Tetraarylphosphonium Salts as Novel Solubility Control Groups: Phosphonium Supported Triphenylphosphine and Azodicarboxylate Reagents

Jean-Christophe Poupon, Alessandro A. Boezio and André B. Charette*

Département de Chimie, Université de Montréal, P.O. Box 6128, Station Downtown, Québec, Canada H3C 3J7

Contents

General Procedure .............................................................................................................................................2
Experimental Procedures for Scheme 1 ................................................................................................. 2-4
Experimental Procedures for Equation 1 ............................................................................................... 4
Experimental Procedures for Table 1 ......................................................................................................... 4-5
Experimental Procedures for Table 2 ......................................................................................................... 5-6
Experimental Procedures for Scheme 2 ................................................................................................. 6-9
¹H and ¹³C NMR spectra .............................................................................................................................. 10-46
Thermo Gravimetric Experiments ............................................................................................................. 47-48
Notes and references ..................................................................................................................................49
**General:** All non-aqueous reactions were run under an inert atmosphere (nitrogen or argon) with rigid exclusion of moisture from reagents and glassware using standard techniques for manipulating air-sensitive compounds.[1] All glassware was stored in the oven and/or was flame-dried prior to use under an inert atmosphere of gas. Anhydrous solvents were obtained either by filtration through drying columns (THF, ether, CH₂Cl₂, benzene, DMF, CH₂CN, toluene, hexane, methanol) on a GlassContour system (Irvine, CA), by distillation over calcium hydride (Et₃N, CICH₂CH₂Cl, pyridine, disopropylamine, isopropanol) or by distillation over sodium/benzophenone (DME). Analytical thin-layer chromatography (TLC) was performed on precoated, glass-backed silica gel (Merck 60 F₂54). Visualization of the developed chromatogram was performed by UV absorbance, aqueous cerium molybdate, ethanolic phosphomolybdic acid, iodine, or aqueous potassium permanganate. Flash column chromatography was performed using 230-400 mesh silica (EM Science or Silicycle) of the indicated solvent system according to standard technique.[2] Melting points were obtained on a Buchi melting point apparatus and are uncorrected. Infrared spectra were taken on a Perkin Elmer Spectrum One FTIR and are reported in reciprocal centimeters (cm⁻¹). Nuclear magnetic resonance spectra (¹H, ¹³C, DEPT 135, COSY, HMQC, NOESY) were recorded either on a Bruker AV 300, AMX 300, AV 400, ARX 400, or DMX 600 spectrometer. Chemical shifts for ¹H NMR spectra are recorded in parts per million from tetramethylsilane with the solvent resonance as the internal standard (chloroform, δ 7.27 ppm). Data are reported as follows: chemical shift, multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, qn = quintet, sext = sextuplet, m = multiplet and br = broad), coupling constant in Hz, integration. Chemical shifts for ¹³C NMR spectra are recorded in parts per million from tetramethylsilane using the central peak of deuterochloroform (77.23 ppm) as the internal standard. All spectra were obtained with complete proton decoupling. When ambiguous, proton and carbon assignments were established using COSY, NOESY, HMQC and DEPT experiments. Combustion analyses were performed by the Laboratoire d’analyse élémentaire de l’Université de Montréal. Thermogravimetric experiments were done on a TGA Q500V5.3 Build 151.

**3-Bromophenyl(diphenyl)phosphine (1).**
To a solution of 1,3-dibromobenzene (7.4 mL, 61 mmol, 1.05 equiv) in THF (70 mL) at -90 °C was added n-BuLi (2.5 M in hexane, 25.5 mL, 64 mmol, 1.10 equiv) dropwise. The reaction mixture was stirred 45 min then diphenylchlorophosphine (10.7 mL, 58 mmol, 1.0 equiv) was added dropwise, and the resulting dark brown solution was warmed to room temperature for 15 min and filtered through a pad of celite. The solvent was evaporated under reduced pressure and the residue was purified by flash chromatography (Et₂O/hexane, 0:100-5:95) to afford pure 1 (18.1 g, 91%) as a viscous colorless oil.[3]

