

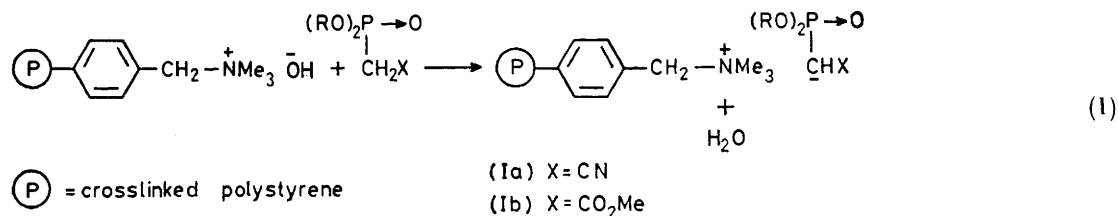
Polymer-supported Phosphonates. Olefins from Aldehydes, Ketones, and Dioxolans by means of Polymer-supported Phosphonates

By Gianfranco Cainelli,* Michele Contento, Francesco Manescalchi, and Rodolfo Regnoli, Istituto Chimico G. Giamician, Università degli Studi, Via Selmi 2, 40126 Bologna, Italy

Phosphonates substituted with electron-withdrawing groups (CN and CO₂Me) have been supported, by means of a neutralization reaction, on the macroreticular anion-exchange resin Amberlyst A-26. Treatment of carbonyl compounds with the polymer-bound phosphonate in various solvents gave olefins in high yields, at room temperature. Either batch or column techniques are employed, the latter offering the opportunity of a continuous procedure. The simultaneous use of the phosphonate resin and of an acidic one (Amberlyst 15 H) allowed the direct sequential hydrolysis and olefination of dioxolans.

THE use of stabilized phosphonates bearing in the α -position an electron-withdrawing group, *e.g.* CN, CO₂R, or COR, in the olefination of carbonyl compounds, the so-called Horner-Wittig synthesis, has been explored in depth and exhaustively reviewed.¹ Owing to our interest in nucleophilic substitutions, performed by polymer-supported anions,² we have tried to apply this technique to the Horner-Wittig reagents. In fact, as long as the acidity of the C-H bonds α to electron-withdrawing substituents in phosphonates is in the pK_a

compound were stirred with 10 mmol of freshly prepared phosphonate resin in tetrahydrofuran (THF) at room temperature. The reaction was monitored by g.l.c. or t.l.c. and was generally complete in 1 h. The resin was filtered off and the solvent removed by gentle distillation, to give the unsaturated products which were purified and identified, on the basis of spectral evidence, as a mixture of *E*- and *Z*-isomers (see Table 1). The stereoselectivity of the olefin formation was such that in some instances (entries 2, 3, 6, 8) a mixture of *E/Z*



range *ca.* 6–9,³ such compounds may be supported on a basic anion-exchange resin by a simple neutralization process. To effect this, a dilute ethereal solution of the phosphonate, prepared by standard procedures reported in the literature,⁴ was percolated through a column filled with Amberlyst A-26, a macroreticular anion-exchange resin, in the OH⁻ form. According to the neutralization reaction (1), we obtained the polymer-supported phosphonates (Ia) and (Ib). The resin was then rinsed with ether and dried *in vacuo* at room temperature for several hours. By weighing the amount of recovered phosphonate, we could estimate for reagent (Ia) an average capacity of 3.4 mmol g⁻¹ of dried resin, in good agreement with the resin capacity as given by the manufacturer. For the reagent (Ib) a somewhat lower value of 2.53 mmol g⁻¹ was determined probably owing to the lower acidity of the corresponding phosphonate. These reagents are somewhat unstable and undergo slow decomposition and loss of activity with time: they were therefore prepared immediately before use.

