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1-Chlorobenzotriazole: a New Oxidant¹

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Benzotriazole is rapidly and quantitatively converted by sodium hypochlorite into its stable, crystalline 1-chloroderivative, the chemistry of which is dominated by the positive-halogen character of the chlorine atom.

1-Chlorobenzotriazole has considerable potential as an oxidant; it oxidises alcohols to carbonyl compounds, hydrazo- to azo-compounds, and 1,1-disubstituted hydrazines, all in high yield under very mild conditions.

1-Chlorobenzotriazole reacts with diethyl ether to give 1-(1-ethoxyethyl)benzotriazole; the same product was formed, unexpectedly, by treatment of benzotriazole in ether with chloramine or nitrosyl chloride.

Radical chain mechanisms are proposed for these oxidation and substitution reactions.

1-CHLOROBENZOTRIAZOLE (I) was initially of interest as a possible precursor to N-substituted benzotriazoles by way of nucleophilic displacement of chlorine from nitrogen. It was easily prepared by treatment of benzotriazole in aqueous acetic acid with sodium hypochlorite; the colourless, stable 1-chlorobenzotriazole crystallised quantitatively on dilution with water. Its structure was supported by analytical and mass spectral data, and the position of the chlorine atom was confirmed by the absence of an NH absorption in the i.r. spectrum, and by the aromatic proton region of the n.m.r. spectrum, which was typical of a 1-substituted benzotriazole.



1-Chlorobenzotriazole was also obtained by direct chlorination of benzotriazole in an inert solvent, but in this case its purification was complicated by the presence of benzotriazole and benzotriazole hydrochloride. Although the chlorination of benzotriazole has been reported, this has only been *C*-chlorination under much more vigorous conditions.² Under our preparative conditions no tendency for migration of chlorine from nitrogen to carbon, as occurs in the Orton rearrangement, was observed.

In 1-chlorobenzotriazole, nucleophilic displacement of chlorine proved to be impossible and the chemistry was entirely consistent with that of a positive-halogen compond. Thus although it dissolved readily in dilute aqueous base the compound was reprecipitated on acidification, and even after several hr. under reflux in 10% aqueous potassium hydroxide, 35% was recovered; some decomposition had occurred to give benzotriazole but no 1-hydroxybenzotriazole was formed. Attempts to obtain 1-aminobenzotriazole by treatment of the 1-chloro-compound with sodamide also failed, even with pure sodamide under the conditions where N-chloroacetanilide gave N-aminoacetanilide.3 Attempted displacement by methoxide ion resulted only in the oxidation of the methoxide ion and gave no trace of 1-methoxybenzotriazole. Treatment of 1-chlorobenzotriazole with activated zinc or with the sodium salt of benzotriazole similarly gave no 1,1'-bisbenzotriazole.

The positive halogen character of 1-chlorobenzotriazole was shown particularly by its ready oxidation of a variety ² A. E. Crouch, B.P. 1,013,931 (*Chem. Abs.*, 1966, **64**, **6662**); F. R. Benson and W. L. Savell, *Chem. Rev.*, 1950, **46**, 1. ³ W. F. Short, *J. Chem. Soc.*, 1921, 1446.

¹ Preliminary communication, C. W. Rees and R. C. Storr, Chem. Comm., 1968, 1305.

of alcohols, and 1,1- and 1,2-disubstituted hydrazines, and of phenylhydroxylamine. Thus when equimolar amounts of an alcohol and 1-chlorobenzotriazole were warmed in carbon tetrachloride or benzene, without an initiator, a rapid exothermic reaction resulted, after a brief induction period, and the carbonyl compound was formed in good yield. In the case of 1,2- and particularly 1,1-disubstituted hydrazines and phenylhydroxylamine the oxidations occurred readily in the cold. In all cases the other products of the oxidation, benzotriazole and hydrogen chloride, separated cleanly as benzotriazole hydrochloride. Residual traces of benzotriazole hydrochloride could be removed by washing with dilute aqueous sodium hydroxide leaving the pure product in solution.

