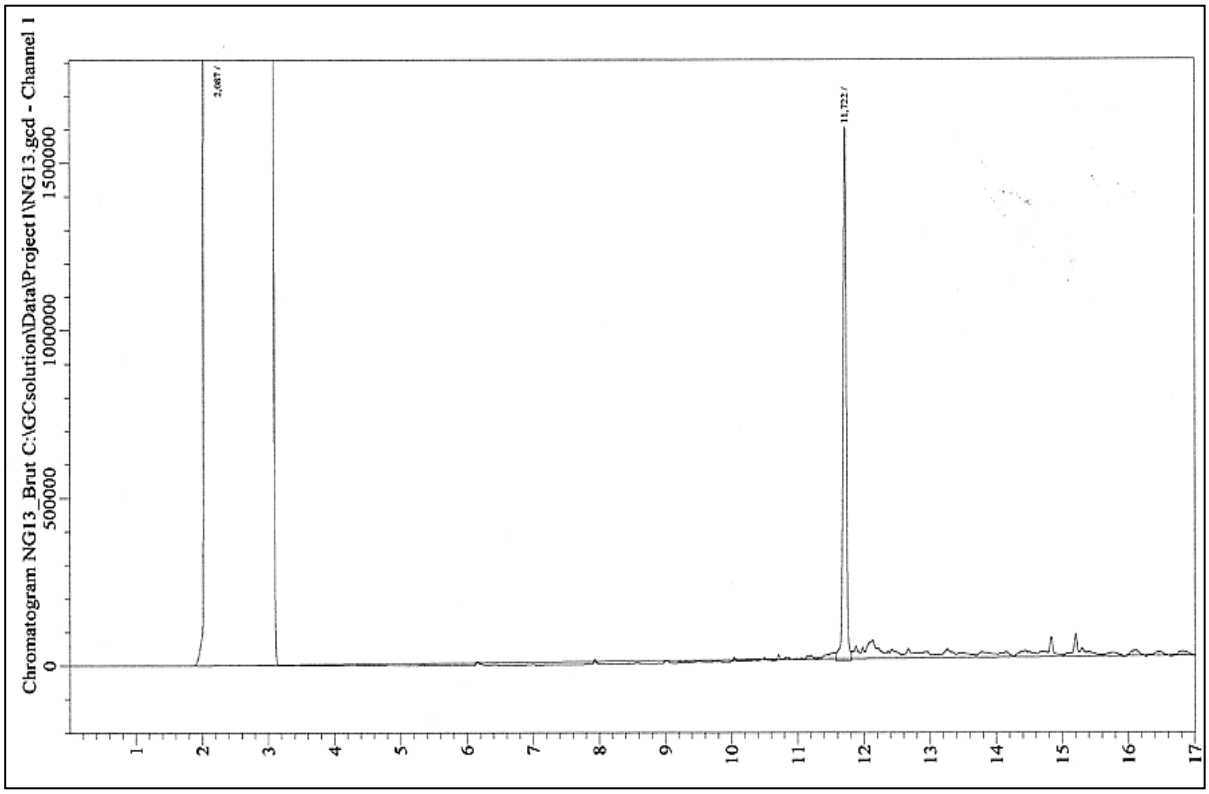
GC chromatogram Table 2, entry 6

Rt 4-bromotoluene = 6.51 min
Rt 4-(phenylethenyl)toluene = 11.08, 12.38 min (*E* and *Z* isomers)
Rt 4-(phenylethynyl)toluene = 12.12 min