The olefination of (Ia) and (Ib) with carbonyl compounds was performed either by batch or column techniques. In the former case, 5 mmol of carbonyl

isomers in a *ca.* 2:1 ratio was obtained. Similar behaviour was observed in the phase-transfer catalysed Horner-Wittig synthesis.⁵

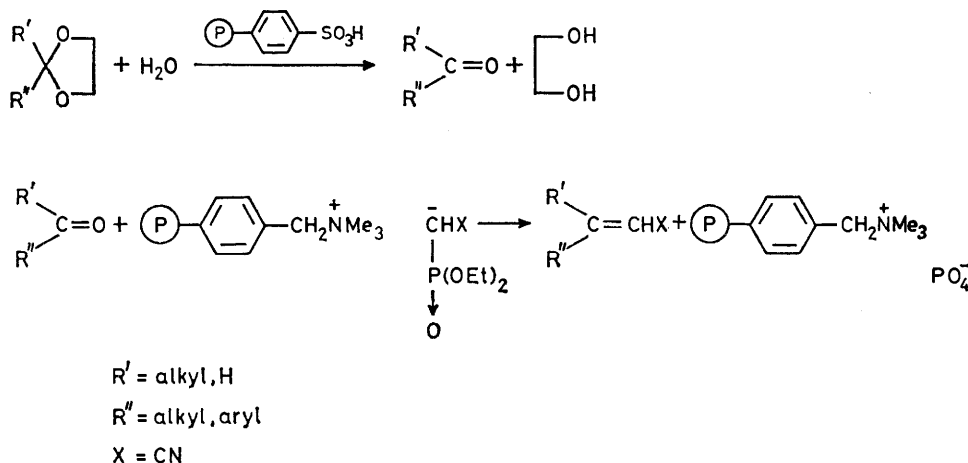
Reagent (Ia) has also been employed using a column technique. This procedure is interesting since it offers the opportunity of a continuous procedure, the olefin being directly obtained by slowly percolating the carbonyl compound solution through the column packed with the phosphonate resin. Regeneration of the polymeric reagent was then accomplished by washing, successively, with aqueous hydrochloric acid, sodium hydroxide, and phosphonate. The same resin batch was thus used more than ten times without any loss in efficiency. Product yields by the column method are practically the same as in the batch method (Table 1). The column technique proved to be unsuitable for reagent (Ia) because of its lower reactivity.

Perhaps the most remarkable advantage of performing a reaction with the aid of a polymer support is that the process is independent of the nature of the solvent employed, the resin providing a microenvironment in which the reaction site is made almost independent of the external medium. Thus less expensive and less

poisonous solvents may often be employed. An example of this versatility is illustrated by reactions 2 and 4 in Table 1, in which hexane, methanol, benzene, and THF-water (9 : 1) were used without any change in yield or reaction time.

An aspect of polymer-supported reactions which has not until now received attention is the possibility of per-

after dehydration over anhydrous sodium sulphate. From the results collected in Table 2 it may be seen that the product yields are high and the procedure a general one both for the dioxolans of ketones as well as of aromatic and $\alpha\beta$ -unsaturated aldehydes. In contrast, the dioxolans of saturated aldehydes failed to react being recovered unchanged. This may be due to the



forming in the same vessel sequential reactions by means of a mixture of two polymer-supported reagents which would be incompatible when in homogeneous solution. Thus dioxolans, which are widely employed as a temporary protection of carbonyl groups and readily undergo quantitative hydrolysis by aqueous acid, underwent direct olefination by the simultaneous use of the strongly acidic resin Amberlyst 15 H and of the phosphonate resin (Ia) in THF-water (9 : 1). Such a reaction would be impossible in solution since immediate neutralization of the acidic catalyst by the basic phosphonate reagent would take place.

The reaction, performed with molar ratios of 2 : 1 : 0.5 of phosphonate, dioxolan, and Amberlyst 15 H (H^+ form) was stirred at room temperature for 1–3 h; the resins were then filtered off and the solvent removed

higher stability to hydrolysis of this type of compound, suggesting the possibility of selective olefinations. Reagent (I_b) in contrast seems not to be effective under similar conditions.

