First three-component addition reaction in a series of 1,5-bis(dialkylamino)pentamethinium salts: a simple and efficient approach to tridentate chelating ligand systems

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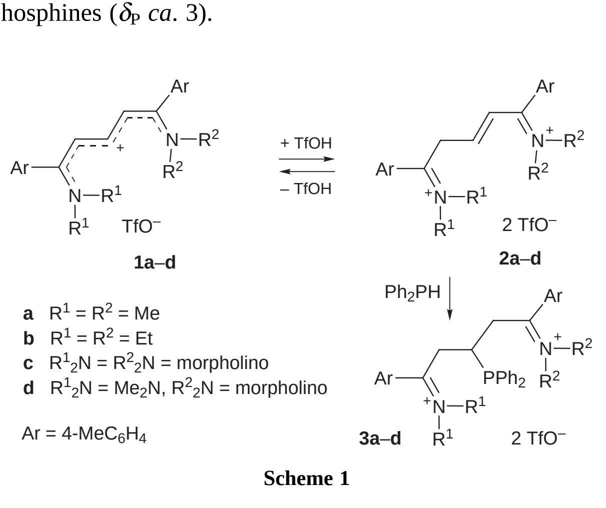
A new approach to tridentate chelating NPN, NPO and OPO ligand systems is described *via* a tandem reaction of easily available 1,5-bis(dialkylamino)pentamethinium salts (streptocyanine dyes) with diphenylphosphine in the presence of TfOH.

The role of polymethine dyes as components of industrially important technologies has long been acknowledged.[1] It is surprising, therefore, that the reported chemistry of polymethine salts is rather sparse.[2,3] This is due to the relatively high thermodynamic stability of the polymethine chain and its tendency to be regenerated after reaction. In the pentamethinium series this enables introduction of nucleophilic or electrophilic groups into the chain by substitution rather than addition to the double bonds.

To exploit the synthetic potential of easily available pentamethinium salts[2,4] we now report the application of tandem methodology in the preparation of chelating polyheteroatomic compounds,[5] starting from 1,5-diaryl-substituted pentamethinium salts **1**.

Since non-ionic protic nucleophiles are not capable of direct addition to pentamethinium salts, activation of the latter towards the addition of phosphines might be achieved in the presence of strong protic acid, thus facilitating nucleophilic attack on the intermediate dicationic species.

Treatment of the pentamethinium salts **1** with the Ph_2PH and TfOH in the molar ratio 1:1:1 in a CH_2Cl_2 solution at -35 °C resulted in the quantitative formation of the diiminium salts **3** (Scheme 1). We obtained **3**‡ as colorless crystals in 83–95% yield. NMR signals at *ca.* δ 1.9 (HCP) and 3.2 (CH_2CHP, d, $^3J_{HH}$ 7 Hz) in the ^1H NMR spectra and *ca.* δ 187 ($C{=}N^+$), 35 (C3, $^1J_{CP}$ 22 Hz) and 39 (C2, C4, $^2J_{CP}$ 9 Hz) in the ^{13}C NMR spectra are diagnostic for structure **3**. The ^{31}P NMR signal is observed as a singlet in the range expected for alkyldiphenylphosphines (δ_P *ca.* 3).



Scheme 1

Single crystals of salt **3b** were obtained from MeCN at 20 °C and X-ray data were collected at 160 K.§ The compound crystallizes along with 1 equiv. of MeCN in space group $P1$ Fig. 1. The C(3) atom in **3b** displays a slightly distorted tetrahedral geometry. The P–C(3) bond length [1.873(2) Å] lies at the higher limit of the normal P–C(sp^3) range, as in the sterically overcrowded compound $HC(PPh_2)_3$ (av. 1.872 Å).[6] Iminium nitrogens are sp^2-hybridized. The distances between the C(sp^2) atoms and nitrogen atoms [C(1)–N(1) and C(5)–N(2), av. 1.294 Å] are considerably shorter than in 1,5-diaryl-substituted pentamethinium salts (*ca.* 1.325 Å)[7] but comparable with those observed in other iminium salts.[8] The C(1)–C(2) and C(4)–C(5) distances are 1.498(3) and 1.507(3) Å, approximately 0.035 Å shorter than the C(2)–C(3) and C(3)–C(4) bonds. This may imply hyperconjugation in the $[HCC(Ar)N]^+$ bond system.

To gain some insight into possible intermediates leading to **3**, we treated **1b** with TfOH in CH_2Cl_2 at -50 °C. Monitoring the reaction *via* ^{13}C NMR spectroscopy clearly showed the reversible build-up of **2b** [δ 186.7 and 176.3 (C^1, C^5), 155.8 (C^3), 128.3 (C^4), 40.1 (C^2)]. The protonation of **1b** was achieved when 1.5-fold molar excess of TfOH was added. Subsequent warming of the solution in the NMR probe resulted in the disappearance of the signals due to **2b** due to its degradation with the loss of the $[Et_2NH_2^+TfO^-]$ salt. The yield of **3** sharply decreased if Ph_2PH was not added to the pentamethinium salt at the same time as the TfOH. The reaction pathway begins with an attack of the proton at the C^2 methine carbon of the substrate. The non-isolable dicationic intermediate **2** allows the efficient trapping of Ph_2PH in the subsequent nucleophilic addition.