**[3-(Diphenylphosphino)phenyl](triphenyl)phosphonium bromide (2).**
To a solution of NiBr₂ (dry under vacuum for 2 h at 140 °C) (3.6 g, 16 mmol, 0.5 equiv) in benzonitrile (dry overnight over activated molecular sieves 4 Å) (250 mL) was added triphenylphosphine (26.0 g, 49 mmol, 3 equiv). The solution was heated under reflux 15 min and became dark green then was cooled to room temperature. Phosphine 1 (11.1 g, 32.5 mmol, 1.0 equiv) in benzonitrile (20 mL + 5 mL rinse) was added to the solution. The resulting solution was heated under reflux for 4 h then cooled to room temperature, and a 10% (w/w) KBr aqueous solution (250 mL) was added. The layers were separated, and the aqueous layer was washed twice with CH₂Cl₂ (250 mL). The organic solution was washed three times
with water (100 mL), dried over anhydrous MgSO₄, filtered and concentrated under reduced pressure. To the resulting solution was added hexane (750 mL) to precipitate the crude product. The precipitate was washed with hexane and diluted with CH₂Cl₂ (20 mL). Et₂O (150 mL) was added to the resulting solution and the precipitate was filtered and purified by flash chromatography (0 to 10% MeOH/CH₂Cl₂ to afford 2 (>95% purity) as a white solid (15.3 g, 78%): mp 215-220 °C; ¹H NMR (400 MHz, CDCl₃): δ 7.60-6.80 (m, 29H); ¹³C NMR (100 MHz, CDCl₃): δ 142.1 (dd, J = 18.5, 11.1 Hz, 1C), 139.4 (dd, J = 22.1, 2.3 Hz, 1C), 137.2 (dd, J = 13.2, 11.0 Hz, 1C), 135.4 (d, J = 2.6 Hz, 3C), 134.5 (d, J = 10.6 Hz, 2C), 133.9 (d, J = 10.3 Hz, 6C), 133.8 (dd, J = 10.4, 1.1 Hz, 1C), 133.4 (d, J = 20.2 Hz, 4C), 130.4 (d, J = 12.8 Hz, 6C), 129.7 (dd, J = 12.6, 6.4 Hz, 1C), 129.5 (s, 2C), 128.7 (d, J = 7.4 Hz, 4C), 118.1 (d, J = 86.9, 3.1 Hz, 1C), 116.7 (d, J = 88.7 Hz, 3C); ³¹P NMR (162 MHz, CDCl₃): δ 23.2, -4.5; IR (film) 1974, 1913, 1827, 1585, 1474, 1432, 1433, 1386, 1108 cm⁻¹; LRMS (APCI, Pos) calc. for C₉₀H₉₂P₂ [M⁺]: 523.2, found 523.1.

[3-(Diphenylphosphino)phenyl](triphenyl)phosphonium perchlorate (3).
To phosphonium salt 2 (15.0 g, 25 mmol, 1.0 equiv) in CH₃CN (30 mL) and CH₂Cl₂ (10 mL) was added LiClO₄•3H₂O (4.2 g, 26 mmol, 1.05 equiv). After 15 min, the mixture was concentrated under reduced pressure and diluted with CH₂Cl₂ (200 mL). The resulting mixture was washed with water (100 mL). The aqueous layer was washed with CH₂Cl₂ (100 mL). The organic solution was washed three times with water (50 mL), dried over MgSO₄, filtered and concentrated under reduced pressure. The crude product was diluted with CH₂Cl₂ (30 mL) and was crunched with Et₂O (150 mL). This operation was repeated twice to afford pure 3 as a white solid (14.7 g, 95%): mp 160-165 °C; ¹H NMR (400 MHz, CDCl₃): see 2; ¹³C NMR (100 MHz, CDCl₃): see 2; ³¹P NMR (162 MHz, CDCl₃): see 2; IR (film) 1585, 1483, 1435, 1388, 1079 cm⁻¹; LRMS (APCI, Pos) see 2; LRMS (APCI, Neg) calc. for PF₆ClO₄ [M⁺]: 99.0, found 99.0; calc. for PF₆ClO₄ [M⁺]: 101.1, found 101.1.

[3-(Diphenylphosphino)phenyl](triphenyl)phosphonium hexafluorophosphate (4).
To perchlorate 3 (1.24 g, 2 mmol, 1.0 equiv) in CH₃CN (8 mL) and H₂O (4 mL) was added KPF₆ (442 mg, 2.4 mmol, 1.2 equiv). After 1 h, the mixture was concentrated under reduced pressure and diluted with CH₂Cl₂ (50 mL). The resulting mixture was washed with water (20 mL). The aqueous layer was washed with CH₂Cl₂ (10 mL). The organic solution was washed twice with water (10 mL), dried over MgSO₄ and concentrated under reduced pressure to give pure compound 4 (1.27 g, 95%) as a solid foam: mp 80-85 °C; ¹H NMR (400 MHz, CDCl₃): see 2; ¹³C NMR (100 MHz, CDCl₃): see 2; ³¹P NMR (162 MHz, CDCl₃): δ 23.2, -4.5, -143.9 (sept, J = 713 Hz); ¹⁹F NMR (376 MHz, CDCl₃): δ 7.63 (d, J = 713 Hz); IR (film) 1586, 1483, 1436, 1388, 1107, 829 cm⁻¹; LRMS (APCI, Pos) see 2; LRMS (APCI, Neg) calc. for PF₆ClO₄ [M⁺]: 145.0, found 145.0.

