Reaction of Dichlorotriphenylphosphorane with Bis(trimethylsilyl) Peroxide. A New Method for the Formation of Electrophilic Chlorine Source

Kazusato SHIBATA, Yukinori ITOH, Norihiro TOKITOH,
Renji OKAZAKI,* and Naoki INAMOTO
Department of Chemistry, Faculty of Science, The University of Tokyo, Hongo, Tokyo 113

(Received August 23, 1991)

Synopsis. Reactions of dichlorotriphenylphosphorane with bis(trimethylsilyl) peroxide in the presence of some organic compounds have been found to give chlorinated products. Aromatic hydrocarbons bearing electron-donating substituents give the corresponding monochloroarenes, while an enol silyl ether is converted into α-chloro ketone. The mechanism is briefly discussed.

In the course of our study on silicon-Polonovski reactions,[1] we became interested in a reagent which was capable of transferring "Me_3SiO^+" species. We thought that the reaction of dichlorotriphenylphosphorane (DCTP) with bis(trimethylsilyl) peroxide (BSPO) would afford a peroxide **1** which might act as a "Me_3SiO^+" source (Scheme 1).

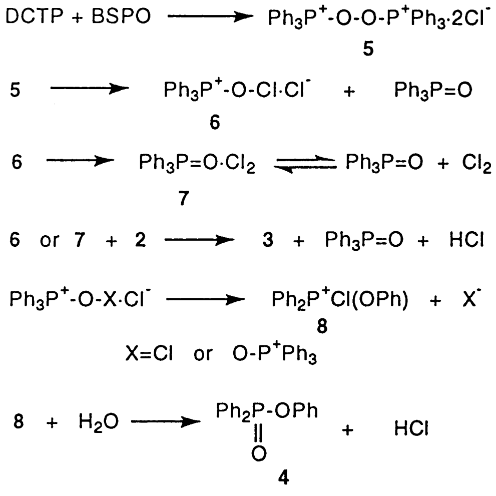
We have found that the reaction of DCTP with BSPO does not produce **1** but it provides a new source for electrophilic chlorine. Reported and discussed are the results observed for chlorination of some organic substrates using this DCTP-BSPO system.

When the reaction of DCTP (2 equiv) (generated in situ from triphenylphosphine and hexachloroethane[2]) with BSPO (1 equiv) in acetonitrile at room temperature was monitored by ^{31}P NMR, a new, single signal (δ_P=30.4) appeared while the signal of DCTP (δ_P=49.0) disappeared completely. When a similar reaction was carried out using 4 equiv of DCTP and 1 equiv of BSPO, two signals were observed roughly in a 1 : 1 ratio; one was the same as the above-mentioned signal while the other is a signal due to remaining DCTP. These facts clearly indicate that DCTP and BSPO react in a 2 : 1 ratio. Furthermore, ^{1}H, ^{13}C, and ^{29}Si NMR of the solution resulting from the reaction of 2 equiv of DCTP with 1 equiv of BSPO showed the presence of chlorotrimethylsilane (δ_H=0.00, δ_C=2.3, δ_{Si}=31.65) as a sole compound having a trimethylsilyl group; under identical conditions in acetonitrile an authentic sample of chlorotrimethylsilane showed δ_H=0.00, δ_C=1.92, and δ_{Si}=31.61 while that of BSPO exhibited δ_H=−0.29, δ_C=−2.65, and δ_{Si}=26.57. This observation is also in keeping with the above conclusion that DCTP and BSPO react in a 2 : 1 ratio.

When the reaction of DCTP (2 equiv) with BSPO (1 equiv) was conducted at room temperature in the presence of 1,3,5-tri-*t*-butylbenzene (**2**) (1 equiv), 1,3,5-tri-*t*-butyl-2-chlorobenzene (**3**) was obtained in 86% along with triphenylphosphine oxide (95%) and phenyl diphenylphosphinate (**4**, 5%). A similar reaction using DCTP, BSPO, and **2** in a molar ratio of 4 : 2 : 1 gave **3** in 95% in addition to triphenylphosphine oxide (73%) and the phosphinate **4** (13%).