EXPERIMENTAL

I.r. spectra were recorded on a Perkin-Elmer 710 B spectrometer. ^1H N.m.r. spectra were measured at 60 MHz in CCl_4 solution by a Perkin-Elmer R1 2B instrument, with SiMe_4 as internal standard. Mass spectra were measured on a Hitachi-Perkin-Elmer RMU 6D (single focus) spectrometer at 60 eV. G.l.c. analysis was performed on a Hewlett Packard 5750 instrument equipped with an FFAP stainless-steel column (10 ft \times 0.25 in). T.l.c. was performed on silica gel HF₂₅₄ (Merck), and column chromatography on silica gel 0.05–0.20 mesh (Merck) with hexane-ether as eluant. Bulb-to-bulb distillation was achieved

TABLE 1
Reaction of polymer-supported phosphonates, (Ia) and (Ib) with carbonyl compounds at room temperature

Carbonyl compounds	Products from reagent (Ia) ^a	% Yields (E/Z isomers)	Products from reagent (Ib) ^a	% Yields (100%E)
(1) <i>p</i> -Chlorobenzaldehyde	<i>p</i> -Chlorocinnamionitrile	83 (E 100%)	Methyl <i>p</i> -chlorocinnamate	97
(2) 3,7-Dimethylocta-2,6-dienal ^c	5,9-Dimethyldeca-2,4,8-trienenitrile	97 (1 : 1) ^d	Methyl 5,9-dimethyldeca-2,4,8-trienoate ^b	95
(3) Heptanal	Non-2-enenitrile	75 (3 : 1)		
(4) Nonanal			Methyl undec-2-enoate	64
(5) Cyclohexanone	Cyclohexylideneacetone nitrile	96.8 (E 100%)		
(6) Undecan-2-one	3-Methyl dodec-2-enenitrile	95 (2 : 1)		
(7) Acetophenone	3-Methyl cinnamionitrile	90 (E 100%)		
(8) β -Ionone	β -Ionylidene acetone nitrile ^b	93 (2 : 1)		

^a 1 h. ^b 2 h. ^c E at Δ^2 . ^d Refers to newly formed double bond.

under reduced pressure by means of a Büchi-Kugelrohr oven. Dioxolans were obtained following standard procedures reported in the literature.⁶

Amberlyst A-26, OH⁻ Form.—Amberlyst A-26, chloride form (Rohm e Haas Co.; 200 g), was converted into the OH⁻ form by washing with 1M-aqueous sodium hydroxide, employing the usual column technique. After rinsing with water and then with methanol, the resin was stored in a refrigerator under methanol.

Amberlyst A-26, Phosphonate Form.—Amberlyst A-26, OH⁻ form, (5 g) and diethylphosphonoacetonitrile (1.78 g, 10 mmol) in methanolic solution were shaken mechanically for 2 h. The resin was then filtered off and thoroughly washed with THF. By distilling off the solvent and weigh-

also identified by g.l.c. retention time comparison with an authentic sample.⁷

Cyclohexylideneacetonitrile.—The reaction was carried out on a 3.5 mmol scale to give the title compound (0.41 g, 96.8%); n.m.r.: δ 1.7 (m, 6 H), 2.45 (m, 4 H), and 5.1 (s, 1 H); ν_{\max} 2 200 cm⁻¹; m/e 121 (M^+) (Found: C, 79.5; H, 9.0; N, 11.7. C₈H₁₁N requires C, 79.3; H, 9.2; N, 11.6%).

3-Methyldeca-2-enenitrile.—This reaction was carried out on a 5 mmol scale and the crude product purified by column chromatography [eluant, hexane-ether (9:1)]. The title compound (0.916 g, 95%) was obtained as a mixture of *E/Z* isomers (2:1 as evaluated by g.l.c. and n.m.r.); n.m.r.: δ 0.9 (t, 3 H), 1.3 (m, 14 H), 1.9 (s, 3 H, *Z*-isomer), 2.1 s, 3 H, *E*-isomer), 2.3 (m, 2 H), and 5.1 (s, 1 H); ν_{\max} 2 230 and

TABLE 2
Reaction of polymer-supported phosphonate (Ia) with dioxolans

Dioxolans	Products	Reaction time(h)	Yields(%)
2-Phenyl-1,3-dioxolan	Cinnamionitrile	1	98
2-(2,6-Dimethylhepta-1,6-dienyl)-1,3-dioxolan	5,9-Dimethyldeca-2,4,8-trienenitrile	1	90
1,4-Dioxaspiro[4.5]decane	Cyclohexylideneacetonitrile	3	90
2-Methyl-2-phenyl-1,3-dioxolan	3-Methylcinnamionitrile	1	40

ing the residual phosphonate the amount of the polymer-supported reagent (Ia) was evaluated as 5.6 mmol; this corresponds to 3.5 mmol g⁻¹ of dried resin (mean value over a number of trials).

