The Utility of Hexachlorodisilane for the Deoxygenation of Nitrones, 2*H*-Imidazole 1-Oxides, 5*H*-Pyrazole 1-Oxides, and Related *N*-Hydroxy Compounds

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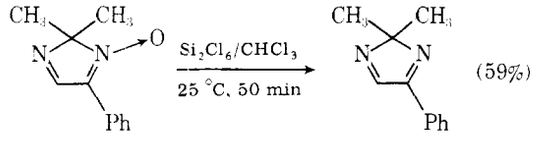
Several reports describing the use of trichlorosilane for the reduction of phosphine oxides to phosphines[1] and for the reductive deoxygenation of several types of S→O bonds[2] have appeared. Subsequently, the utility of hexachlorodisilane (Si_2Cl_6) in similar applications has been described[3,4] and extended to the reduction of phosphine sulfides,[5] amine oxides,[3] azo *N*-oxides,[6] azo *N,N'*-dioxides,[6] and aryl nitro compounds;[7] selected nonhalogenated disilanes have also been found to deoxygenate several classes of *N*-oxides under suitably vigorous conditions.[7,8]

In conjunction with several studies currently in progress we required a mild, selective technique for the reductive cleavage of N–O bonds in nitrones, 2*H*-imidazole 1-oxides, 5*H*-pyrazole 1-oxides, and related *N*-hydroxy substituted heterocycles. We report here that Si_2Cl_6 is a satisfactory and potentially general reagent for the deoxygenation of a variety of such substances; furthermore, the reductions we have studied were found to proceed cleanly and under remarkably mild conditions (see Experimental Section) and were quite selective in several cases where standard procedures[9] for the deoxygenation of *N*-oxides either yielded rearranged products of deoxygenation, or were not sufficiently selective with regard to avoidance of further reduction of the C=N bond of the initial deoxygenation products (e.g., in the case of Zn/HOAc) to be of practical use.

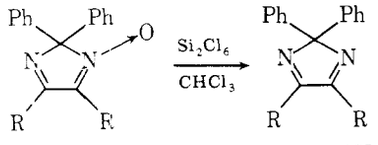
We first recognized the potential usefulness of Si_2Cl_6 in the deoxygenation of 2*H*-imidazole 1-oxides while attempting to establish the structure of the previously unreported *N*-oxide **1** (one of several products formed in the thermally induced



1 **2**

cyclization–rearrangement of *N*-nitroso-3-methyl-2-phenyl-2-butenaldimine[10]) by deoxygenating it to obtain **2**, the parent 2*H*-imidazole. As indicated below, treatment of **1** with Si_2Cl_6 afforded **2** in 59% yield (isolated and purified) under the conditions shown.

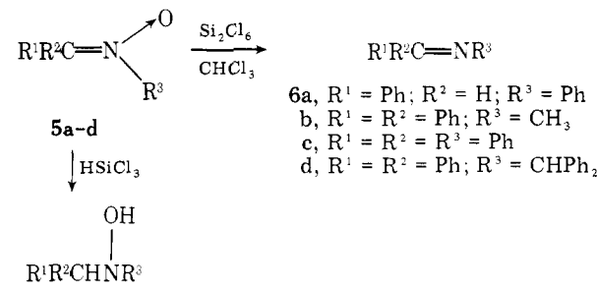
To further assess the generality of this surprisingly mild N–O deoxygenation procedure, the known 2*H*-imidazole 1-oxides **3a** and **3b**[11] were prepared and treated with Si_2Cl_6



3a,b 4a, R = CH_3; b, R = Ph

under similar conditions; the corresponding pure 2*H*-imidazoles, **4a** and **4b**, were isolated in 75% and 79% yield, respectively.

The obvious similarity of the N → O containing moiety of **1**, **3a**, and **3b** to that of nitrones led to an extension of the deoxygenation procedure to the reduction of the acyclic nitrones **5a–d**; the isolated yields of the corresponding imines

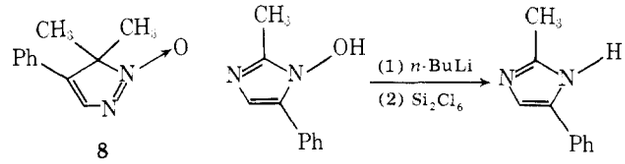


7a, 7b

6a–d in pure form were uniformly in the range of ca. 70–80%.