Yield

				(%) of benzo- triazole
			Yield	hvdro-
Starting material	Solvent	Product	(%)	chloride
Benzvl alcohol		Benzaldehvde ª	80	
Benzyl alcohol	CH.Cl.	Benzaldehvde "	70	60
Benzyl alcohol	C.H.	Benzaldehvde b	50	
Propan-2-ol	C _s H _s	Acetone ^b	70	70
Cyclohexanol	CH,ĈI,	Cyclohexanone a	70	85
Cyclohexanol	C _e H _e	Cyclohexanone ^b	60	
1-Phenylethanol	CČ1,	Acetophenone 4	65	50
Diphenylmethanol	CC1	Benzophenone a	65	50
Hydrazobenzene	CH_2Cl_2	Azobenzene	90	70
Dimethyl hydr-	CH_2Cl_2	Dimethyl azo-	High	95
Ethyl quinoline- 2-hydrazodi-	CH_2Cl_2	Ethyl quinoline- 2-azodi-	96	92
4,5-Diphenyl- pyrazolidin-3- one (II)	CH ₂ Cl ₂	trans-Stilbene	75	70
1-Amino-4,5-di- phenyl-1,2,3- triazole	CH ₂ Cl ₂	Diphenyl- acetylene	75	80
1-Aminobenzo- triazole	CH_2Cl_2	Benzyne °	80	
2-Aminobenzo- triazole	CH ₂ Cl ₂	cis,cis-1,4-Di- cyano-buta- 1,3-diene	75	85
Phenylhydroxyl-	CH ₂ Cl ₂	Nitrosobenzene		

amine

^a Isolated as the 2,4-dinitrophenylhydrazone. ^b Estimated by g.l.c. • Isolated as tetraphenylnaphthalene (see text).

The oxidations are summarised in the Table; no attempt has been made to optimise conditions.* The reactions could be conveniently carried out on a substantial scale as shown by treatment of ethyl quinoline-2-hydrazocarboxylate (10 g.) with 1-chlorobenzotriazole, which gave the corresponding azo-compound rapidly and cleanly in 96% yield. As with other N-halogenocompounds, secondary alchols were more easily oxidised than primary alcohols.⁴ The carbonyl compounds were estimated as their 2,4-dinitrophenylhydrazones and yields were based on the amount of oxidant, since a small excess of the alcohol was used. Yields based on the alcohol, with the oxidant in slight excess, were estimated by g.l.c.

(V)

Although 1 molar proportion of 1-chlorobenzotriazole oxidised 1-amino-4,5-diphenyltriazole completely, to give diphenylacetylene, 2 molar proportions were required for complete oxidation of 1-aminobenzotriazole. In the presence of tetraphenylcyclopentadienone, the benzyne product, tetraphenylnaphthalene, was isolated in high yield, but in its absence chlorobenzene (20%) and o-dichlorobenzene (45%) were obtained. Presumably there are competing rapid reactions between benzyne and the hydrogen chloride and chlorine produced from the N-chloro-compound.

Although we have not fully investigated the scope of oxidations with 1-chlorobenzotriazole, our initial observations suggest that it may be very useful, especially in view of its ease of preparation, its stability, its mild and rapid action, and the ease of removal of side products.

That there is an induction period followed by a very fast reaction suggests that oxidations are radical in character, possibly involving a chlorine atom chain similar to that in the reactions of N-halogeno-imides⁵ (see Scheme 1).



The intermediacy of 1-chlorobenzotriazole would also explain anomalous products obtained in the attempted N-nitrosation and N-amination of benzotriazole. Treatment of the sodium salt of benzotriazole with nitrosyl chloride in diethyl ether gave 1-(1-ethoxyethyl)benzotriazole (III) and no nitrosated products.⁶ Similar treatment of the sodium salt of benzotriazole with ethereal chloramine gave no trace of the expected 1-aminobenzotriazole, which is surprising since both benzotriazole and naphtho[1,8-d,e]triazine are readily aminated with hydroxylamine-O-sulphonic acid and the triazine is equally well aminated with chloramine.⁷

^a R. Filler, Chem. Rev., 1963, 63, 21.
⁵ J. Adam, P. A. Gosselain, and P. Goldfinger, Nature, 1953, 171, 704; R. E. Pearson and J. C. Martin, J. Amer. Chem. Soc., 1963, 85, 3142; C. Walling, A. L. Rieger, and D. D. Tanner, *ibid.*, p. 3129; C. Walling and A. L. Rieger, *ibid.*, p. 3134.
⁶ C. D. Campbell and C. W. Rees, unpublished results.
⁷ (a) C. D. Campbell and C. W. Rees, J. Chem. Soc. (C), 1969, 742; (b) C. W. Rees and R. C. Storr, *ibid.*, p. 756.