[3-(Diphenylphosphino)phenyl](triphenyl)phosphonium perchlorate (5).
White solid: mp 214-216 °C; ¹H NMR (400 MHz, CDCl₃): δ 8.00-7.30 (m, 29H); ¹³C NMR (100 MHz, CDCl₃): δ 138.3 (dd, J = 9.7, 2.9 Hz, 1C), 137.5 (dd, J = 10.3, 2.3 Hz, 1C), 137.0 (t, J = 11.0 Hz, 1C), 136.6 (dd, J = 98.3, 11.2 Hz, 1C), 135.6 (d, J = 2.7 Hz, 3C), 134.2 (d, J = 10.3 Hz, 6C), 132.5 (d, J = 2.5 Hz, 2C), 131.7 (d, J = 10.0 Hz, 4C), 130.9 (t, J = 11.5 Hz, 1C), 130.6 (d, J = 10.6 Hz, 6C), 130.1 (d, J = 105.2 Hz, 2C), 128.7 (d, J = 12.8 Hz, 4C), 119.0 (dd, J = 89.0, 11.6 Hz, 1C), 116.5 (d, J = 89.0 Hz, 3C); ³¹P NMR (162 MHz, CDCl₃): δ 28.3, 23.3;
IR (film) 1585, 1483, 1435, 1388, 1079 cm⁻¹; LRMS (APCI, Pos) calc. for C₃₆H₂₉P₂O [M]⁺: 539.2, found 539.1.

Recycling of the phosphine oxide (5).
To a 0 °C solution of 5 (200 mg, 0.30 mmol, 1.0 equiv) in benzonitrile (3 mL, 0.1 M) was added \(N,N\text{-dimethylaniline (160 \( \mu \)L, 1.2 mmol, 4.0 equiv) and trichlorosilane (63 \( \mu \)L, 0.62 mmol, 2.0 equiv). The solution was heated to 170 °C over 2 h and it became blue. Precipitation was induced by adding hexane (20 mL). The crude product was redissolved in CH₂Cl₂ (1 mL) and precipitated by adding Et₂O (10 mL). This operation was repeated twice to afford a crude blue solid.

To this crude solid (ca 0.30 mmol, 1.0 equiv) in CH₂CN (1.5 mL) was added LiClO₄ (32 mg, 0.30 mmol, 1.0 equiv). After 2 h, the mixture was concentrated under reduced pressure and diluted with CH₂Cl₂ (10 mL). The resulting mixture was washed with water (5 mL). The aqueous layer was washed with CH₂Cl₂ (2 mL). The organic solution was washed three times with water (2 mL), dried over MgSO₄ and concentrated under reduced pressure. The crude product was diluted with CH₂Cl₂ (1 mL) and was precipitated with Et₂O (10 mL) to afford pure 3 as a white solid (173 mg, 93%).

Typical procedure for the gem-dibromoalkene formation. (4,4-Dibromobut-3-enyl)benzene (6).
To phosphine 3 (1.5 g, 2.5 mmol, 2.5 equiv) under an argon atmosphere was added CH₂Cl₂ (5 mL), CBr₄ (825 mg, 2.5 mmol, 2.5 equiv) and zinc dust < 10 micron (163 mg, 2.5 mmol, 2.5 equiv). The mixture was heated at reflux for 30 min and then cooled to 0 °C. 3-Phenylpropanal (134 mg, 1.0 mmol, 1.0 equiv) in CH₂Cl₂ (1 mL) was added. After 3 h of stirring at room temperature, the mixture was filtered on a small pad of silica gel, rinsed with CH₂Cl₂ (2 mL) and with Et₂O (40 mL) that induced the precipitation of the phosphonium salt. The mixture was filtered on a small pad of celite. The precipitate was dissolved in CH₂Cl₂ (5 mL) and precipitated by the addition of Et₂O (25 mL). The mixture was filtered on the same pad of celite used for the preceding filtration. This operation was repeated once, and the organic liquid phase was concentrated in vacuo to afford the nearly pure compound. A quick flash chromatography on silica gel (2% diethyl ether/pentane) gave the gem-dibromo olefin 6 (274 mg, 94%).[^4]

(2,2-Dibromovinyl)cyclohexane (7).
The title compound (242 mg, 90%)[^5] was obtained from cyclohexanecarbaldehyde (112 mg, 1.0 mmol) according to the typical procedure described above.

