Polyhalogeno-aromatic Compounds. Part XXXII.[1] Synthesis and Some Reactions of Tetrachloropyridine-2-thiol and Related Compounds †

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On reaction with thiourea or *NN'*-diethylthiourea, pentachloropyridine *N*-oxide gives bis(tetrachloro-2-pyridyl) disulphide from which tetrachloropyridine-2-thiol is obtained by reduction. This thiol is prepared less conveniently from tetrachloro-2-pyridyl-lithium and sulphur or by reaction of tetrachloro-2-nitropyridine with potassium hydrogen sulphide. The thiol has been converted into a number of derivatives. With potassium hydrogen sulphide, pentachloropyridine *N*-oxide gives either a mixture of tetrachloropyridine-2-thiol *N*-oxide, starting material, and polymer, or a mixture of the same thiol *N*-oxide and the 2,6-dithiol *N*-oxide, or the 2,6-dithiol *N*-oxide exclusively, depending on the amount of reagent used. Some reactions of the mono- and the di-thiol *N*-oxide are reported. Pentachloropyridine *N*-oxide gives tetrachloropyridine-4-thiol with phosphorus pentasulphide. Oxidation of tetrachloropyridine-4-sulphonyl chloride gives the corresponding *N*-oxide which reacts with dimethylamine to give *NN*-dimethyltetrachloropyridine-4-sulphonamide 1-oxide. Dimethyl 4,6,7-Trichlorothieno-[3,2-*c*]pyridine-2,3-dicarboxylate has been prepared from lithium tetrachloropyridine-4-thiolate and dimethyl acetylenedicarboxylate.

We have examined the chemistry of tetrachloropyridine-2-thiol (6)‡ because several tetrachloropyridine-4-sulphonamides [2] possess interesting biocidal activity.[3] Since pentachloropyridine gives the 4-thiol exclusively with potassium or sodium hydrogen sulphide,[4] several routes were explored for the synthesis of the 2-isomer (6).

Tetrachloro-2-pyridyl-lithium (1) is obtained together with its 3- and 4-isomer (ratio 68 : 16 : 16) (total yield 43%) when pentachloropyridine is treated with n-butyl-lithium in methylcyclohexane.[5] Successive treatment of such a mixture with sulphur and acid gave the thiol (6). This procedure is limited, however, by the low conversion of pentachloropyridine into the 2-lithium compound (1). The absence of pyridine-3- (and 4)-thiol in the product was established by treatment with dimethyl sulphate, which gave tetrachloro-2-methylthiopyridine (7) exclusively. Presumably tetrachloro-2-pyridyl-lithium (1) is relatively more stable than the isomeric 3- and 4-lithium compounds, which readily eliminate lithium chloride.[6]

A monohalogeno-pyridine [7] (see also ref. 8) or -pyridine *N*-oxide [9,10] will react with thiourea to give the corresponding pyridylisothiouronium halide, which is decomposed by alkali to give a salt of the corresponding pyridinethiol. Pentachloropyridine *N*-oxide (15) [11] reacted with thiourea to give a pale yellow solid which surprisingly gave tetrachloropyridine-2-thiol (6) and not

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‡ Recently, some of the compounds reported in this paper have been prepared independently by S. D. Moshchitskii, G. A. Zalesskii, and A. F. Pavlenko, *Khim. geterotsikl. Soedinenii*, 1974, 96 (*Chem. Abs.*, 1974, **80**, 108,318). See also S. D. Moshchitskii, L. S. Sologub, Ya. N. Ivashchenko, and T. A. Kozeiko, U.S.S.R. P. 418,473/1974 (*Chem. Abs.*, 1974, **80**, 133,274), in which it is claimed that pentachloropyridine reacts with sodium hydrogen sulphide in dioxan at 50° to give tetrachloropyridine-2-thiol (6).

[1] Part XXXI, N. J. Foulger and B. J. Wakefield, *J.C.S. Perkin I*, 1974, 871.

[2] E. Ager, B. Iddon, and H. Suschitzky, *J. Chem. Soc.* (*C*), 1970, 1530.

[3] C. D. S. Tomlin, B. Iddon, and E. Ager, B.P. 1,293,909/1972 (*Chem. Abs.*, 1973, **78**, 58,255).

[4] E. Ager, B. Iddon, and H. Suschitzky, *J. Chem. Soc.* (*C*), 1970, 193, and references cited therein.

[5] J. D. Cook and B. J. Wakefield, *J. Organometallic Chem.*, 1968, **13**, 15.

[6] J. D. Cook and B. J. Wakefield, *J. Chem. Soc.* (*C*), 1969, 1973.