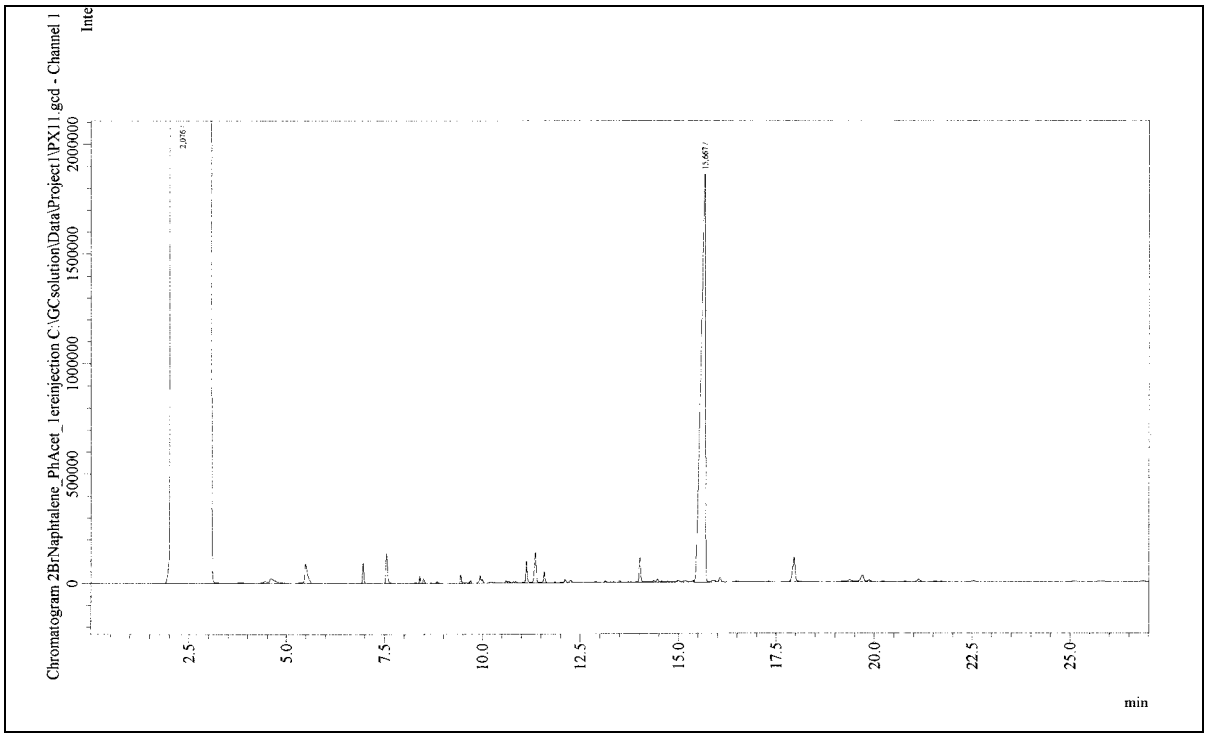
GC chromatogram Table 2, entry 7

Rt 2-bromotoluene = 6.16 min
Rt 2-(phenylethynyl)toluene = 11.72 min



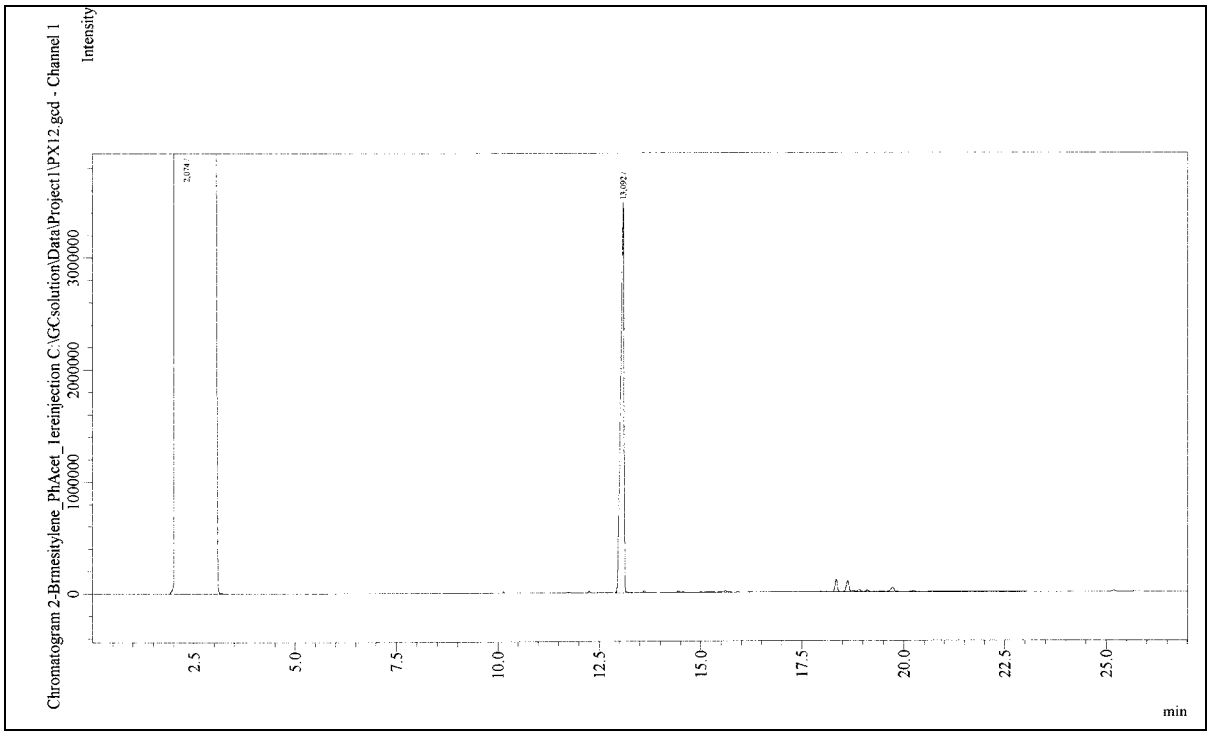
GC chromatogram Table 2, entry 8