By a similar procedure, 10 g of Amberlyst A-26, OH⁻ form, supported 5.2 mmol of methyl diethylphosphonoacetate to give reagent (Ib). Both reagents may also be prepared by a column technique, in which an ethereal phosphonate solution is slowly percolated through a column packed with Amberlyst A-26, OH⁻ form, the latter then being washed with ether.

***p*-Chlorocinnamionitrile: General Procedure.**—*p*-Chlorobenzaldehyde (0.49 g, 3.5 mmol) and Amberlyst A-26 [form (Ia); 5 g, 5.6 mmol] in wet form were stirred at room temperature in THF (10 ml). The reaction, followed by g.l.c., was complete in 1 h. The resin was filtered off and the solvent removed by gentle distillation to give the title compound (0.47 g, 83%); 100% *E*-isomer; n.m.r.: δ 5.85 (d, 1 H, *J* 13 Hz), 7.35 (d, 1 H, *J* 13 Hz), and 7.38 (s, 4 H); ν_{\max} 2 200 cm⁻¹; m/e 163 (M^+ , ³⁵Cl), 165 (M^+ , ³⁷Cl) (Found: C, 66.3; H, 3.6; Cl, 21.5; N, 8.8. C₉H₆ClN requires C, 66.1; H, 3.7; Cl, 21.7; N, 8.6%).

5,9-Dimethyldeca-2,4,8-trienenitrile.—The reaction was carried out on a 3.5 mmol scale to give the title compound (0.594 g, 97%) as a mixture of *E/Z* isomers in a 1:1 ratio (g.l.c. determination); n.m.r.: δ 1.6 (s, 3 H), 1.7 (s, 3 H), 1.9 (s, 3 H), 2.2 (m, 4 H), 5.1 (t, 1 H), 5.3br (m, 1 H, *E/Z*), 5.8—6.6br (m, 1 H, *E/Z*), and 7.6—7.9br (m, 1 H, *E/Z*); ν_{\max} 2 200 and 2 250 cm⁻¹ (Found: C, 81.9; H, 9.6; N, 8.2. Calc. for C₁₂H₁₇N: C, 82.2; H, 9.8; N, 7.9%).

The *E*-isomer was also identified by g.l.c. retention time comparison with an authentic sample.⁷

Non-2-enenitrile.—This reaction, carried out on a 3 mmol scale and the crude product being purified by column chromatography [eluant, hexane-ether (9:1)], gave a mixture (0.31 g, 75%) of *E/Z* isomers (3:1; by g.l.c. determination) of the title compound; n.m.r.: δ 0.9 (t, 3 H), 1.3 (m, 8 H), 2.1 (m, 2 H), 5.23 (d, 1 H, *Z*-isomer), 5.27 (d, 1 H, *E*-isomer), and 6.2—6.9br (m, 1 H, *E/Z*); ν_{\max} 2 230 and 2 250 cm⁻¹ (Found: C, 79.0; H, 10.9; N, 10.3. Calc. for C₉H₁₅N: C, 78.8; H, 11.0; N, 10.2%). The *E*-isomer was

2 270 cm⁻¹; m/e 193 (M^+) (Found: C, 80.5; H, 11.9; N, 7.3. C₁₃H₂₃N requires C, 80.7; H, 12.0; N, 7.2%).