For comparison, the reactions of **5a** and **5b** with $HSiCl_3$ were also run. In both cases, the corresponding *hydroxylamines* (**7a** and **7b**) were the major products. Although the desired deoxygenations were not achieved in these two cases, such reductions of nitrones to hydroxylamines using relatively inexpensive $HSiCl_3$ may have some potential economic advantages over reported procedures[12] which utilize either $LiAlH_4$ or $NaBH_4$ as reductant for this purpose.

Finally, in studies related to that which afforded **1**,[10] two other previously unreported N–O containing heterocycles, **8** and **9**, were encountered. The key to their identification in each instance was their facile Si_2Cl_6-mediated reductive



8 **9** **10**

deoxygenation to the corresponding parent heterocycle; viz. **8** yielded 3,3-dimethyl-4-phenyl-3*H*-pyrazole,[13] and **9** (via its oxyanion)[10] yielded **10**; the latter *dehydroxylation* of an *N–OH* containing heterocycle is also unexampled in the reductions known, till now, to be effected by Si_2Cl_6.

Experimental Section[14]

Preparation of 2*H*-Imidazole 1-Oxides (1, 3a, and 3b), Nitrones (5a–d), and the 1-Hydroxyimidazole 9. 4,5-Dimethyl-2,2-diphenyl-2*H*-imidazole 1-oxide (**3a**),[11] 2,2,4,5-tetraphenyl-2*H*-imidazole 1-oxide (**3b**),[11] α,*N*-diphenylnitrone (**5a**),[15a] α,α-diphenyl-*N*-methylnitrone (**5b**),[15b] α,α,*N*-triphenylnitrone (**5c**),[15c] and α,α-diphenyl-*N*-benzhydrylnitrone (**5d**)[15d] were prepared according to published procedures. The 2*H*-imidazole 1-oxide **1** and the 1-hydroxyimidazole **9** were obtained as products in an ongoing study of the cyclization–rearrangement reactions of *N*-nitroso-2-phenyl-2-butenaldimines.[10]

2,2-Dimethyl-4-phenyl-2*H*-imidazole (2). To a solution of 2,2-dimethyl-5-phenyl-2*H*-imidazole 1-oxide (**1**) (92 mg, 0.49 mmol) in 5 mL of $CHCl_3$ at 25 °C and under N_2 was added dropwise 187 mg (0.66 mmol) of Si_2Cl_6 (PCR, Inc.). After the resulting mixture was stirred for an additional 50 min at 25 °C it was added to 4 mL of cold aqueous NaOH (10%). The resulting white suspension was diluted further with H_2O and extracted with $CHCl_3$. The extracts were dried over anhydrous Na_2SO_4 and K_2CO_3. Removal of the $CHCl_3$ in vacuo afforded 65 mg (77%) of crude **2** which, after chromatography over neutral Al_2O_3 (Woelm; dry column) using CH_2Cl_2 as developer and eluent, yielded 50 mg (59%) of nearly pure **2** as a light yellow solid. An analytical sample of **2** was obtained by sublimation at 32 °C (0.5 mm): mp 48.5–50 °C; NMR ($CDCl_3$) δ 1.56 (s, 6), 7.35–7.62 (m, 3), 7.85–8.12 (m, 2), 8.38 (s, 1); IR (CCl_4) 1615, 1538, 1452, 1358, 1348, 1267, 1220, 1165, 932, 695, and 588 cm^{-1}; IR (CS_2) additional peak at 773 cm^{-1}; UV λ_{max} (cyclohexane) 208 nm (ε 29 200), 221 (12 300), 258 (9410), 278 (2670 sh) and 289 (960); mass spectrum (70 eV) *m/e* (rel intensity) M^+ 172 (43), 145 (100), 104 (69), 89 (4), 77 (15), 69 (58), 51 (8), and 42 (32). Anal. Calcd for $C_{11}H_{12}N_2$: C, 76.71; H, 7.02; N, 16.26. Found: C, 76.74; H, 6.97; N, 16.23.