Rt 2-bromonaphtalene = 10.09 min
Rt 2-(phenylethynyl)naphtalene = 15.67 min



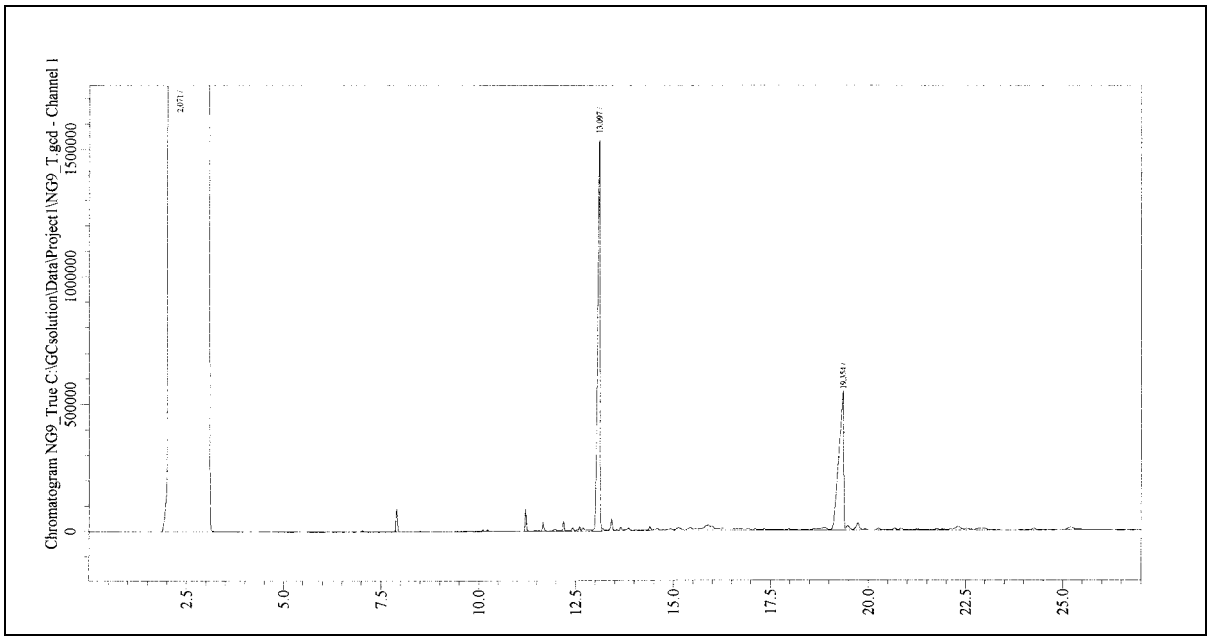
GC chromatogram Table 2, entry 9

Rt 2-bromomesitylene = 8.35 min
Rt (Phenylethynyl)mesitylene = 13.09 min