[7] M. A. Phillips and H. Shapiro, *J. Chem. Soc.*, 1942, 584.

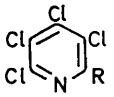
[8] M. P. V. Boarland and J. F. W. McOmie, *J. Chem. Soc.*, 1951, 1218.

[9] T. Itai, *J. Pharm. Soc. Japan*, 1949, **69**, 542 (*Chem. Abs.*, 1950, **44**, 4474).

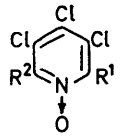
[10] E. Shaw, J. Bernstein, K. Losee, and W. A. Lott, *J. Amer. Chem. Soc.*, 1950, **72**, 4362.

[11] G. E. Chivers and H. Suschitzky, *J. Chem. Soc.* (*C*), 1971, 2867.

the expected thiol *N*-oxide (18) with aqueous alkali. Deoxygenation was not expected [9,10] and probably occurs after the introduction of a 2-sulphur substituent, since pentachloropyridine does not react with thiourea



(1) R = Li* [a]
(2) R = F*
(3) R = NH_2*
(4) R = NO_2*
(5) R = OH*
(6) R = SH
(7) R = SMe
(8) R = SO_2Me
(9) R = SO_2Ph*
(10) R = SO_2Cl
(11) R = SO_2NH_2
(12) R = SCH_2CO_2H
(13) R = SCH_2COMe
(14) R = $C_5Cl_4NS_2$ [b]



(15) $R^1 = R^2 = Cl$*
(16) $R^1 = NH_2$, $R^2 = Cl$
(17) $R^1 = OH$, $R^2 = Cl$
(18) $R^1 = SH$, $R^2 = Cl$
(19) $R^1 = SMe$, $R^2 = Cl$
(20) $R^1 = C_5Cl_4NOS_2$,[c] $R^2 = Cl$
(21) $R^1 = R^2 = SH$
(22) $R^1 = R^2 = SMe$
(23) $R^1 = R^2 = SO_2Me$

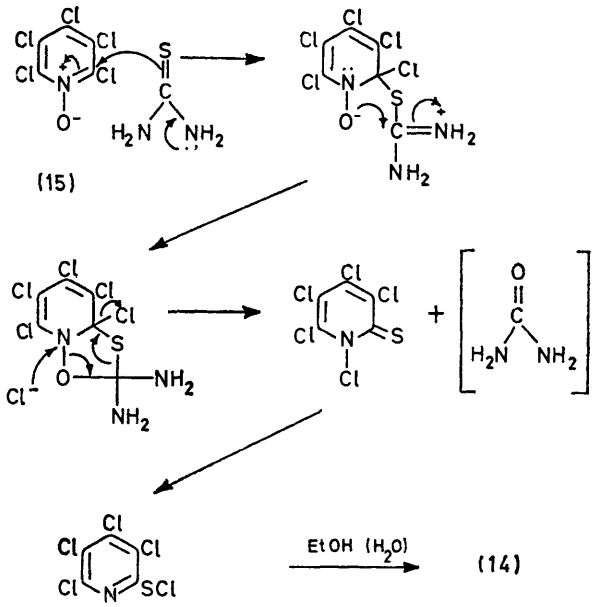
[a] An asterisk indicates that the compound has been reported previously. [b] C_5Cl_4N = tetrachloro-2-pyridyl. [c] C_5Cl_4NO = *N*-oxide of tetrachloro-2-pyridyl.

under these conditions. Pyridine *N*-oxide is deoxygenated by thiourea,[12] but at much higher temperatures (140°) than that used in the present work (boiling ethanol). The pale yellow solid was bis(tetrachloro-2-pyridyl) disulphide (14), identical with a sample prepared by oxidation of tetrachloropyridine-2-thiol (6), and not the expected isothiouronium salt. Isolation of the disulphide (14) and its reduction with zinc and acid was the most convenient method for the synthesis of the 2-thiol (6). Alkaline cleavage of a disulphide gives thiol together with other products.[13] A plausible mechanism (Scheme 1) involves initial formation of the isothiouronium salt which undergoes an intramolecular deoxygenation reaction, to give tetrachloropyridine-2-sulphenyl chloride.† A closely related mechanism [14] accounts for the formation of 3-hydroxy-6-methylpyridine-2(1*H*)-thione during the reaction of 2-bromo-3-hydroxy-6-methylpyridine with cysteine. In support of our scheme, tetrachloropyridine-4-sulphenyl chloride [2] and pyrazolesulphenyl chlorides [15] are reported to give the corresponding disulphide exclusively under similar conditions. Pentachloropyridine *N*-oxide (15) reacted also with *NN'*-diethylthiourea to give bis(tetrachloro-2-pyridyl) disulphide (14). We were not able to isolate urea or *NN'*-diethylurea from the complex residues of our reactions. Pentachloropyridine *N*-oxide did not react with urea or guanidine. Our results recall those of Coe *et al.*[16] who found that thiourea reacts with activated polyfluoroarenes, but to give polyfluorodiaryl *sulphides*.