1,1-Dibromoocct-1-ene (8).
The title compound (243 mg, 90%)[^6] was obtained from heptanal (114 mg, 1.0 mmol) according to the typical procedure described above.

(2,2-Dibromovinyl)benzene (9).
The title compounds (251 mg, 96%)[^7] was obtained from benzaldehyde (106 mg, 1.0 mmol) according to the typical procedure described above.

4-(2,2-Dibromovinyl)benzonitrile (10).
The title compound (276 mg, 96%) was obtained from 4-formylbenzonitrile (131 mg, 1.0 mmol) according to the typical procedure described above.

1-Bromo-4-(2,2-dibromoviny)benzene (11).
The title compound (335 mg, 98%) was obtained from 4-bromobenzaldehyde (185 mg, 1.0 mmol) according to the typical procedure describe above with 3 equiv of each reagent.

1,4-bis(2,2-Dibromoviny)benzene (12).
The title compound (211 mg, 95%) was obtained from terephthaladehyde (67 mg, 0.5 mmol) according to the typical procedure described above with 6 equiv of each reagent.

4-(2,2-Dibromoviny)benzaldehyde (13).
The title compound (246 mg, 85%) was obtained from 4-(diethoxymethyl)benzaldehyde (208 mg, 1.0 mmol) according to the typical procedure described above.

White solid: mp 60-65 °C; \( ^{1}H \) NMR (400 MHz, CDCl\(_3\)): \( \delta \) 9.96 (s, 1H), 7.83 (d, \( J = 8.2 \) Hz, 2H), 7.64 (d, \( J = 8.2 \) Hz, 2H), 7.48 (s, 1H); \( ^{13}C \) NMR (100 MHz, CDCl\(_3\)): \( \delta \) 191.5, 140.9, 135.9, 135.8, 129.8, 129.0, 92.8; IR (film) 1691, 1587, 1419, 1213, 811 cm\(^{-1}\); GCMS (EI) calc. for C\(_9\)H\(_6\)Br\(_7\)BrO \([M+H]^+\): 288.9, found 289.0; calc. for C\(_9\)H\(_6\)Br\(_8\)BrO \([M+1]^+\): 290.9, found 291.0; calc. for C\(_9\)H\(_6\)Br\(_8\)BrO \([M+1]^+\): 292.9, found 293.0.

[(5,5-Dibromopent-4-enyl)oxy](triisopropyl)silane (14).
The title compound (385 mg, 96%) was obtained from 4-(triisopropylsilyloxy)butanal (244 mg, 1.0 mmol) according to the typical procedure described above.

(1\(S\),2\(S\),5\(R\))-2-Isopropyl-5-methylcyclohexyl 4-nitrobenzoate (15).
(-)-Menthol ((1\(R\),2\(S\),5\(R\))-2-isopropyl-5-methylcyclohexanol) (156 mg, 1.0 mmol, 1.0 equiv) and phosphine 3 (1.0 g, 1.6 mmol, 1.6 equiv) were dissolved in CH\(_2\)Cl\(_2\) (5 mL) and then toluene (10 mL) was added. The solution was cooled to -5 °C and DEAD (255 \( \mu \)L, 1.6 mmol, 1.6 equiv) was added dropwise over 5 min. Then 4-nitrobenzoic acid (220 mg, 1.3 mmol, 1.3 equiv) was added and the solution was warmed slowly to room temperature over 3 h during which time a white precipitate appeared (phosphine oxide). After 9 h, Et\(_2\)O (25 mL) was added to the solution and the resulting mixture was filtered through a cotton pad and concentrated under reduced pressure. The resulting crude product was dissolved in CH\(_2\)Cl\(_2\) (1 mL) and hexane (9 mL) was added. The hydrazine and 4-nitrobenzoic acid residues precipitated and the resulting mixture was filtered through cotton pad, concentrated under reduced pressure and purified by flash chromatography (Et\(_2\)O/hexane= 20:80) to afford pure ester as a white crystalline solid 15 (245 mg, 79%): \([\alpha]_D^{25}\) +17.5 (c 1.0, CHCl\(_3\)); lit \([\alpha]_D^{25}\) +18.0 (c 1.0, CHCl\(_3\)).

(1\(R\)-2-Ethoxy-1-methyl-2-oxoethyl 4-nitrobenzoate (16).
The title compound was obtained as white solid (117 mg, 83%) from ethyl (2\(S\))-2-hydroxypropanoate (59 mg, 0.5 mmol) according to the typical procedure described above: \([\alpha]_D^{25}\) -14.3 (c 1.1, EtOH); lit \([\alpha]_D^{25}\) -13.1 (c 1.2, EtOH).