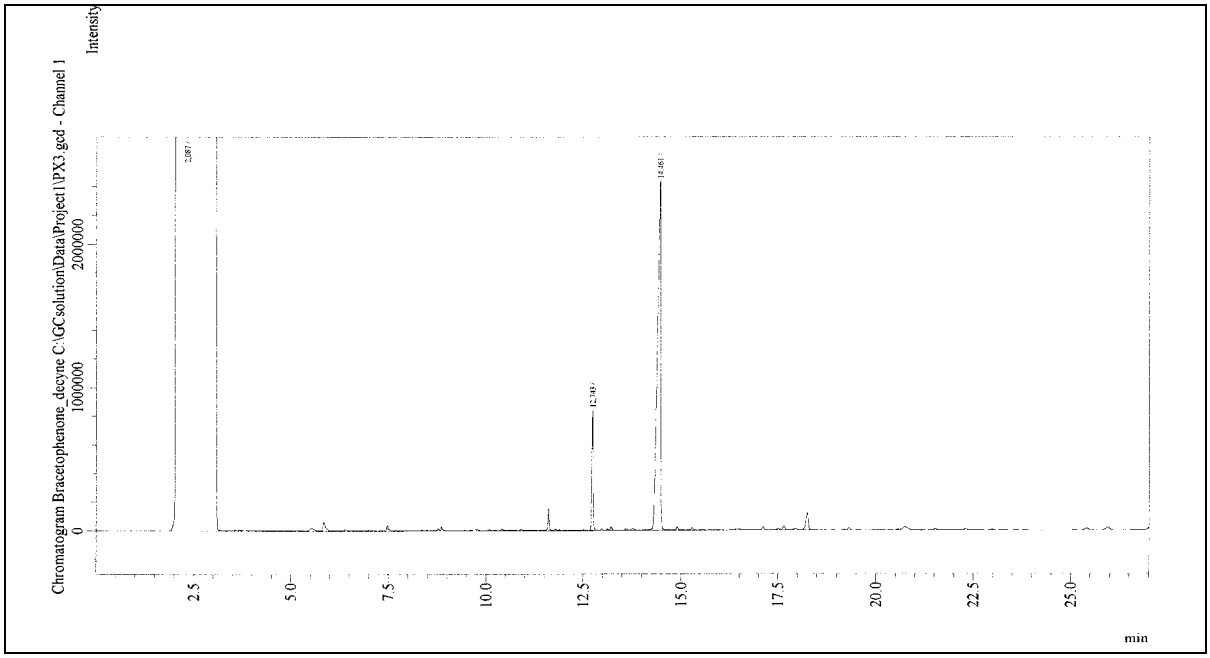
GC chromatogram Table 2, entry 10

Rt 1,2-dibromobenzene = 7.89 min
Rt 1-Bromo-2-(phenylethynyl)benzene = 13.10 min
Rt 1,2-Bis(phenylethynyl)benzene = 19.35 min