The spectral properties and melting point of the product were identical with those of an authentic sample of **2** prepared as follows by condensation of ammonia, acetone, and phenylglyoxal.[16] Ammonia

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(NH_3) gas was rapidly bubbled through a solution of acetone (300 mg, 5.17 mmol) in 10 mL of dry diethyl ether (Et_2O) at 25 °C. After 5 min, a solution of phenylglyoxal (130 mg, 0.970 mmol) in dry Et_2O (4 mL) was added dropwise to the acetone–ammonia mixture, following which ammonia was bubbled through the reaction mixture for an additional 10 min. The flask was stoppered, and the reaction mixture was stirred overnight at 25 °C and then refluxed for 2 h. The residue which remained after the Et_2O was removed was subjected to dry column chromatography over neutral Woelm Al_2O_3 (activity grade III). Elution with CH_2Cl_2–CCl_4 (5:1) afforded 120 mg (72%) of nearly pure 2,2-dimethyl-4-phenyl-2*H*-imidazole (**2**) which, after sublimation at 30 °C (0.6 mm), yielded material having mp 48.5–50 °C. A mixture melting point of **2** with the product obtained by deoxygenation of **1** with Si_2Cl_6, as described above, showed no depression.

General Procedure for the Deoxygenation of 2*H*-Imidazole 1-Oxides (3a, 3b) and Nitrones (5a–d) with Si_2Cl_6. Hexachlorodisilane (Si_2Cl_6) obtained from Aldrich and from PCR was used without purification. The substituted 2*H*-imidazole 1-oxide or nitrone was dissolved in a given amount of $CHCl_3$ or tetrahydrofuran (THF) and Si_2Cl_6 (1.0 to 1.2 mol equiv) was added slowly via a syringe at ice-bath temperature (0–5 °C). The ice bath was removed and the reaction mixture was allowed to stand at ambient temperature for 0.5 to 1.0 h. The reaction mixture was again cooled to 0–5 °C and maintained at that temperature as an excess of cold aqueous NaOH (20%) solution was added with rapid stirring. The organic phase was separated and washed with 5% $NaHCO_3$ and saturated NaCl solutions and dried ($MgSO_4$). The solvent was removed at reduced pressure.

4,5-Dimethyl-2,2-diphenyl-2*H*-imidazole (4a). A solution of 4,5-dimethyl-2,2-diphenyl-2*H*-imidazole 1-oxide (**3a;** 1.32 g, 0.005 mol) in 10 mL of $CHCl_3$ was treated with Si_2Cl_6 and worked up according to the general procedure to yield 1.11 g of a crude yellow solid (mp 160–191 °C) which afforded 0.99 g (80%) of pure **4a,** mp 197–198.5 °C, upon recrystallization from ethanol: NMR ($CDCl_3$) δ 2.29 (s, 6) and 6.9–7.8 (m, 10); mass spectrum (70 eV) *m/e* (rel intensity) M^+ 248 (4.3), 208 (14.8), 207 (100), 206 (5.3), 167 (19.0), 166 (96.1), 165 (87.9), 164 (6.9), 163 (5.1), 139 (5.0), 115 (2.7), 113 (1.8), 104 (3.7), 103 (2.7), 83 (9.7), 82 (14.9), 81 (10.4), 76 (4.6), 69 (3.5), and 62 (2.9). Three additional recrystallizations from ethanol afforded an analytical sample of **4a:** mp 198–198.4 °C. Anal. Calcd for $C_{17}H_{16}N_2$: C, 82.22; H, 6.49; N, 11.28. Found: C, 82.34; H, 6.42; N, 11.14.

2,2,4,5-Tetraphenyl-2*H*-imidazole (4b). A solution of 776 mg (2.00 mmol) of 2,2,4,5-tetraphenyl-2*H*-imidazole 1-oxide (**3b**) in 5 mL of $CHCl_3$ was deoxygenated and worked up as outlined above to yield 585 mg (79%) of pure **4b,** mp 197.8–198.2 °C (lit.[11] 199–201 °C).

Benzylidineaniline (6a). A solution of α,*N*-diphenylnitrone (**5a;** 1.97 g, 0.010 mol) in 20 mL of anhydrous THF (freshly distilled from $LiAlH_4$ and CaH_2) was deoxygenated with Si_2Cl_6 according to the general procedure to yield a yellow oil which was triturated with petroleum ether. Removal of the solvent from the resulting petroleum ether solution afforded 1.39 g (77%) of **6a** as a yellow solid: mp 46.5–48.5 °C (lit.[17a] 47–49 °C). Recrystallization from EtOH–H_2O raised the melting point to 49.7–51.0 °C; a mixture melting point with authentic **6a** was 49–50 °C.