(1\(R\)-1-Methylheptyl 4-nitrobenzoate (17).
The title compound was obtained as white solid (163 mg, 91%) from (2S)-octan-2-ol (83 mg, 0.64 mmol) scale according to the typical procedure described above with 1.2 equiv of all reactive and warmed to room temperature over 6 h.

White solid: mp 28-30 °C; \(^1\)H NMR (400 MHz, CDCl\(_3\)): \(\delta\) 8.24-8.14 (m, 4H), 5.14 (sext, \(J = 6.3\) Hz, 1H), 1.75-1.71 (m, 1H), 1.71-1.78 (m, 1H), 1.42-1.20 (m, 11H), 0.81 (t, \(J = 6.7\) Hz, 3H); \(^{13}\)C NMR (100 MHz, CDCl\(_3\)): \(\delta\) 164.3, 150.5, 136.4, 130.7, 123.5, 73.1, 36.0, 31.8, 29.2, 25.4, 22.6, 20.0, 14.1; IR (film) 1717, 1606, 1523, 1278, 1105 cm\(^{-1}\); [\(\alpha\)]\(_D\)\(^{25}\) +21.8 (c 1.1, CHCl\(_3\)).

(3α,5α)-Cholesterol-3-yl 4-nitrobenzoate (18).

(+)-Dihydrocholesterol ([3\(\beta\),5\(\alpha\)]-cholestan-3-ol) (389 mg, 1.0 mmol, 1.0 equiv) and phosphine 3 (1.0 g, 16 mmol, 1.6 equiv) were dissolved in CH\(_2\)Cl\(_2\) (10 mL) and toluene (20 mL) was added. The solution was cooled to -5 °C and DEAD (255 µL, 1.6 mmol, 1.6 equiv) was added dropwise over 5 min. Then 4-nitrobenzoic acid (270 mg, 1.6 mmol, 1.6 equiv) was added and the solution was warmed to room temperature for 6 h during which time a white precipitate of phosphine oxide appeared. Then phosphine 3 (0.5 g, 8 mmol, 0.8 equiv) and DEAD (127 µL, 0.8 mmol, 0.8 equiv) were added. After 6 h, 50 mL of Et\(_2\)O was added to the solution and the resulting mixture was filtered through a cotton pad and concentrated under reduced pressure. The resulting crude product was dissolved in CH\(_2\)Cl\(_2\) (1 mL) and hexane (9 mL) was added. The hydrazine and 4-nitrobenzoic acid residues precipitated and the resulting mixture was filtered through a cotton pad, concentrated under reduced pressure and purified by flash chromatography (0 to 50% CH\(_2\)Cl\(_2)/hexane) to afford pure ester 18 as a white crystalline solid (419 mg, 78%).

White solid: mp 95-100 °C; \(^1\)H NMR (400 MHz, CDCl\(_3\)): \(\delta\) 8.45-8.15 (m, 4H), 5.28 (br s, 1H), 2.0-0.64 (m, 46H); \(^{13}\)C NMR (100 MHz, CDCl\(_3\)): \(\delta\) 164.1, 150.5, 136.7, 130.8, 123.7, 72.3, 56.7, 56.5, 54.5, 42.7, 40.7, 40.1, 39.7, 36.3, 36.1, 36.0, 35.6, 33.4, 33.1, 32.1, 28.5, 28.4, 28.2, 26.4, 24.3, 24.0, 23.0, 22.7, 21.0, 18.8, 12.2, 11.6; IR (film) 2929, 1711, 1606, 1523, 1289, 1105 cm\(^{-1}\); [\(\alpha\)]\(_D\)\(^{25}\) +17.3 (c 1.0, CHCl\(_3\)).

Ethyl (3\(\beta\),5\(\beta\),7\(\alpha\),12\(\alpha\))-7,12-dihydroxy-3-[4-nitrobenzoyloxyl]cholan-24-oate (19).

The title compound was obtained from ethyl (3\(\alpha\),5\(\beta\),7\(\alpha\),12\(\alpha\))-7,12-trihydroxycholan-24-oate (437 mg, 1.0 mmol) as white solid (524 mg, 89%) according to the typical procedure described above with CH\(_2\)Cl\(_2\) (10 mL) and THF (20 mL) as solvents and DIAD (315 µL, 1.6 mmol, 1.6 equiv) and warmed to room temperature over 2 h. 19 could be quantitatively extracted from the phosphonium salt (5 cycles of solubilization in CH\(_2\)Cl\(_2\) and precipitation by adding Et\(_2\)O). But, in order to eliminate the hydrazine residue, it is more useful in this case to obtain the product directly by flash chromatography (0 to 2% MeOH/CH\(_2\)Cl\(_2)/MeOH).