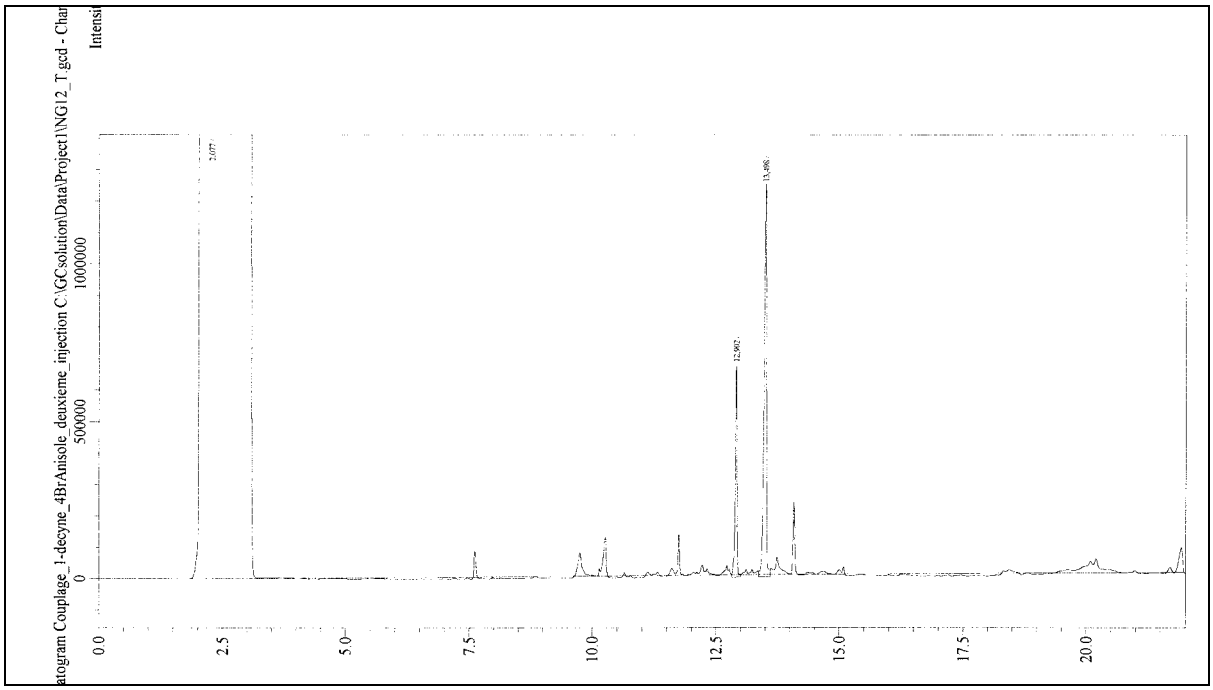
GC chromatogram Table 2, entry 11

Rt 4-bromoacetophenone = 8.80 min
Rt diyne (due to excess of 1-decyne) = 12.74 min
Rt 4-(1-Decyn-1-yl)acetophenone = 14.46 min