***N*-Methylbenzophenone Ketimine (6b).** A solution of α,α-diphenyl-*N*-methylnitrone (**5b;** 634 mg, 3.00 mmol) in 2 mL of $CHCl_3$ was treated with Si_2Cl_6 as described above to afford 427 mg (73%) of pure **6b** as a pale yellow oil after evaporative distillation of the crude product at 100–105 °C (0.7 mm): NMR ($CDCl_3$) 3 H singlet at δ 3.13 (lit.[17b] δ 3.13).

***N*-Phenylbenzophenone Ketimine (6c).** A solution of α,α,*N*-triphenylnitrone (**5c;** 276 mg, 1.01 mmol) in 5 mL of $CHCl_3$ upon deoxygenation with Si_2Cl_6 in the usual manner afforded 192 mg (74%) of pure **6c,** mp 111–112.5 °C, upon recrystallization from EtOH–H_2O (lit.[17c] 112–113 °C); a mixture melting point with authentic **6c** was 112–113 °C.

***N*-Benzhydrylbenzophenone Ketimine (6d).** Deoxygenation of α,α-diphenyl-*N*-benzhydrylnitrone (**5d;** 1.09 g, 0.003 mol) with Si_2Cl_6 in 8 mL of $CHCl_3$ according to the general procedure yielded 1.015 g of white solid (mp 135–140 °C) which afforded 0.832 g (80%) of pure **6d** upon recrystallization from ethanol: mp 151–151.5 °C (lit.[17d] 149–150 °C).

Benzylphenylhydroxylamine (7a). A solution of α,*N*-diphenylnitrone (**5a;** 985 mg, 5.00 mmol) in 10 mL of anhydrous THF was reduced with 0.8 mL (ca. 8 mmol) of $HSiCl_3$ using the procedure described below for the reduction of **5b** to **7b.** A yellow solid (970 mg) was obtained which was triturated with a small amount of pentane to afford, upon removal of the supernatant pentane solution, 665 mg (67%) of **7a** (87 ± 2% pure by NMR assay) as slightly yellow crystals, mp 75–80 °C. The product resisted attempts at further purification by recrystallization from several solvents. Further trituration with hexane afforded a small amount of pure benzylphenylhydroxylamine (**7a**): mp 87–88 °C (lit.[18a] 86 °C); NMR (CCl_4) δ 4.21 (s, 2), 5.63 (br s, 1) and 6.8–7.4 (m, 10).

***N*-Methyl-*N*-benzhydrylhydroxylamine (7b).** Trichlorosilane ($HSiCl_3$; 0.8 mL, ca. 0.008 mol; treated with quinoline and distilled before using) was added slowly via a syringe to a solution of nitrone **5b** (1.056 g, 0.005 mol) in 4 mL of $CHCl_3$ at ca. −30 °C (dry ice–acetone bath) and under N_2. The reaction mixture was allowed to stand at ambient temperature. After 20 min it was transferred slowly via pipet into 6 mL of cold aqueous NaOH (20%) solution while stirring thoroughly. The product was extracted with 10 portions of CH_2Cl_2 and the combined extracts were dried (Na_2SO_4). Removal of the solvent in vacuo left 0.972 g (91%) of crude *N*-methyl-*N*-benzhydrylhydroxylamine (**7b**) as colorless crystals, mp 79–81 °C, which could be recrystallized efficiently from cyclohexane to afford pure **7b:** mp 81.5–82 °C (lit.[18b] 82 °C); NMR (CCl_4) δ 2.24 (s, 3), 4.48 (s, 1), 5.93 (br s, 1, OH), 6.8–7.4 (m, 10).