White solid: mp 190-195 °C; \(^1\)H NMR (400 MHz, CDCl\(_3\)): \(\delta\) 8.32-8.19 (m, 4H), 5.33 (br s, 1H), 4.14-4.11 (m, 2H), 4.02 (br s, 1H), 3.91 (br s, 1H), 2.68 (br t, \(J = 13.9\) Hz, 1H), 2.40-1.20 (m, 28H), 1.02 (br s, 6H), 0.73 (br s, 3H); \(^{13}\)C NMR (100 MHz, CDCl\(_3\)): \(\delta\) 174.4, 164.0, 150.3, 136.5, 130.6, 123.5, 73.2, 72.8, 68.5, 60.2, 47.3, 46.6, 41.7, 39.3, 37.2, 35.4, 35.2, 34.3, 33.5, 31.4, 30.9, 30.8, 28.5, 27.6, 25.7, 24.9, 23.3, 23.0, 17.3, 14.2, 12.4; IR (film) 3453, 2935, 1713, 1606, 1524, 1278, 1105 cm\(^{-1}\); [\(\alpha\)]\(_D\)\(^{25}\) +21.8 (c 1.1, CHCl\(_3\)).

1-Chloro-4-[(E)-2-(4-chlorophenyl)vinyl]benzene (20).

To zinc dust < 10 micron (flame dried under argon) (10.2 g, 156 mmol, 2.19 equiv) was added THF (215 mL) the resulting mixture was cooled to -10 °C. Then TiCl\(_4\) (8.3 mL, 76.0 mmol,
1.07 equiv) was carefully added to the solution. After 5 min, 4-chlorobenzaldehyde (9.9 g, 70.0 mmol, 1.0 equiv) was added in one portion. The resulting mixture was heated under reflux for 20 h then cooled to room temperature, and a 10% (w/w) K₂CO₃ aqueous solution (150 mL) was added. The clear organic phase was collected and the aqueous mixture was washed with Et₂O (100 mL). The organic phase was concentrated under reduced pressure to afford a crude crystalline product washed with Et₂O to afford pure 20 as a white solid(7.9 g, 91%).

Triphenyl(4-{([E]-2)-[4-(triphenylphosphonio)phenyl]vinyl}phenyl)phosphonium dibromide (21).
A solution of NiBr₂ (19.0 g, 86 mmol, 2.0 equiv), triphenylphosphine (45.0 g, 172 mmol, 4 equiv) and 20 (10.6 g, 43 mmol, 1.0 equiv) in benzonitrile (300 mL, 0.15 M) was heated under reflux 2 h. The solution was cooled to 60 °C and a 10% (w/w) KBr aqueous solution (100 mL) was added. The layers were separated, the aqueous layer was washed twice with CH₂Cl₂ (100 mL) and once with a solution of CH₂Cl₂ (100 mL) and MeOH (25 mL). The organic solution was washed with a half saturated NaCl aqueous solution (100 mL), dried over anhydrous MgSO₄ and was the desired product was precipitated upon Et₂O (100 mL). The precipitate was filtered on a Büchner and washed with Et₂O (2x100 mL) and then dried under reduced pressure overnight to afford a crystalline product 21 as a white solid (38.6 g, ca. 105%) containing some amount of benzonitrile. An aliquot was purified by dissolution in CH₂Cl₂ and precipitation by Et₂O to afford pure 21: mp >250 °C; ¹H NMR (400 MHz, CDCl₃+ CD₃OD (trace)): δ 7.97-7.84 (m, 4H), 7.72-7.63 (m, 6H), 7.60-7.46 (m, 14H), 7.38-7.31 (m, 16H); ¹³C NMR (100 MHz, CDCl₃+ CD₃OD (trace)): δ 143.3 (d, J = 2.9 Hz, 2C), 135.2 (d, J = 2.5 Hz, 6C), 134.2 (d, J = 10.6 Hz, 4C), 133.7 (d, J = 10.3 Hz, 12C), 131.1 (s, 2C), 130.2 (d, J = 12.8 Hz, 12C), 128.8 (d, J = 13.2 Hz, 4C), 117.0 (d, J = 89.1 Hz, 2C), 115.1 (d, J = 90.8 Hz, 6C); ³¹P NMR (162 MHZ, CDCl₃+ CD₃OD (trace)): δ 23.3; IR (film) 3055, 1821, 1593, 1436, 1106, 917 cm⁻¹; LRMS (API-ES, Pos) calc. for C₅₀H₄₀P₂ [M]+ CD₃OD (trace): 351.1, found 351.2.