† A 1,3-dipolar cycloaddition reaction between the *N*-oxide and thiourea followed by collapse of the resulting bicyclic intermediate (shown in Scheme 1) would give the same result.

[12] D. J. Relyea, P. O. Tawney, and A. R. Williams, *J. Org. Chem.*, 1962, **27**, 477.
[13] J. P. Danehy, *Internat. J. Sulfur. Chem.* (*B*), 1971, **6**, 103.
[14] K. Undheim and G. A. Ulsaker, *Acta Chem. Scand.*, 1973, **27**, 1390.

Attempts to prepare tetrachloropyridine-2-thiol (6) from pentachloropyridine *N*-oxide (15) and potassium (or sodium) hydrogen sulphide were unsatisfactory. One equivalent of the reagent gave a mixture of starting material (24% recovery), tetrachloropyridine-2-thiol *N*-oxide (18) (38% yield), and an unidentified polymer. Pentachloropyridine [4] and hexafluorobenzene [17] also react with hydrogen sulphide ion to give polymers if



SCHEME 1

the molar ratio of nucleophile to reactant is $<1{\cdot}5:1$. In these cases the difficulties are overcome by increasing the amount of potassium hydrogen sulphide used. However, with 2·5 equiv. of the reagent, pentachloropyridine *N*-oxide (15) gave an inseparable mixture of tetrachloropyridine-2-thiol *N*-oxide (18), trichloropyridine-2,6-dithiol *N*-oxide (21), and polymer. With 4 equiv. of the reagent, it gave exclusively the dithiol *N*-oxide (21) (96% yield). An attempt to prepare the thiol (6) from pentachloropyridine *N*-oxide (15) and phosphorus pentasulphide gave only tetrachloropyridine-4-thiol.[4]

With potassium hydrogen sulphide tetrachloro-2-nitropyridine (4) [18] gave the thiol (6) in 45% yield. We obtained tetrachloro-2-nitropyridine (4) from the corresponding amine (3),[18] which was prepared by treatment of pentachloropyridine *N*-oxide (15) with aqueous ammonia followed by deoxygenation of the resulting 2-aminotetrachloropyridine *N*-oxide (16). Tetrachloro-2-fluoropyridine (2) reacts with aqueous ammonia to give 2-aminotetrachloropyridine (3) but is not readily

[15] R. J. Alabaster and W. J. Barry, *J. Chem. Soc.* (*C*), 1970, 78.
[16] P. L. Coe, N. E. Milner, J. C. Tatlow, and R. T. Wragg, *Tetrahedron*, 1972, **28**, 105.
[17] P. Robson, M. Stacey, R. Stephens, and J. C. Tatlow, *J. Chem. Soc.*, 1960, 4754.
[18] S. M. Roberts and H. Suschitzky, *J. Chem. Soc.* (*C*), 1968, 2844.

available. It reacts with hydrogen sulphide ion exclusively in the 4-position.[19]

The methylsulphonyl group in tetrachloro-4-methylsulphonylpyridine is displaced readily by nucleophiles,[20] but an attempt to displace the phenylsulphonyl group in tetrachloro-2-phenylsulphonylpyridine (9) [21] with hydrogen sulphide ion failed.

Although tetrachloropyridin-4-ol is converted into tetrachloropyridine-4-thiol with phosphorus pentasulphide,[4] similar attempts to prepare the thiol (6) failed. Tetrachloropyridin-2-ol (5) was prepared by reaction of pentachloropyridine *N*-oxide (15) with aqueous sodium hydroxide or with a mixture of acetic anhydride and anhydrous sodium acetate followed by deoxygenation of the resulting *N*-oxide (17).

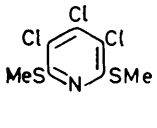
In contrast to tetrachloropyridine-4-thiol, which is stable in air for long periods,[4] the 2-isomer (6) is oxidised rapidly to bis(tetrachloro-2-pyridyl) disulphide (14). Tetrachloropyridine-2-thiol *N*-oxide (18) and trichloropyridine-2,6-dithiol *N*-oxide (21) appear to be oxidised by air even more rapidly to give the disulphide (20) and a polydisulphide, respectively. It was not possible to recrystallise these three thiols or to record meaningful m.p.s, and reactions were carried out on freshly prepared samples.