The formation of **3** is suggestive of the generation of electrophilic chlorine in the reaction of DCTP with BSPO. A plausible mechanism for the reaction is shown in Scheme 2.

A combination of a chloride anion with some organic peroxides such as benzoyl peroxide[3] and nitrobenzenesulfonyl peroxides[4] has been known to act as a chlorinating reagent in electrophilic aromatic substitutions and the corresponding acyl or sulfonyl hypochlorites have been proposed as a species responsible for the chlorination. Although a hypohalite like **6** has not been known in the literature, it can be a chlorinating agent. It is not clear at present, however, whether the real reactive species is **6**, phosphine oxide–chlorine complex **7** or molecular chlorine. It has been reported that phosphine oxides including triphenylphosphine oxide form a complex with halogen.[5] Since the only one ^{31}P NMR signal (δ=30.4) was observed in the reaction mixture from DCTP (2 equiv) and BSPO (1 equiv) as



$$\text{DCTP} + \text{BSPO} \longrightarrow \underset{\mathbf{5}}{Ph_3P^+\text{-}O\text{-}O\text{-}P^+Ph_3\cdot 2Cl^-}$$

$$\mathbf{5} \longrightarrow \underset{\mathbf{6}}{Ph_3P^+\text{-}O\text{-}Cl\cdot Cl^-} + Ph_3P{=}O$$

$$\mathbf{6} \longrightarrow \underset{\mathbf{7}}{Ph_3P{=}O\cdot Cl_2} \rightleftharpoons Ph_3P{=}O + Cl_2$$

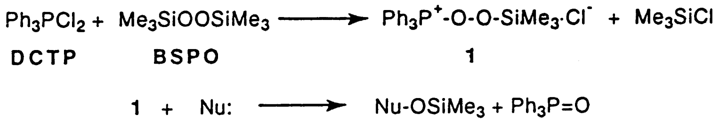
$$\mathbf{6}\ \text{or}\ \mathbf{7} + \mathbf{2} \longrightarrow \mathbf{3} + Ph_3P{=}O + HCl$$

$$Ph_3P^+\text{-}O\text{-}X\cdot Cl^- \longrightarrow \underset{\mathbf{8}}{Ph_2P^+Cl(OPh)} + X^-$$

$$X{=}Cl\ \text{or}\ O\text{-}P^+Ph_3$$

$$\mathbf{8} + H_2O \longrightarrow \underset{\mathbf{4}}{\underset{\underset{O}{\|}}{Ph_2P\text{-}OPh}} + HCl$$

Scheme 2.



$$\underset{\textbf{DCTP}}{Ph_3PCl_2} + \underset{\textbf{BSPO}}{Me_3SiOOSiMe_3} \longrightarrow \underset{\mathbf{1}}{Ph_3P^+\text{-}O\text{-}O\text{-}SiMe_3\cdot Cl^-} + Me_3SiCl$$

$$\mathbf{1} + \text{Nu:} \longrightarrow \text{Nu-OSiMe}_3 + Ph_3P{=}O$$

Scheme 1.

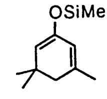
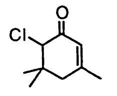
$$5 + \mathrm{ArH} \longrightarrow \underset{\mathbf{9}}{\mathrm{Ar\text{-}O\text{-}P^{+}Ph_3{\cdot}Cl^{-}}} + \mathrm{Ph_3P{=}O} + \mathrm{HCl}$$

$$7 \longrightarrow \mathrm{ArCl} + \mathrm{Ph_3P{=}O}$$

Ar : 2,4,6,-tri-t-butylphenyl

Scheme 3.