^{*} Dimethyl sulphoxide cannot be used as a solvent for 1chlorobenzotriazole since the two compounds react explosively with each other.

⁴ R. Filler, Chem. Rev., 1963, 63, 21.

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Benzotriazole itself with ethereal chloramine gave 1-(1-ethoxyethyl)benzotriazole (III) together with benzotriazole hydrochloride. A further product was also isolated in low yield; the i.r. spectrum suggested that this was the isomeric 2-(1-ethoxyethyl)benzotriazole (IV). When the sodium salt of benzotriazole was used the ether (III) was not isolated.

The formation of the substituted ether (III) in the nitrosyl chloride reaction could be explained by decomposition of initially formed 1-nitrosobenzotriazole but this cannot apply in the chloramine reaction since 1-aminobenzotriazole is stable under such conditions. Thus it appeared that nitrosyl chloride and chloramine were acting as chlorinating agents to give 1-chlorobenzotriazole, which reacted further.

This possibility was confirmed by the formation of benzotriazole hydrochloride and 1-(1-ethoxyethyl)benzotriazole (III), together with a trace of its suspected 2-isomer, when 1-chlorobenzotriazole was treated with diethyl ether.

1-Chlorobenzotriazole gave an analogous product, (V), with tetrahydrofuran but none of the 2-benzotriazolyl isomer was isolated. In this case, as with diethyl ether, the reaction showed the long induction period followed by rapid reaction, characteristic of a radical mechanism. The induction period was shorter when peroxides had not been removed from the ether and when the reaction mixture was irradiated with u.v. light. The probable reactions are shown in Scheme 2.

$$\begin{array}{c} \text{BCl} \longrightarrow \text{B} \cdot + \text{Cl} \cdot \\ \text{Cl} \cdot + \text{Et}_2\text{O} \longrightarrow \text{HCl} + \text{Me}\dot{\text{C}}\text{HOEt} \\ \text{Me}\dot{\text{CHOEt}} + \text{BCl} \longrightarrow \text{Cl} \cdot + \text{B}\text{-CH}\text{-OEt} \\ & & & & \\ & & & \\ & & & \\ \text{Me} \\ \text{Me} \\ \text{Cl} \\ \text{Me} \\ \text{Me} \\ \text{Cl} \\ \text{Me} \\ \text{He}\dot{\text{CHOEt}} + \text{BCl} \longrightarrow \text{B} \cdot + \text{Me}\dot{\text{CHOEt}} \\ \text{B} \cdot + \text{Et}_2\text{O} \longrightarrow \text{BH} + \text{Me}\dot{\text{CHOEt}} \\ \text{B} \cdot + \text{HCl} \longrightarrow \text{BH} + \text{Cl} \cdot \\ \text{BCl} + \text{HCl} \longrightarrow \text{BH} + \text{Cl}_2 \\ \text{Scheme } 2 \end{array}$$

A similar reaction of N-bromosuccinimide with benzyl ethers has been reported 8,9 and a basically similar mechanism has been proposed,9 although with the succinimide radical rather than the (more likely) bromine atom as chain carrier.

EXPERIMENTAL

NOTE: 1-Chlorobenzotriazole reacts violently with dimethyl sulphoxide.

1-Chlorobenzotriazole (I).--(a) 2M-Sodium hypochlorite solution (50 ml., 0.1 mole) was added dropwise at room temperature to a stirred solution of benzotriazole (10 g., 0.08 mole) in aqueous acetic acid (1:1). After dilution with water the resulting solid was collected and recrystallised once from methylene chloride-petroleum to give pure 1-chlorobenzotriazole (13 g., 90%), colourless needles, m.p.