Tetrachloropyridine-2-thiol (6) reacted with dimethyl sulphate to give a stable methylthio-derivative (7) which gave tetrachloro-2-methylsulphonylpyridine (8) with peracetic acid. Under similar conditions tetrachloro-4-methylthiopyridine yields the methylsulphinyl derivative.[4] This difference in behaviour is presumably due to steric hindrance to oxidation in the case of the 4-isomer. The 2-thiol (6) reacted with chloroacetic acid or chloroacetone in the presence of alkali to give (tetrachloro-2-pyridylthio)acetic acid (12) and (tetrachloro-2-pyridylthio)acetone (13), respectively.

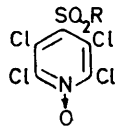
Previously we [2] reported the synthesis of tetrachloropyridine-4-sulphenyl chloride by treatment of the corresponding thiol or disulphide with chlorine in anhydrous acetic acid or carbon tetrachloride. These reactions may be followed by the appearance of a characteristic orange colour. When a solution of the 4-sulphenyl chloride in anhydrous acetic acid is poured on ice, it gives the corresponding sulphonyl chloride. The conversion of bis(tetrachloro-2-pyridyl) disulphide (14) (the thiol is oxidised to the disulphide in solution) into the 2-sulphonyl chloride (10) proved difficult under these conditions. In one case a low yield of the sulphonyl chloride (10) was obtained; in other cases the disulphide failed to react. Treatment of the disulphide (14) with neat sulphuryl chloride [22] or in carbon tetrachloride were similarly unsuccessful.

Tetrachloropyridine-2-sulphenyl chloride was prepared, however, by cleavage of the disulphide (14) with chlorine in carbon tetrachloride in the presence of aluminium chloride. It was not isolated but converted with acetone into the derivative (13). When a solution of the sulphenyl chloride in carbon tetrachloride was poured on ice, it gave a low yield of tetrachloropyridine-2-sulphonyl chloride (10) together with pentachloropyridine. With aqueous ammonia it gave the sulphonamide (11).

Tetrachloropyridine-2-thiol *N*-oxide (18) was oxidised to the corresponding disulphide (20) and reduction of this disulphide regenerated the 2-thiol *N*-oxide (18). With dimethyl sulphate, compound (18) gave the methylthio-derivative (19) which gave tetrachloro-2-methylthiopyridine (7) with phosphorus trichloride. Compound (18) with phosphorus trichloride gave the 2-thiol (6). Trichloro-2,6-bismethylthiopyridine (24) and its



(24)



(25) R = Cl

(26) R = NMe_2

N-oxide (22) were prepared similarly. Oxidation of the latter compound with a mixture of hydrogen peroxide, acetic acid, and concentrated sulphuric acid gave trichloro-2,6-bismethylsulphonylpyridine *N*-oxide (23). Attempts to prepare tetrachloropyridine-2-sulphonyl chloride *N*-oxide from the 2-thiol *N*-oxide (18) or the corresponding disulphide (20) failed.

Kwart and Body [23] proposed that an imino-conjugated chlorosulphonyl group, $-N{=}C{\cdot}[C{=}C]_n{\cdot}SO_2Cl$, is not unstable, but becomes unstable when the imino-nitrogen atom acquires a threshold magnitude of positive character such as results from protonation or conversion into the *N*-oxide. A similar degree of positive character is conferred on the nitrogen atom during the conversion of pyridine-2(and 4)-thiol into the corresponding sulphonyl chloride through co-ordination of the unshared electron pair on nitrogen with the powerfully electrophilic halogen. This incipient charge on nitrogen is believed to be the driving force for an S_Ni rearrangement, as shown in Scheme 2. The order of effectiveness of the charge appears to be protonation < *N*-oxidation < co-ordination with chlorine. Pyridine-2(and 4)-sulphonyl chloride can be prepared only in concentrated hydrochloric acid near 0° or at lower temperatures; pyridine-2(and 4)-thiol are converted by chlorine into 2- and 4-chloropyridine, respectively, in the absence of a strong acid. The *N*-oxide of pyridine-4-sulphonyl chloride appears to be extremely unstable.

Tetrachloropyridine-4-sulphonyl chloride is remarkably stable by comparison with pyridine-2(and 4)-

[19] B. Iddon, H. Suschitzky, and A. W. Thompson, *J.C.S. Perkin I*, 1973, 2971.