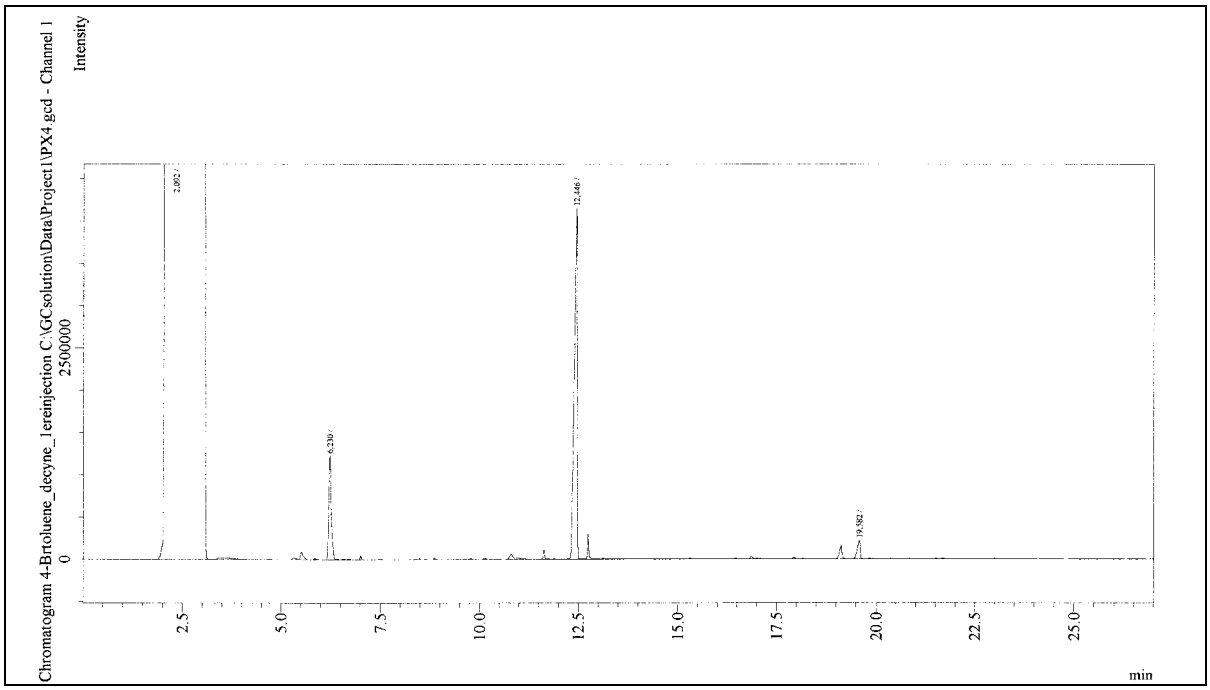
GC chromatogram Table 2, entry 12b

Rt 4-bromoanisole = 7.62
RT phenyldecyne = 11.73 min
Rt diyne (due to excess of 1-decyne) = 12.90 min
Rt 4-(1-Decyn-1-yl)anisole = 13.95 min
Rt enyne isomerization product = 14.03 min



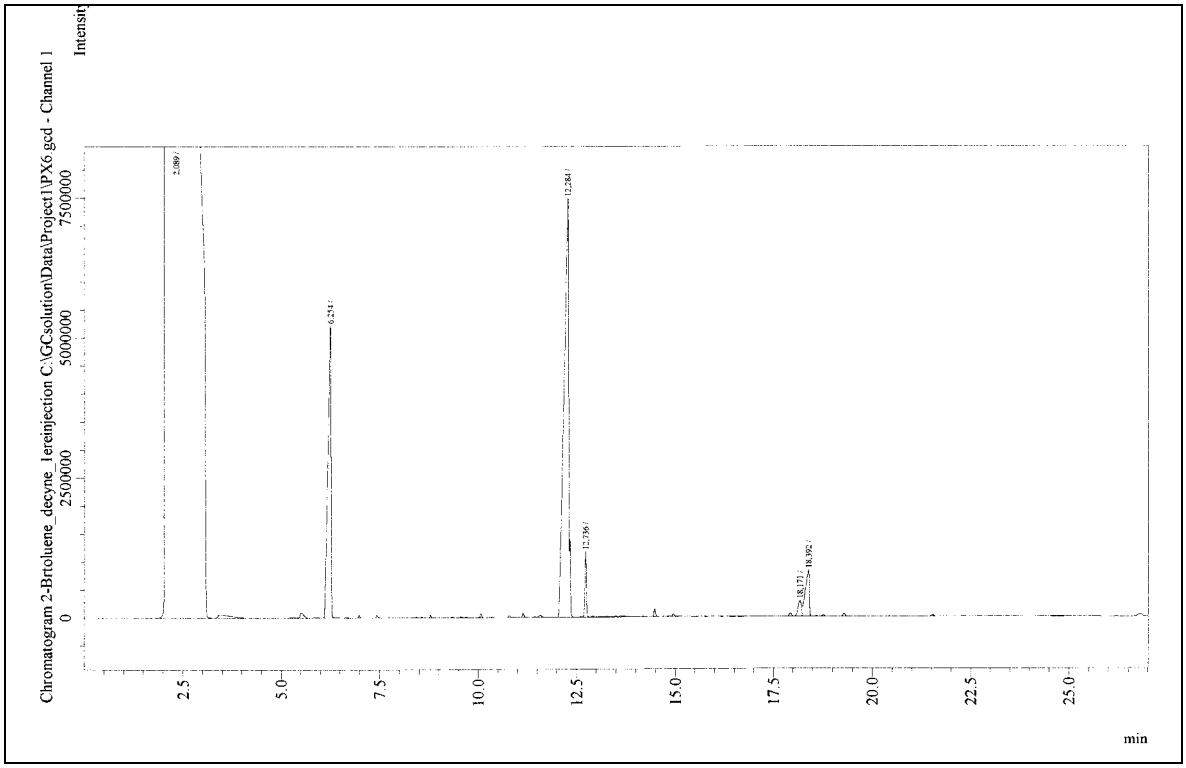
GC chromatogram Table 2, entry 13

Rt 4-bromotoluene = 6.23 min
Rt 4-(1-Decyn-1-yl)toluene = 12.45 min



GC chromatogram Table 2, entry 14

Rt 2-bromotoluene = 6.25 min
Rt 2-(1-Decyn-1-yl)toluene = 12.28 min
Rt diyne (due to excess of 1-decyne) = 12.74 min