⁸ D. G. Markees, J. Org. Chem., 1958, 23, 1490.
 ⁹ L. L. Braun and J. H. Looker, J. Org. Chem., 1961. 26, 574.

104-106° (Found: C, 47.2; H, 2.7; N, 27.4. C₆H₄ClN₃ requires C, 46.9; H, 2.6; N, 27.4%), ν_{max} , 1610, 1558, 1442, 1234, 1060, 1046, 774, 759, and 745 cm.⁻¹, λ_{max} , 252 (log ϵ 3.72), 257 (3.71), and 275 (3.60) mµ, m/e 155, 153. The n.m.r. spectrum was typical of a 1-substituted benzotriazole.

(b) Benzotriazole (10 g.) suspended in carbon tetrachloride was treated with an excess of chlorine in the same solvent and the mixture was stirred for 2 hr. Benzotriazole hydrochloride (5 g., 38%) and benzotriazole (3 g., 30%) were filtered off. Evaporation of the filtrate left impure 1-chlorobenzotriazole (3.5 g., 26%). Several recrystallisations from methylene chloride-petroleum gave the pure compound, m.p. 104-106°. Benzotriazole hydrochloride was identical with a specimen prepared by passing hydrogen chloride gas into an ethereal solution of benzotriazole.¹⁰

1-Chlorobenzotriazole and Potassium Hydroxide.-1-Chlorobenzotriazole dissolved in potassium hydroxide solution (2N) and was recovered unchanged (80%) on neutralisation.

1-Chlorobenzotriazole was refluxed in potassium hydroxide solution (10%) for 5 hr. Acidification gave unchanged 1-chlorobenzotriazole (35%) which was filtered off. Extraction of the filtrate with ether gave impure benzotriazole (42%). No 1-hydroxybenzotriazole was detected (direct comparison).

1-Chlorobenzotriazole and Sodamide.-1-Chlorobenzotriazole in dry benzene was treated with an excess of fresh sodamide; the transfer of reagents was carried under dry nitrogen. A vigorous reaction occurred with gas evolution. When the reaction was complete, methanol was added to destroy the excess of sodamide and the mixture was poured into water. Extraction of the basic solution with ether gave no 1-aminobenzotriazole. Acidification followed by extraction with ether gave benzotriazole (65%).

1-Chlorobenzotriazole and Sodium Methoxide.-1-Chlorobenzotriazole (10 mmoles) was suspended in dry methanol, and sodium methoxide (10 mmoles) in methanol was added. The 1-chlorobenzotriazole dissolved immediately and sodium chloride precipitated in an exothermic reaction. More sodium methoxide (10 mmoles) was necessary for complete reaction. Sodium chloride was filtered off and the mother liquor was concentrated, acidified, and extracted with ether to give benzotriazole (67%). No 1-methoxybenzotriazole was observed (direct comparison).

1-Chlorobenzotriazole and Zinc.-1-Chlorobenzotriazole was stirred in methylene chloride with an excess of activated zinc. A white solid was gradually deposited and was separated by decantation from the heavier zinc. The amorphous powder did not melt below 360° and could not be crystallised. Ignition gave the characteristic zinc oxide residue and the i.r. spectrum indicated a zinc salt of benzotriazole.

1-Chlorobenzotriazole and the Sodium Salt of Benzotriazole. ----l-Chlorobenzotriazole was refluxed with a suspension of the sodium salt of benzotriazole (equimolar quantities) in methylene chloride. No reaction was observed after several days.

Oxidations with 1-Chlorobenzotriazole.---(a) Alcohols. Method (i). 1-Chlorobenzotriazole (1.5 g., 10 mmoles) and a slight excess of the alcohol were dissolved in carbon tetrachloride (25 ml.) and the solution was warmed to reflux. The solution became yellow and benzotriazole hydrochloride separated. This was filtered off and the filtrate was treated with 2,4-dinitrophenylhydrazine solu-¹⁰ F. Krollpfeiffer, H. Pötz, and A. Rosenberg, Ber., 1938, 71, 596.

tion to give the 2,4-dinitrophenylhydrazone of the carbonyl compound, which was compared directly with an authentic specimen. For yields see the Table.