An important aspect of salts **3** is their ability to release Ph_2PH. According a variable-temperature ^{31}P NMR study, the reversible cleavage of **3** in MeCN occurs above 50 °C. The

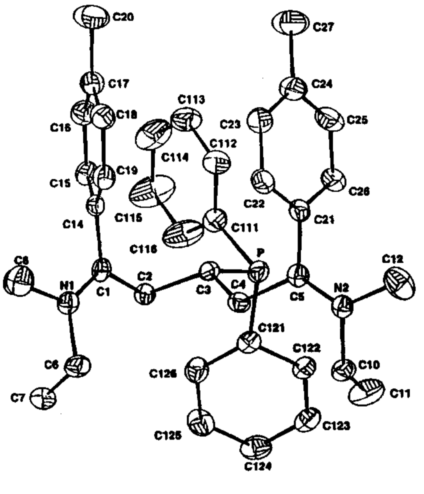
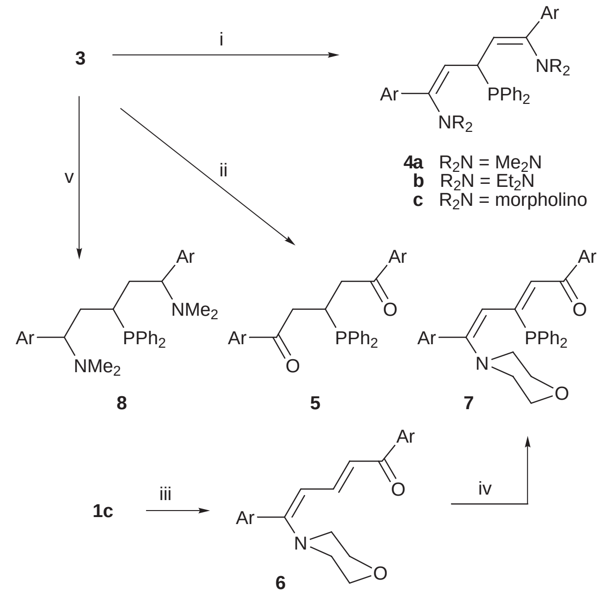


Fig. 1 Molecular structure of **3b** with atomic numbering scheme



Scheme 2 *Reagents and conditions*: i, KOH, EtOH, 20 °C, 1 h; ii, KOH, EtOH–H_2O (5:1), 70 °C; iii, KOH EtOH–H_2O (5:1), 20 °C, 1 h; iv, Ph_2PH, KOH (cat.), MeCN, 20 °C, 24 h; v, $NaBH_4$, EtOH, −20 °C

addition of 3 mol% TfOH or an equimolar amount of pyridine to a CH_2Cl_2 solution of **3** promotes rupture of the C–P bond and the appearance of a broadened singlet at δ_P −38, indicating a fast proton exchange for the three-component system (**1**/Ph_2PH/TfOH). The cleavage of **3** proceeds slowly at 20 °C in alcohols and very fast in highly polar basic solvents such as HMPA, DMF or NMP. Evaporation of the solvent allows the recovery of **3**. Strong acids (catalytically) and weak bases tend to cleave the P–C(3) bond in **3** due to reversible protonation at the P centre and deprotonation of the chain methylene group. The treatment of **3** in EtOH at 20 °C with 2 equiv. of KOH affords the neutral compounds **4**¶ (Scheme 2). The deprotonation of the dication **3** and the formation of **4** is a highly regioselective reaction if the alternative pathway including protonation of the P atom and subsequent splitting up Ph_2PH is blocked or inhibited. The products **4** were isolated as crystalline materials and, in the case of **4c**, characterised by single-crystal X-ray structure determination.§ The most interesting difference between **3b** and **4c** is a lengthening of the P–C(3) bond [1.892(2) Å for **4c** *vs*. 1.873(2) Å for **3b**]. Meanwhile, compounds **4** do not display evidence for structural lability. Thus factors favouring P–C bond scission in **3** are of electronic rather than steric character.

When **3** was allowed to react with 2 equiv. of KOH in aq. EtOH at 60 °C for 2 h (Scheme 2) the dicarbonyl derivative **5**¶ was obtained. The conversion includes the intermediate formation of **4** and its subsequent hydrolysis. Efforts to synthesize **7** under similar conditions (1 equiv. of KOH, EtOH–H_2O, 60 °C) were not successful. However, reaction of **1c** with 1 equiv. of KOH in EtOH gave a yellow microcrystalline precipitate **6** (78%). Compound **7** was then constructed *via* treatment of **6** with Ph_2PH.¶ Finally, the reduction of **3a** with $NaBH_4$ proceeded smoothly in EtOH at −20 °C to give **8** (62%).¶

In summary, these results illustrate the ability of strong electrophiles to interact with the electron deficient pentamethinium chain, leading to the formation of adducts which are stabilised by addition of proton-donor nucleophiles. Polymethine salts are prospective starting materials for organoelement and coordination chemistry.