2-Methyl-4(5)-phenylimidazole (10). *n*-Butyllithium (1.2 mmol; 0.6 mL of a 2 M solution in hexane obtained from Ventron) was added dropwise with stirring to a cold (0–5 °C) slurry of 1-hydroxyl-2-methyl-5-phenylimidazole (**9;** 200 mg, 1.20 mmol) in 7 mL of dry THF under N_2. After 3 min, Si_2Cl_6 (0.23 mL [350 mg], 1.3 mmol) was added, by means of a syringe, to the vigorously stirred reaction mixture at 0–5 °C. The reaction mixture was heated at 35 °C for 1 h and then poured into 25 mL of saturated aqueous Na_2CO_3 solution and extracted with $CHCl_3$. The combined extracts were washed with H_2O and brine, dried (Na_2SO_4), and concentrated in vacuo. Dry-column chromatography over alumina (Woelm; activity grade III) eluting with 4% EtOH in $CHCl_3$ afforded 72 mg (40%) of ca. 95% pure 2-methyl-4(5)-phenylimidazole (**10**). A sample of **10** which was recrystallized from $CHCl_3$–Et_2O (1:4) exhibited mp 159–160.5 °C (lit.[19] 161 °C); ^1H NMR ($CDCl_3$) δ 2.35 (s, 3), 7.13–7.80 (m, 6) and 11.6 (br s, 1); ^1H NMR ($CDCl_3$/CD_3OD) δ 2.38 (s, 3), 4.64 (s, 1), 7.10 (s, 1), and 7.15–7.72 (m, 5); ^{13}C NMR (CD_3OD/$CDCl_3$) δ (downfield from Me_4Si) 13.5 [rel. intensity, 15.6], 116.0 [21.0], 124.7 [45.7], 125.6 [10.3], 126.8 [28.7] and 128.8 [44.0]; IR ($CHCl_3$) 3470, 2960, 1610, 1588, 1452, 1406, 1156, 1136, 1105, 955, 945, and 560 cm^{-1}; UV λ_{max} (EtOH) 203 nm (ϵ 16 300) and 267 (15 200).

The spectral properties and melting point of **10** were identical with those of an authentic sample of **10** obtained as follows. Ammonia (NH_3) gas was bubbled through a solution of acetaldehyde (130 mg, 3.0 mmol) in 10 mL of dry Et_2O. After 5 min, 130 mg (1.0 mmol) of phenylglyoxal in 4 mL of dry Et_2O was added dropwise to the reaction mixture. The addition of NH_3 was continued during the addition and for 5 min longer. The reaction mixture was then stirred overnight at 25 °C followed by 3 h at reflux temperature. Concentration of the resulting solution followed by dry-column chromatography of the residue afforded 110 mg (70%) of nearly pure **10** which exhibited mp 159–160.5 °C after recrystallization from $CHCl_3$–Et_2O (1:4). A mixture melting point with **10** obtained by deoxygenation of **9** as described above showed no depression.

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Registry No.—**1,** 65776-47-8; **2,** 65776-48-9; **3a,** 57891-99-3; **3b,** 57892-00-9; **4a,** 65776-49-0; **4b,** 7196-81-8; **5a,** 1137-96-8; **5b,** 7500-79-0; **5c,** 4504-13-6; **5d,** 5076-57-3; **6a,** 538-51-2; **6b,** 13280-16-5; **6c,** 574-45-8; **6d,** 5350-59-4; **7a,** 3376-40-7; **7b,** 27865-53-8; **9,** 65776-50-3; **10,** 13739-48-5; Si_2Cl_6, 13465-77-5; $HSiCl_3$, 10025-78-2; *N*-nitroso-2-phenyl-2-butenaldimine, 65776-51-4; *N*-nitroso-3-methyl-2-phenyl-2-butenaldimine, 65776-52-5; acetone, 67-64-1; phenylglyoxal, 1074-12-0; acetaldehyde, 75-07-0.

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(13) Cf. the deoxygenations of azoxy compounds to afford intermediate azo compounds which are cited in ref 6.
(14) All melting points and boiling points are uncorrected. The following spectrometers were used: NMR, Varian A-60A; IR, Perkin-Elmer 457; UV, Cary 14. Microanalyses were performed by Galbraith Laboratories, Knoxville, Tenn.
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Nucleophilic Substitution Reactions of *N*-Alkyldi(trifluoromethane)sulfonimides. Role of the Solvent Hexamethylphosphoric Triamide