Table 1. Chlorination with Dichlorotriphenylphosphorane (DCTP)-Bis(trimethylsilyl) Peroxide (BSPO) System[a]

Substrate	Reaction time	Product	Yield/%[b]
ArH[c]	6 h	ArCl[c]	86 (95)[d]
Mesitylene	6 h	MesCl[e]	44
Anisole	1 h	*p*-chloroanisole	61 (71)[d]
		o-chloroanisole	7 (9)[d]
 **10**	4.5 h	 **11**	44
Ph_2S	2.5 d	$Ph_2S{=}O$	12[f]
$(PhCH_2)_3N$	6 d	$(PhCH_2)_2NH{\cdot}HCl$	20[g]

a) Reactions were carried out in acetonitrile at room temperature using 1 equiv of the substrate, 2 equiv of DCTP and 1 equiv of BSPO. b) Isolated yield except for chloroanisoles where the yields were determined by gas chromatography. c) Ar denotes 2,4,6-tri-*t*-butylphenyl. d) Values in parentheses are yields for the reactions where DCTP(4 equiv) and BSPO(2 equiv) were used. e) Mes denotes mesityl (2,4,6-trimethylphenyl). f) Ph_2S was recovered in 88% yield. g) $(PhCH_2)_3N$ was recovered in 77% yield.

mentioned above, the exchange reaction between **6** and triphenylphosphine oxide as well as the equilibrium between **7** and triphenylphosphine oxide/molecular chlorine is considered to be fast on NMR time scale at room temperature.

Although a mechanism involving an oxygenation followed by a displacement with a chloride anion as shown in Scheme 3 is also conceivable, this possibility can be ruled out by the fact that **9** prepared in a separate experiment from 2,4,6-tri-*t*-butylphenol and DCTP was intact under the reaction conditions even in the presence of chlorotrimethylsilane which might act as Lewis acid by coordination toward the phenolic oxygen to promote an nucleophilic attack by a chloride anion. The formation of the phosphinate **4** can be explained by the shift of a phenyl group in **5** and/or **6** onto the adjacent oxygen atom followed by hydrolysis as shown in Scheme 2. Similar rearrangement of a phenyl group from phosphorus to oxygen has been reported for bis(diphenylphosphinyl) peroxide, $[Ph_2P(=O)O]_2$,[6] suggesting the validity of the involvement of **5** and **6** in the present reaction.

In order to study the scope and limitation of the present chlorinating system (DCTP–BSPO system), some other substrates were submitted to chlorination, the results being summarized in Table 1. Activated arenes such as mesitylene and anisole were also chlorinated, but less reactive substrates like toluene, benzene, and chlorobenzene did not react under similar conditions even when the prolonged reaction time (2 d) was used. This result suggests that the DCTP–BSPO system is less reactive than arenesulfonyl peroxide-chloride system[4] where benzene and toluene are reportedly chlorinated at room temperature. Enol silyl ether **10** was also chlorinated to give α-chloro ketone **11** in a moderate yield, thus providing a new approach to α-chloro ketones. Oxidation of a sulfide to a sulfoxide[6] and dealkylation of a tertiary amine[7] by positive halogen reagents are known processes.

Experimental

Melting points are uncorrected. ^{1}H (89.60 MHz), ^{13}C (22.53 MHz), ^{29}Si (17.80 MHz), and ^{31}P NMR (36.27 MHz) spectra were measured with JEOL FX-90Q and Brucker AM-500 spectrometers using tetramethylsilane as an internal or external standard for ^{1}H, ^{13}C, and ^{29}Si NMR, and 85% phosphoric acid as an external standard for ^{31}P NMR. Mass spectra were obtained with a JEOL D-300 mass spectrometer. Gas chromatographic analyses were performed with Shimadzu GC-7A. All reactions were carried out under an argon atmosphere.

Material. Bis(trimethylsilyl) peroxide (BSPO),[9] 1,3,5-tri-*t*-butylbenzene (**2**),[10] and 4,6,6-trimethyl-2-trimethylsilyloxy-1,3-cyclohexadiene (**10**)[11] were prepared by the reported method. Dichlorotriphenylphosphorane (DCTP) was prepared in situ in acetonitrile at room temperature by the method of Appel[2] and used for reactions with BSPO without isolation.