[4-(Hydroxymethyl)phenyl](triphenyl)phosphonium perchlorate (22).
Dibromide 21 (8.63 g, ca. 9.6 mmol, 1.0 equiv) was dissolved in CH₂Cl₂ (60 mL) and dry LiClO₄ (3.5 g, 22.0 mmol, 2.3 equiv) was added followed by MeOH (30 mL). After 10 min, saturated aqueous NaCl (40 mL) and water (10 mL) were added. The layers were separated and the aqueous layer was washed with a solution of 60:40 CH₂Cl₂:MeOH (100 mL) and MeOH (30 mL) and with a solution composed of CH₂Cl₂ (30 mL) and MeOH (10 mL). The organic solution was dried over Na₂SO₄, filtered and cooled to -78 °C. O₃ was bubbled through the solution. When the solution became clear blue, O₂ and argon were bubbled into the solution to remove excess ozone. NaBH₄ (740 mg, 20 mmol, 2.1 equiv) was added to the solution and after 30 min, the solution was warmed to 0 °C for 1 h. A saturated aqueous solution of NH₄Cl (100 mL) was carefully added. The layers were separated, and the aqueous layer was washed twice with CH₂Cl₂ (50 mL). The organic phase was dried over Na₂SO₄ and concentrated under reduced pressure. The crude product was diluted with CH₂Cl₂ (15 mL) and was the desired product was precipitated upon Et₂O (100 mL) addition. Filtration afforded pure 22 as a white solid (6.9 g, 77% 2 steps): mp 225-230 °C; ¹H NMR (400 MHz, CD₂Cl₂): δ 7.85-7.70 (m, 3H), 7.63-7.60 (m, 8H), 7.54-7.45 (m, 8H), 4.71 (s, 2H), 4.30 (bs, 1H); ¹³C NMR (100 MHz, CD₂Cl₂): δ 150.8 (d, J = 3.0 Hz, 1C), 135.4 (d, J = 1.7 Hz, 3C), 134.4 (d, J = 10.2 Hz, 6C), 134.3 (d, J = 10.6 Hz, 2C), 130.3 (d, J = 12.8 Hz, 6C), 128.1 (d, J = 13.2 Hz,
over Na aqueous layers were washed with CHCl₃ twice with water (11 mL) and saturated aqueous NaCl (20 mL). The solution was stirred at 0 °C without light for 30 min and was washed with a solution containing water (11 mL) and saturated aqueous Na₂S₂O₃ (11 mL). The aqueous layer was washed with CH₂Cl₂ (20 mL). The organic solution was washed once with water (10 mL), with water (20 mL) and was dried over Na₂SO₄ and concentrated under reduced pressure. The crude product was diluted with CH₂Cl₂ (5 mL). The combined organic layers were dried over Na₂SO₄ and concentrated under reduced pressure. The crude product was diluted with

\[
\{4-[((\text{Etoxycarbonyl})\text{diazenyl})\text{carbonyl}]\text{oxy}][\text{methyl}]\text{phenyl}\}[(\text{triphenyl})\text{phosphonium} \text{ perchlorate. (23).}]
\]

To a solution of triphosgene (1.3 g, 4.3 mmol, 0.43 equiv) in CH₂Cl₂ (75 mL) at -30 °C was added dropwise pyridine (2.1 mL, 26 mmol, 2.6 equiv). The resulting mixture was warmed to room temperature for 30 min (it became a clear yellowish homogeneous solution) then was cooled to -78 °C (it became a milky yellowish mixture). A solution of 22 (4.7 g, 10 mmol, 1.0 equiv) in CH₂Cl₂ (75 mL, rinse with 1 mL) at -78 °C was added dropwise for 5 min to the mixture (the mixture had to be kept below -70 °C and became a clear limpid solution at the end of the addition). After 10 min, a solution of ethyl carbazate (2.1 g, 20 mmol, 2.0 equiv) in CH₂Cl₂ (25 mL) at -78 °C was added dropwise to the solution. The solution became yellow and the external bath was warmed to -60 °C and was left to warm to -20 °C over 2 h and to 0 °C over 0.5 h. The resulting solution was washed with water (100 mL). The aqueous layer was washed twice with CH₂Cl₂ (100 mL, 50 mL). The combined organic layers were washed with water (100 mL). The aqueous layer was washed with CH₂Cl₂ (50 mL). The organic solution was washed with a solution of LiClO₄•3H₂O (1.6 g, 10 mmol, 1.0 equiv) in water (10 mL), with water (20 mL) and was dried over Na₂SO₄ and concentrated under reduced pressure. The crude product was diluted with CH₂Cl₂ (25 mL) and the desired product was precipitated with Et₂O (100 mL) and filtration afforded pure 23 as a white solid foam (5.7 g, 95%): mp 95-100 °C; ¹H NMR (400 MHz, CDCl₃): δ 8.00-7.85 (m, 3H), 7.85-7.70 (m, 8H), 7.70-7.65 (m, 8H), 7.31 (bs, 1H), 6.82 (bs, 1H), 5.26 (s, 2H), 4.12 (q, J = 7.1 Hz, 2H), 1.20 (t, J = 7.1 Hz, 3H); ¹³C NMR (100 MHz, CDCl₃): δ 156.7 (s, 1C), 156.3 (s, 1C), 144.8 (s, 1C), 135.7 (d, J = 2.3 Hz, 3C), 134.5 (d, J = 10.7 Hz, 2C), 134.3 (d, J = 10.3 Hz, 6C), 130.7 (d, J = 12.9 Hz, 6C), 129.0 (d, J = 12.9 Hz, 2C), 117.5 (d, J = 89.0 Hz, 3C), 116.5 (d, J = 90.1 Hz, 1C), 65.6 (s, 1C), 61.9 (s, 1C), 14.4 (s, 1C); IR (film) 1720, 1437, 1266, 1217, 1067 cm⁻¹; ³¹P NMR (162 MHZ, CDCl₃): δ 23.2; LRMS (APCI, Pos) calc. for C₂₉H₂₂N₂O₄P [M⁺]: 499.2, found 499.1; LRMS (APCI, Neg) calc. for ³⁵ClO₄⁻ [M⁻]: 99.0, found 98.9; calc. for ³⁷ClO₄⁻ [M⁻]: 101.0, found 101.0.