NMR data, elemental analysis or mass spectrometry for coupling products.[a]

4-(Phenylethynyl)acetophenone.
^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.92 (d, *J* = 8.1 Hz, 2H), 7.59 (d, *J* = 8.1 Hz, 2H), 7.53 (m, 2H), 7.35 (m, 3H), 2.58 (s, 3H). Anal. Calcd for $C_{16}H_{12}O$: C, 87.28; H, 5.47. Found: C, 87.44; H, 5.26.

4-(Phenylethynyl)benzonitrile.
^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.62-7.58 (m, 4H), 7.55-7.52 (m, 2H), 7.39-7.34 (m, 3H). Anal. Calcd for $C_{15}H_9N$: C, 88.64; H, 4.46. Found: C, 88.92; H, 4.38.

Phenyl-(3,5-bis(trifluoromethyl)phenyl)acetylene.
^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.95 (s, 2H, Ar), 7.82 (s, 1H, Ar), 7.58-7.50 (m, 2H, Ar),7.42-7.35 (m, 3H, Ar). ^{13}C {^{1}H}NMR ($CDCl_3$) : δ = 132.1 (q, J_{CF} = 30 Hz, 2C), 131.9, 131.5(q, J_{CF} = 4 Hz, 2C), 129.4, 128.7, 124.8, 123.4 (q, J_{CF} = 260 Hz, 2C),121.6 (q, J_{CF} = 4 Hz, 2C),121.7, 92.9, 86.4. MS (70eV); m/z (%): 314 ($M^{+\cdot}$,100), 295 (12), 243 (8), 225 (10), 157 (9), 122 (83).

Diphenylacetylene.
^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.50-7.46 (m, 4H), 7.32-7-28 (m, 6H). Anal. Calcd for $C_{14}H_{10}$: C, 94.35; H, 5.65. Found: C, 94.38; H, 5.59.

4-(Phenylethynyl)anisole.
^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.50-7.48 (m, 2H), 7.45 (d, *J* = 8.8 Hz, 2H), 7.32 (m, 3H), 6.86 (d, *J* = 8.8 Hz, 2H), 3.80 (s, 3H). Anal. Calcd for $C_{15}H_{12}O$: C, 86.51; H, 5.81. Found: C, 86.55; H, 5.67.

4-(Phenylethynyl)toluene.
^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.50 (d, *J* = 7.7 Hz, 3H), 7.41 (d, *J* = 7.9 Hz, 2H), 7.30-7.25 (m, 3H), 7.13 (d, *J* = 7.7 Hz, 2H), 2.43 (s, 3H). Anal. Calcd for $C_{15}H_{12}$: C, 93.75; H, 6.25. Found: C, 93.88; H, 6.22.

2-(Phenylethynyl)toluene.
^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.63-7.57 (m, 3H), 7.45-7.38 (m, 3H), 7.30-7.20 (m, 3H), 2.60 (s, 3H). MS (70eV); m/z (%): 192 ($M^{+\cdot}$,100), 191 (96), 190 (18), 187 (42), 165 (33), 135 (13), 115 (18), 94 (15), 82 (14), 63(10), 51(8).

2-(Phenylethynyl)naphtalene.
MS (70eV); m/z (%): 228 ($M^{+\cdot}$,100), 227 (8), 226 (30), 202 (4), 200 (4), 188 (2), 176 (2), 163 (2), 150 (2), 138 (1), 126 (2), 114 (16), 113 (15), 101 (10), 88 (5), 75 (2), 63 (2), 51 (2).