Reaction of 1,3,5-Tri-*t*-butylbenzene (2) with DCTP-BSPO System. An acetonitrile solution of the phosphorane DCTP was prepared[2] by stirring triphenylphosphine (253 mg, 0.966 mmol) and hexachloroethane (229 mg, 0.966 mmol) in acetonitrile (0.4 ml) for 30 min at room temperature. To this solution was added the peroxide BSPO (103 µl, 0.483 mmol) by a syringe (exothermic reaction). After stirring for 30 min an acetonitrile solution (1.4 ml) of **2** was added and the mixture was stirred at room temperature for 6 h during which time white precipitates were formed gradually. The solvent was evaporated to give 520 mg of crude products, which were separated by dry column chromatography (DCC) (silica gel, hexane) to give a mixture of **2** and 1,3,5-tri-*t*-butyl-2-chlorobenzene (**3**) (129 mg), phenyl diphenylphosphinate (**4**) (30 mg, 5%), and triphenylphosphine oxide (257 mg, 95%). The yields of **2** (10%) and **3**[12] (86%) were determined by gas chromatography (column, OV-1; column temperature, 150 °C) by comparing the authentic samples. **3**: ^{1}H NMR ($CDCl_3$) δ=1.31 (s, 9H), 1.53 (s, 18H), and 7.38 (s, 2H); ^{13}C NMR ($CDCl_3$) δ=30.63, 31.49, 34.96, 37.29, 123.16, 131.36, 147.13, and 147.83.

The phosphinate **4**[13] was identified by NMR and mass spectra; ^{1}H NMR ($CDCl_3$) δ=6.65—7.54 (m, 5H), and 7.54—8.06 (m, 10H); ^{13}C NMR ($CDCl_3$) δ=120.56, 120.77, 124.62, 127.57, 128.28, 128.87, 129.58, 131.47, 131.96, 132.42, 132.53, and 133.72; ^{31}P NMR δ=28.8 (CH_3CN); δ=30.4 ($CDCl_3$); MS *m/z* (rel intensity) 294 (M^+, 52), 293 (53), 20 (100), 77 (71), 65 (25), and 51 (44).

Reactions of Other Substrates with DCTP-BSPO System. Reactions with other substrates were carried out in a similar way to that described for **2**.

(a) Reaction with mesitylene (112 mg, 0.935 mmol), after separation by preparative TLC, gave 2-chloro-1,3,5-trimethylbenzene[14] (63 mg, 44%), phosphinate **4** (55 mg, 9%), and triphenylphosphine oxide (483 mg, 87%) along with recovered mesitylene (11%). 2-Chloro-1,3,5-trimethylbenzene: ^{1}H NMR ($CDCl_3$) δ=2.19 (s, 3H), 2.28 (s, 6H), and 6.78 (s, 2H); ^{13}C NMR ($CDCl_3$) δ=20.48, 20.61, 129.18, 131.59, 135.49, and 135.81.

(b) In the reaction with anisole (100 µl, 0.92 mmol), the products, chloroanisoles, were analyzed by gas chromatography (column, Carbowax 20M; column temperature, 130 °C). The yields thus obtained are listed in Table 1. The yields of **4** and triphenylphosphine oxide were not determined.

(c) Reaction products with enol silyl ether **10** (0.23 ml, 0.973 mmol) were purified by DCC (silca gel, hexane:ether=2:1—1:2) to give 6-chloro-3,5,5-trimethyl-2-cyclohexen-1-one (**11**) (74 mg, 44%),[15] phosphinate **4** (18 mg, 3%), triphenylphosphine oxide (544 mg, 97%), and 3,5,5-trimethyl-2-cyclohexen-1-one (isophorone) (23 mg, 17%) which was identified by comparison with an authentic sample. **11**: ^{1}H NMR ($CDCl_3$) δ=0.84—1.35 (m, 6H), 1.80—2.15 (m, 3H), 2.15—2.50 (m, 2H), 3.99 (s, 1H), and 5.85 (br s 1H); ^{13}C NMR ($CDCl_3$) δ=23.78, 24.27, 26.30, 27.95, 38.17, 43.12, 69.26, 123.08, 160.22, and 191.85; MS *m*/*z* (rel intensity) 172 (M^+, 16), 118 (11), 116 (29), 82 (100), 77 (11), 54 (11), 53 (12), and 52 (16).