\[
\{4-[((\text{Etoxycarbonyl})\text{diazenyl})\text{carbonyl}]\text{oxy}][\text{methyl}]\text{phenyl}\}[(\text{triphenyl})\text{phosphonium} \text{ perchlorate. (24).}]
\]

To a solution of 23 (2.4 mg, 4.0 mmol, 1.0 equiv) in CH₂Cl₂ (20 mL) at 0 °C was added pyridine (500 µL, 1.5 mmol, 1.5 equiv) and in one portion NBS (856 mg, 4.8 mmol, 1.2 equiv). The solution was stirred at 0 °C without light for 30 min and was washed with a solution containing water (11 mL) and saturated aqueous Na₂S₂O₃ (11 mL). The aqueous layer was washed with CH₂Cl₂ (20 mL). The organic solution was washed once with water (10 mL), twice with a 5% aqueous HCl solution (20 mL) and once with water (10 mL). Each time the aqueous layers were washed with CH₂Cl₂ (5 mL). The combined organic layers were dried over Na₂SO₄ and concentrated under reduced pressure. The crude product was diluted with
CH₂Cl₂ (5 mL) and the desired product was precipitated upon the addition of Et₂O (30 mL). Filtration afforded pure 24 as a yellow solid foam (2.2 g, 91%): \textbf{mp} 85-80 °C; \textbf{¹H NMR} (400 MHz, CDCl₃): δ 7.95-7.65 (m, 19H), 5.59 (s, 2H), 4.49 (q, \(J = 7.1\) Hz, 2H), 1.41 (t, \(J = 7.1\) Hz, 3H); \textbf{¹³C NMR} (100 MHz, CDCl₃): δ 160.2 (s, 1C), 160.0 (s, 1C), 142.1 (d, \(J = 2.9\) Hz, 1C), 135.9 (d, \(J = 2.6\) Hz, 3C), 135.0 (d, \(J = 10.6\) Hz, 2C), 134.6 (d, \(J = 10.3\) Hz, 6C), 130.9 (d, \(J = 12.9\) Hz, 6C), 130.0 (d, \(J = 13.1\) Hz, 2C), 118.3 (d, \(J = 89.5\) Hz, 1C), 117.3 (d, \(J = 89.1\) Hz, 3C), 69.0 (s, 1C), 63.7 (s, 1C), 14.2 (s, 1C); \textbf{³¹P NMR} (162 MHZ, CDCl₃): δ 23.2; \textbf{IR} (film) 1777, 1439, 1266, 1224, 1090 cm⁻¹; \textbf{LRMS} (APCI, Pos) calc. for C₂₉H₂₆N₂O₄P₁ [M]⁺: 497.2, found 497.1; \textbf{Elem. Anal.} Calc. (%) for C₂₉H₂₆ClN₂O₈P: C 58.35, H 4.39, found: C 58.37, H 4.27.
Thermogravimetric experiment

![Thermogravimetric analysis graph](image)

- **Br**
- **Ph₄P**

- Temperature at 383.57°C
- Weight loss at 403.76°C
- Weight (mg): 4.020 mg
- Weight loss (%): 92.18%

---

Poupon, J.-C.; Boezio, A. A.; Charette, A. B. Page 47
References and Notes