(Phenylethynyl)mesitylene.
MS (70eV); m/z (%): 220 ($M^{+\cdot}$,100), 205 (95), 204 (24), 203 (28), 202 (27), 203 (28), 190 (17), 189 (22), 178 (15), 165 (13), 110 (10), 101 (18), 89 (11), 77 (10), 63 (8), 51 (10).

a) 1-Bromo-2-(phenylethynyl)benzene.
MS (70eV); m/z (%): 258 (95), 257 ($M^{+\cdot}$,18), 256 (100), 176 (80), 151 (35), 150 (25), 88 (40), 75 (19).

b) 1,2-bis(phenylethynyl)benzene.
MS (70eV); m/z (%): 278 ($M^{+\cdot}$,18), 277 (33), 276 (75), 274 (25), 250 (8), 237 (4), 224 (6), 137 (16), 138 (35), 125 (15), 112 (8), 111 (6), 87 (4), 63 (4), 50 (3).

4-(1-Decyn-1-yl)acetophenone.
^{1}H NMR (300 MHz, $CDCl_3$) : δ = 7.85 (d, *J* = 8.3 Hz, 2H, Ar), 7.44 (d, *J* = 8.3 Hz, 2H, Ar), 2.57 (s, 3H, CH_3), 2.41 (t, *J* = 7.0 Hz, 2H, CH_2), 1.60 (m, 2H, CH_2), 1.50-1.15 (m, 10H, CH_2), 0.87 (t, *J* = 7.0 Hz, 3H, CH_3).
^{13}C {^{1}H}NMR ($CDCl_3$) : δ = 197.3, 135.6, 131.6, 129.2, 128.1, 94.4, 80.1, 31.8, 29.2, 29.1, 28.9, 28.5, 26.5, 22.6, 19.5, 14.1.
Anal. Calcd for $C_{18}H_{24}O$: C, 84.32; H, 9.44. Found: C, 84.12; H, 9.57.

4-(1-Decyn-1-yl)anisole.
^{1}H NMR (300 MHz, $CDCl_3$) : δ = 7.31 (d, *J* = 8.3 Hz, 2H, Ar), 6.79 (d, *J* = 8.3 Hz, 2H, Ar), 3.70 (s, 3H, CH_3), 2.36 (t, *J* = 7.0 Hz, 2H), 1.58-130 (m, 12H, CH_2), 0.87 (t, *J* = 7.0 Hz, 3H, CH_3). MS (70ev); m/z (%): 244 ($M^{+\cdot}$,36), 188 (34), 173 (40), 159 (35), 147 (100), 145 (70), 121 (35), 102 (25), 91(20).

4-(1-Decyn-1-yl)toluene.
MS (70eV); m/z (%): 228 ($M^{+\cdot}$,25), 172 (15), 171 (16), 158 (22), 157 (45), 144 (15), 143 (43), 142 (32), 141 (17), 131 (100), 129 (81), 128 (46), 115 (32), 105 (36), 91 (16), 77 (12).

2-(1-Decyn-1-yl)toluene.
^{1}H NMR (300 MHz, $CDCl_3$) : δ = 7.49 (d, *J* = 7.6 Hz, 1H, Ar), 7.28 (m,3H, Ar), 2.40 (s, 3H, CH_3), 2.36 (t, *J* = 6.8 Hz, 2H, CH_2), 1.59 (m, 12H, CH_2), 0.87 (t, *J* = 7.0 Hz, 3H, CH_3).
^{13}C {^{1}H}NMR ($CDCl_3$) : δ = 141.3, 132.0, 128.8, 128.1,125.1, 123. 0, 90.5, 78.8, 32.0, 29.4, 29.1, 29.0, 28.4, 22.9, 19.0, 14.1, 13.5.
MS (70eV); m/z (%): 228 ($M^{+\cdot}$,52), 213 (10), 157 (17), 144 (15), 143 (100), 142 (13), 141 (13), 129 (20), 128 (22).

[a] NMR spectra were recorded using TMS as external standard (1H 300.13 MHz, 13C 75.47 MHz). NMR spectroscopic data of the coupling products are identical to those reported in the literature, see for instance ref [1-9].

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