3-Methylcinnamionitrile.—This reaction was carried out on a 5 mmol scale to give the title compound (0.643 g, 90%) after purification by column chromatography (*E*-isomer 100%); n.m.r.: δ 2.4 (s, 3 H), 5.6 (s, 1 H), and 7.45 (s, 5 H); ν_{\max} 2 200 cm⁻¹ (Found: C, 83.6; H, 6.2; N, 9.6. Calc. for C₁₀H₉N: C, 83.9; H, 6.3; N, 9.8%). The compound was also identified by retention time comparison with an authentic sample.⁷

***β*-Ionylideneacetonitrile.**—This reaction was carried out on a 1.45 mmol scale and the crude product purified by column chromatography [eluant, hexane-ether (9:1)]. The title compound (0.29 g, 93%) was recovered as a mixture of *E/Z* isomers 2:1 (g.l.c. determination); n.m.r.: δ 1.0 (d, 6 H), 1.65br (m, 6 H), 2.08 (s, 3 H), 2.2 (s, 3 H), 5.1 (s, 1 H, *Z*-isomer), 5.15 (s, 1 H, *E*-isomer), 6.1 (d, 1 H), and 6.55 (d, 1 H); ν_{\max} 2 200 cm⁻¹ (Found: C, 83.8; H, 9.9; N, 6.4. Calc. for C₁₅H₂₁N: C, 83.6; H, 9.8; N, 6.5%). The compound was also identified by retention time comparison with an authentic sample.⁸

Methyl *p*-Chlorocinnamate: General Procedure.—*p*-Chlorobenzaldehyde (0.28 g, 2.0 mmol) and Amberlyst A-26 [form (Ib); 6 g, 4.9 mmol corresponding to 2.53 mmol/g of dried resin], were stirred at room temperature in THF (10 ml). The reaction, followed by g.l.c. was complete in 1 h. The resin was filtered off and the solvent removed by distillation to give the title compound (0.38 g, 97%, only *E*-isomer); n.m.r.: δ 3.8 (s, 3 H), 6.4 (d, 1 H, *J* 12.5 Hz), 7.42 (s, 4 H), and 7.68 (d, 1 H, *J* 12.5 Hz); ν_{\max} 1 720 cm⁻¹; m/e 196 (M^+ , ³⁵Cl); 198 (M^+ , ³⁷Cl). (Found: C, 61.4; H, 4.5; Cl, 18.2. C₁₀H₉ClO₂ requires C, 61.1; H, 4.6; Cl, 18.0%).

Methyl Undec-2-enoate.—The reaction was carried out on a 2.6 mmol scale and the crude product purified by column chromatography [eluant, hexane-ether (9:1)]. The title compound (0.35 g, 64%) was isolated as the pure *E*-isomer; n.m.r.: δ 0.9 (t, 3 H), 1.3 (m, 12 H), 2.1 (m, 2 H), 3.7 (s, 3 H), 5.8 (d, 1 H, *J* 16 Hz), and 7.0 (m, 1 H); ν_{\max} 1 720 cm⁻¹; m/e 198 (M^+) (Found: C, 72.5; H, 11.0. C₁₂H₂₂O₂ requires C, 72.7; H, 11.2%).

Methyl 5,9-Dimethyldeca-2,4,8-trienoate.—The reaction

was carried out on a 2.6 mmol scale and the crude product purified by bulb-to-bulb distillation ($62^{\circ}\text{C}/10^{-2}$ mmHg) to give the title compound (0.514 g, 95% as the *E*-isomer); n.m.r.: δ 1.64 (s, 3 H), 1.68 (s, 3 H), 1.9 (s, 3 H), 2.15 (m, 4 H), 3.7 (s, 3 H), 5.1 (t, 1 H), 5.75 (d, 1 H, J 14 Hz), 6.0 (d, 1 H), and 7.55 (dd, 1 H); ν_{max} 1 720 cm^{-1} (Found: C, 75.0; H, 9.8. $\text{C}_{13}\text{H}_{20}\text{O}_2$ requires C, 74.9; H, 9.7%).

Reaction of Amberlyst A-26 [form (Ia)] with Dioxolans.—The dioxolan (5 mmol) in THF–water (9 : 1) (10 ml) was stirred at room temperature with 10 mmol of Amberlyst A-26 [form (Ia)] and 0.7 g (2.5 mmol) of Amberlyst 15 H (H^+ form); the reaction was followed by g.l.c. or t.l.c. The resin was filtered off and thoroughly washed with ether. The solvent, dried over anhydrous sodium sulphate, was distilled off and the recovered product, purified in the usual way, was identified on the basis of g.l.c. and spectral data.

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