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Notes and References

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‡ *Selected data* for **3b**: δ_C(100 MHz, CD_3CN) 13.7 (s, H_3CCH_2), 21.6 (s, 4-$H_3CC_6H_4$), 34.8 (d, $^1J_{CP}$ 22, C^3), 40.0 (d, $^2J_{CP}$ 9, C^2 and C^4), 51.5 and 54.0 (s, CH_2N), 188.9 (s, C^1 and C^5); δ_P(81 MHz, CD_3CN) 3.0; *m/z* (FAB +ve, MNBA) 725 ($[M^{2+}TfO^-]^+$).

§ *Crystal data* for **3b**: $[C_{39}H_{49}N_2P][CF_3SO_3]_2[MeCN]$, M = 916.00, triclinic, crystal dimensions 0.50 × 0.40 × 0.20 mm^3, space group $P1$, a = 11.379(2), b = 11.464(2), c = 19.099(3) Å, α = 74.06(2), β = 81.82(2), γ = 71.56(2)°, U = 2268(2) Å^3, Z = 2, ρ_{calc} = 1.34 g cm^{-3}, μ = 2.17 cm^{-1}, F000 = 962.96. A total 17841 reflections were measured (6649 independent) with R_m = 0.03. The final R (R_w) values were 0.038 (0.039) for 5455 reflections [$I > 2\sigma(I)$] and 567 variables. For **4c**: $[C_{39}H_{43}N_20_2P][CH_3CN]$, M = 643.82, monoclinic, crystal dimensions 0.60 × 0.30 × 0.10 mm^3, space group Ia, a = 9.445(1), b = 23.713(4), c = 23.305(4) Å, β = 103.64(2)°, U = 3554(3) Å^3, Z = 4, ρ_{calc} = 1.11 g cm^{-3}, μ = 1.20 cm^{-1}, F000 = 1376.6. A total 11211 reflections were measured (5254 independent) with R_m = 0.03. The final R (R_w) values were 0.032 (0.037) for 4586 reflections [$I > 2\sigma(I)$] and 461 variables. CCDC 182–976.

¶ *Selected data* for **4–8**. For **4c**: δ_C[100 MHz, $(CD_3)_2CO$] 21.3 (s, 4-$H_3CC_6H_4$), 38.3 (d, $^1J_{CP}$ 13, C^3), 51.0 (s, H_2CN), 67.4 (s, H_2CO), 107.2 (s, $^2J_{CP}$ 11, C^2 and C^4), 137.7 (d, $^3J_{CP}$ 20, C^1 and C^5); δ_P(81 MHz) 6.3; *m/z* (FAB +ve, MNBA) 603 $(MH)^+$. For **5**: δ_C(100 MHz, $CDCl_3$) 21.8 (s, 4-$H_3CC_6H_4$), 27.9 (d, $^1J_{CP}$ 13, CP), 40.2 (d, $^2J_{CP}$ 15, C^2 and C^4), 198.6 (d, $^3J_{CP}$ 8, C^1 and C^5); δ_P(81 MHz) −2.0; *m/z* (FAB +ve, MNBA) 465 $(MH)^+$. For **6**: δ_C(100 MHz, CD_3CN) 21.13 (s, 4-$H_3CC_6H_4$), 21.28 (s, 4-$H_3CC_6H_4$), 49.2 (s, CH_2N), 66.8 (s, CH_2O), 102.6 (s, CH), 116.6 (s, CH), 146.8 (s, CH), 161.9 (s, =CN), 189.0 (s, C=O); *m/z* (FAB +ve, GLY) 348 $(MH)^+$. For **7**: δ_C(100 MHz, $CDCl_3$) 21.4 (s, 4-$H_3CC_6H_4$), 21.8 (s, 4-$H_3CC_6H_4$), 34.4 (d, $^1J_{CP}$ 12, CP), 42.5 [d, $^2J_{CP}$ 19, $CH_2C(O)$], 49.5 (s, CH_2N), 67.0 (s, CH_2O), 103.9 (d, $^2J_{CP}$ 11, CH), 199.0 (d, $^3J_{CP}$ 12, CO); δ_P(81 MHz) 1.5; *m/z* (DCI/NH_3) 534 $(MH)^+$. For **8**: δ_C(75.47 MHz, $CDCl_3$) 21.2 (s, 4-$H_3CC_6H_4$), 29.9 (d, $^1J_{CP}$ 15.6, CHP), 35.3 (d, $^2J_{CP}$ 9, CH_2), 42.3 (s, H_3CN), 67.1 (s, C^1 and C^5); δ_P(81 MHz) −0.1; *m/z* (DCI/NH_3) 523 $(MH)^+$.

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