Method (ii). A 5% solution of the alcohol in benzene was heated in a closed vessel with a slight excess (1·1 equiv.) of 1-chlorobenzotriazole. Samples were taken through a serum cap and analysed by g.l.c. with a Perkin-Elmer F 11 gas chromatograph. Products were compared with authentic samples and yields (see Table) were calculated with reference to chlorobenzene as internal standard. Control experiments showed that benzene was an inert solvent under the conditions of the reaction.

Propan-2-ol and acetone were chromatographed on a column (Carbowax 1500 on Chromosorb W) maintained at 70°. 1-Chlorobenzotriazole (1·2 equiv.) and propan-2-ol gave acetone (70%) and propan-2-ol (10%).

Cyclohexanol and cyclohexanone were chromatographed on a column (Carbowax 1500 on Chromosorb W) maintained at 130° . 1-Chlorobenzotriazole (1·1 equiv.) and cyclohexanol gave cyclohexanone (60%) and cyclohexanol (15%).

Benzyl alcohol and benzaldehyde were chromatographed on a column (Apiezon L on Chromosorb P) maintained at 170°. 1-Chlorobenzotriazole (1·1 equiv.) and benzyl alcohol gave benzaldehyde (50%) and benzyl alcohol (ca. 20%).

Other oxidations were carried out in the manner described below for hydrazobenzene.

(b) Hydrazobenzene. 1-Chlorobenzotriazole (306 mg., 2 mmoles) in methylene chloride was added to hydrazobenzene (368 mg., 2 mmoles) in the same solvent. Benzotriazole hydrochloride (220 mg., 70%) separated immediately and was filtered off. The filtrate was washed with sodium hydroxide solution (2N), then water, dried (MgSO₄), and evaporated to leave azobenzene (325 mg., 90%), m.p. and mixed m.p. $66-67^{\circ}$.

(c) *Ethyl quinoline-2-hydrazocarboxylate.*¹¹ The reaction was carried out as in (b) by use of ethyl quinoline-2-hydrazocarboxylate (10 g., 0.043 mole) and 1-chlorobenzotriazole (6.8 g., 0.044 mole).

(d) trans-4,5-*Diphenylpyrazolidin*-3-one (II).¹² 4,5-Diphenylpyrazolidin-3-one (238 mg., 1 mmole) and 1-chlorobenzotriazole (154 mg., 1 mmole) gave benzotriazole hydrochloride (110 mg., 70%). The filtrate was evaporated on to basic alumina and chromatographed to give *trans*-stilbene (125 mg., 75%), m.p. and mixed m.p. 124° (from ethanol).

(e) 1-Amino-4,5-diphenyltriazole. 1-Amino-4,5-diphenyltriazole (118 mg., 0.5 mmole) and 1-chlorobenzotriazole (80 mg., 0.5 mmole) gave benzotriazole hydrochloride (60 mg., 80%) and diphenylacetylene (71 mg., 75%) m.p. and mixed m.p. $61-62^{\circ}$, isolated from the filtrate by chromatography on basic alumina.

(f) 1-Aminobenzotriazole.^{7a} 1-Aminobenzotriazole (50 mg., 0.37 mmole) was treated with 1-chlorobenzotriazole (120 mg., 0.75 mmole) in methylene chloride. The resulting solution was made up to 5 ml. and examined by g.l.c. with an R.6 Gas Chromatograph fitted with a column (2 m. \times 0.25 in. o.d.; 10% Carbowax 1500 on 90—110 Celite) maintained at 130°. Comparison with standard solutions indicated the presence of chlorobenzene (20%) and o-dichlorobenzene (45%).