(d) Reaction of tribenzylamine (159 mg, 0.553 mmol) gave white precipitates (tribenzylamine hydrochloride, 115 mg, 64 %) after 2.5 d. DCC (alumina, ether) of the filtrate afforded tribenzylamine (20 mg, 13%), dibenzylamine hydrochloride (26 mg, 20%), **4** (56 mg, 34%), and triphenylphosphine oxide (71 mg, 47%).

(e) Reaction of diphenyl sulfide (0.14 ml, 0.84 mmol) afforded, after DCC (silica gel, hexane–ether), diphenyl sulfoxide (21 mg, 12%) and triphenylphosphine oxide (468 mg, 96%) along with recovered diphenyl sulfide (88%). Diphenyl sulfoxide was identified by comparison with an authentic sample prepared by oxidation of diphenyl sulfide with *m*-chloroperbenzoic acid.

The authors thank Shin-etsu Chemical Co., Ltd. and Tosoh Akzo for the generous gift of chlorosilanes and alkyllithiums, respectively.

References

1) R. Okazaki and N. Tokitoh, *J. Chem. Soc., Chem. Commun.*, **1984**, 192; N. Tokitoh and R. Okazaki, *Tetrahedron Lett.*, **25**, 4677 (1984); *idem., Chem. Lett.*, **1984**, 1937; **1985**, 241; *idem., Bull. Chem. Soc. Jpn.*, **60**, 3291 (1987); **61**, 735 (1988).

2) R. Appel and H. Schöler, *Chem. Ber.*, **110**, 2382 (1977).

3) J. K. Kochi, B. M. Graybill, and M. Kurz, *J. Am. Chem. Soc.*, **86**, 5257 (1964); N. J. Bunce and D. D. Tanner, *ibid.*, **91**, 6096 (1969).

4) M. Yoshida, H. Mochizuki, and N. Kamigata, *Chem. Lett.*, **1988**, 2017.

5) For example, R. A. Zingaro and R. M. Hedges, *J. Phys. Chem.*, **65**, 1132 (1961); C. Laurence, M. Queignec-Cabanetos, and B. Wojtkowiak, *J. Chem. Soc., Perkin Trans. 2*, **1982**, 1605.

6) R. L. Dannley, R. L. Waller, R. V. Hoffman, and R. F. Hudson, *J. Org. Chem.*, **37**, 418 (1972).

7) G. C. Barret, "Comprehensive Organic Chemistry," ed by D. N. Jones, Pergamon Press, New York (1979), Vol. 3, Part 11. 3.

8) E. H. White and D. J. Woodcock, "The Chemistry of the Amino Group," ed by S. Patai, Interscience Publishers, New York (1968), Chap. 8.

9) S. Matsubara, T. Okazoe, K. Oshima, K. Takai, and H. Nozaki, *Bull. Chem. Soc. Jpn.*, **58**, 844 (1985).

10) D. E. Pearson and C. A. Buehler, *Synthesis*, **1971**, 455.

11) G. M. Rubottom, J. M. Gruber, H. D. Jave, Jr., and D. A. Charleson, *Org. Synth.*, Coll. Vol. 7, 282 (1990).

12) M. Yoshifuji, S. Tanaka, and N. Inamoto, *Bull. Chem. Soc. Jpn.*, **48**, 2607 (1975).

13) S. Bradamante and G. A. Pagani, *J. Org. Chem.*, **45**, 114 (1980); S. Hoz, E. J. Dunn, E. Buncel, R. A. B. Bannard, and J. Purdon, *Phosphorus Sulfur*, **24**, 321 (1985).

14) G. Häfelinger, F. Hack, and G. Westermeyer, *Chem. Ber.*, **109**, 833 (1976).

15) E. M. Kosower and G.-S. Wu, *J. Org. Chem.*, **28**, 633 (1963).