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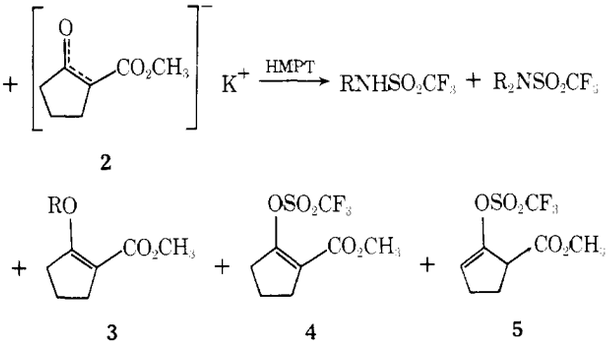
Nucleophilic substitution reactions of *N*-alkyldi(trifluoromethane)sulfonimides **1** have been reported.[1] Analogous reactions with other sulfonimides have also been investigated.[1b,2] To ascertain the synthetic utility of these reactions the alkyl group of the *N*-alkyldi(trifluoromethane)sulfonimide was varied and an assortment of nucleophiles were used.

$RN(SO_2CF_3)_2$

1a, R = n-C_6H_{13}
b, R = $C_6H_5CH_2CH_2$
c, R = $CH_3OCH_2CH_2$
d, R = $(CH_3)_2CHCH_2$
e, R = $CH_3CH_2OCOCH_2$

The results of these studies, all done using HMPT as solvent, are recorded in Tables I and II. In addition the reaction of sulfonimide **1a** with **2** afforded the products shown below. The compounds present after 233 h were n-hexyltrifluoromethanesulfonamide, *N,N*-di-n-hexyltrifluoromethanesulfonamide, **3**, **4**, and **5** in 30, 15, 39, ca. 10, and ca. 5% yield, respectively, as determined by quantitative GC analysis. Each of the products was isolated and compared with authentic material. The last two compounds were characterized by their IR, NMR, and UV spectra and elemental analysis and compared with material prepared according to the method of Stang and Dueber.[3]



These results show that nucleophilic displacements on *N*-alkyldi(trifluoromethane)sulfonimides by iodide ion to give the corresponding alkyl iodide occur in synthetically useful yields. Others have reported[1b,2b] synthetically useful displacement reactions of halide ions with *N*-alkyldi(arene)-sulfonimides.[4] Substitution reactions of sulfonimides in which alkyl iodides are presumably intermediates have also been reported.[1a,2c,f] Thus, although some reactions of sulfonimides with nucleophiles result in S–N cleavage,[2d,e,5] either by attack at sulfur or elimination,[6,7] simple nucleophilic substitution of the sulfonimide group can be achieved in many cases by a two-step sequence:[1a,2c,f] first displacement with iodide ion and then nucleophilic substitution on the alkyl iodide so obtained. An alternative to this sequence which also involves a key role for HMPT in nucleophilic substitution reactions is outlined below.

The displacements on sulfonimides were studied in HMPT because nucleophilic substitution reactions occur faster in this solvent.[8] However, it became apparent that HMPT could function as a nucleophile toward sulfonimides. Thus, NMR spectroscopy revealed that a solution of **1a** in HMPT formed salt **6a** on standing at room temperature overnight. Addition of an aqueous solution of sodium tetraphenylboron resulted in the precipitation of a crystalline salt. This salt (**6a**, X = $B(C_6H_5)_4$) was characterized spectroscopically and by elemental analysis. Similarly, **6b** was formed from **1b** in HMPT. Several other reactions illustrating the nucleophilicity of HMPT have been previously reported.[9] These salts, **6**, which are usually prepared from the corresponding alcohols,[10] are known to be useful alkylating agents.[9e,10,11] Thus reaction of **6a** with sodium cyanide in HMPT produced heptanenitrile in 72% yield, with sodiodiethyl malonate the reaction gave diethyl n-hexylmalonate in 87% yield; and with sodiomalonitrile the reaction gave the corresponding mono- and dialkylated products in 79% yield. A minor change in the procedure for reacting **1a** with sodium cyanide results in a dramatic change in the course of the reaction. If **1a** is added to sodium cyanide in HMPT rapid reaction ensues but no significant amount of heptanenitrile forms. However, if a solution of **1a** in HMPT is allowed to stand at room temperature for 18 h and then sodium cyanide is added, heptanenitrile forms in good

$ROP^+[N(CH_3)_2]_3X^-$

6a, R = n-C_6H_{13}
b, R = $C_6H_5CH_2CH_2$

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