(g) 1-Aminobenzotriazole in the presence of tetracyclone. 1-Chlorobenzotriazole (308 mg., 2 mmole) in methylene chloride was added dropwise to 1-aminobenzotriazole (134 mg., 1 mmole) and tetracyclone (1·15 g., 3 mmoles) in the same solvent. The resulting solution was evaporated on to basic alumina and chromatographed to give 1,2,3,4tetraphenylnaphthalene (336 mg., 80%), m.p. and mixed m.p. 198-200°, and unchanged tetracyclone. Oxidation by the same method using 1-chlorobenzotriazole (1 mmole) gave 1,2,3,4-tetraphenylnaphthalene (181 mg., 42%).

Reaction of Benzotriazole with Chloramine.-Benzotriazole (8 g., 67.2 mmoles) was stirred overnight with ethereal 0.2M-chloramine¹³ (375 ml., 75 mmoles). Benzotriazole hydrochloride (5 g., 48%) was filtered off and the filtrate was evaporated on to silica gel for chromatography. Elution with 10% ether-petroleum gave a trace of a colourless oil; the i.r. spectrum, $\nu_{\rm max}$ 1560, 1130 (C–O), 815, 745, and 715 cm. ^1, was consistent with the presence of 2-(1ethoxyethyl)benzotriazole (IV).14 Elution with 20% etherpetroleum gave 1-(1-ethoxyethyl)benzotriazole (III) (2.3 g., 18%), a colourless oil, b.p. $84^{\circ}/1$ mm. (Found: C, 62.5; H, 6.6; N, 22.2. C₁₀H₁₃N₃O requires C, 62.8; H, 6.8; N, 22.0%), v_{max} 2970 and 2910 (CH), 1610 and 1585 (1-substituted benzotriazole), 1150-1160 (C-O), 780, 768, 745 (1 substituted benzotriazole),¹⁴ and 712 cm.⁻¹, τ 1.71– 2.22 (m, 2H), 2.33-2.82 (m, 2H), 3.62 (q, 1H, J 6 c./sec.), 6.60 (m, 2H), 8.13 (d, 3H, J 6 c./sec.), and 8.95 (t, 3H, J 7 c./sec.), m/e 191. Elution with ether gave benzotriazole (2·0 g., 25%).

Reaction of 1-Chlorobenzotriazole with Diethyl Ether. 1-Chlorobenzotriazole (850 mg.) was dissolved in dry redistilled ether. After an induction period of ca. 2 hr., benzotriazole hydrochloride (340 mg., 40%) separated and was filtered off. The filtrate was evaporated on to silica gel and chromatographed to give 1-(1-ethoxyethyl)benzotriazole (52 mg., 5%) and benzotriazole (250 mg., 32%). The induction period was considerably reduced by irradiation with low energy u.v. light.

Reaction of 1-Chlorobenzotriazole with Tetrahydrofuran.— 1-Chlorobenzotriazole (1 g.) was stirred for several hr. in dry redistilled tetrahydrofuran. Benzotriazole hydrochloride (160 mg., 16%) was filtered off and the filtrate was evaporated to dryness and redissolved in ether. The solution was washed with sodium hydroxide solution, followed by water, dried (MgSO₄), and evaporated to give 1-(*tetrahydro*-2-furyl)benzotriazole (IV) as a slightly discoloured oil (560 mg., 35%). Distillation gave a colourless oil, b.p. 150°/5 mm. (Found: C, 63·3; H, 5·8; N, 22·1. C₁₀H₁₁N₃O requires C, 63·5; H, 5·8; N, 22·2%), v_{max} 2960, 2940, 2870, 1610, 1587, 1490, 1450, 1290, 1274 (1-substituted benzotriazole), 1070, 1030 (C–O), 770, 765, and 745 (1-substituted benzotriazole) cm.⁻¹, τ 1·9—2·9 (complex m, 4H), 3·5br (m, 1H), 6·1 (t, 2H, J 6·5 c./sec.), and 6·9—8·5br (m, 4H).

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¹³ W. Theilacker and E. Wegner, Angew. Chem., 1960, 72, 127.
¹⁴ C. W. Rees and R. C. Storr, following paper.

¹¹ A. Risaliti and A. Monti, Gazzetta, 1960, 90, 397.

¹² L. A. Carpino, J. Amer. Chem. Soc., 1958, 80, 601.