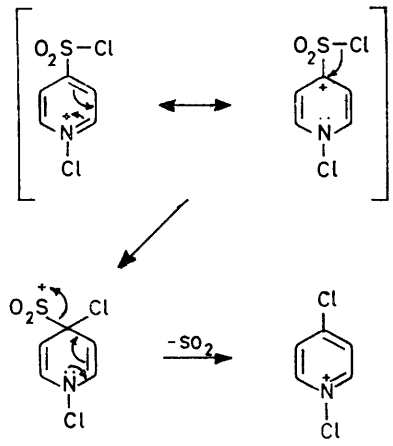
[20] E. Ager, B. Iddon, and H. Suschitzky, *J.C.S. Perkin I*, 1972, 133.

[21] J. Bratt and H. Suschitzky, *J.C.S. Perkin I*, 1973, 1689.

[22] N. Kharasch, U.S.P. 2,929,820/1960 (*Chem. Abs.*, 1960, **54**, 15,318).

[23] H. Kwart and R. W. Body, *J. Org. Chem.*, 1965, **30**, 1188, and references cited therein.

sulphonyl chloride.[2] Its decomposition by a mechanism analogous to that shown in Scheme 2 appears unlikely. We ascribed the stability of this compound, in part, to a buttressing effect exerted by the two *ortho*-chlorine atoms, which prevents an S_Ni rearrangement.[2] A similar



SCHEME 2

argument would account for the stability of trichloro-2-fluoropyridine-4-sulphonyl chloride and 3,5-dichloro-2,6-difluoropyridine-4-sulphonyl chloride.[19] However, tetrafluoropyridine-4-sulphonyl chloride, in which such an effect is much less marked, is also stable by comparison with pyridine-2(and 4)-sulphonyl chloride.[24] Therefore, electronic effects would appear to be more important, and we now suggest that polyhalogenopyridine-4-sulphonyl chlorides are stabilised to some extent by a strong electronic repulsion between the chlorosulphonyl group and the *ortho*-halogen atoms, which prevents an S_Ni rearrangement.

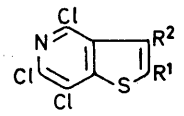
To test whether a positive ring nitrogen atom destabilises a polyhalogenopyridine-4-sulphonyl chloride we oxidised tetrachloropyridine-4-sulphonyl chloride to the sulphonyl chloride *N*-oxide (25), which appears to be stable by comparison with pyridine-4-sulphonyl chloride *N*-oxide. The sulphonyl chloride (25) gave pentachloropyridine *N*-oxide (15) on heating for 20 min in refluxing acetic acid (tetrachloropyridine-4-sulphonyl chloride is stable in acetic acid at 100° for 16 h), and the sulphonamide (26) on treatment with dimethylamine.

Co-ordination of a polyhalogenopyridine with chlorine, as shown in Scheme 2, is unlikely because the ring nitrogen atom is insufficiently basic. The *N*-oxide experiment suggests that, if such co-ordination did occur, it need not necessarily result in decomposition of the sulphonyl chloride by an S_Ni mechanism.

The reasons advanced to explain the stability of polyhalogenopyridine-4-sulphonyl chlorides could account for the difficulty experienced in preparing tetrachloropyridine-2-sulphonyl chloride (10) in which the chlorosulphonyl group is flanked by only one halogen atom. Once formed, however, this compound appears to be more stable than pyridine-2-sulphonyl chloride. We have mentioned already that the formation of the 2-sulphonyl chloride (10) was accompanied by substantial quantities of pentachloropyridine. This may arise by an S_Ni rearrangement of the sulphonyl chloride. However, under certain conditions, conversion of tetrachloropyridine-4-thiol into the corresponding sulphonyl chloride is accompanied by the formation of substantial amounts of pentachloropyridine.[2] We have previously suggested a mechanism which accounts for this.[2] It is unlikely that the basicities of the ring nitrogen atoms in the 4-sulphonyl chloride and its 2-isomer are so different that co-ordination with chlorine occurs with the latter compound but not with its isomer. It is thus not surprising that we failed to prepare tetrachloropyridine-2-sulphonyl chloride *N*-oxide.

There are differences therefore between the chemistry of a polyhalogenopyridine with a sulphur substituent in the 4-position and that of the 2-isomer. In summary, polyhalogenopyridine-4-thiols are relatively stable to oxidation in air whereas their 2-isomers are not. Also, conversion of a 4-thiol, or of the corresponding disulphide or sulphenyl chloride, into the corresponding 4-sulphonyl chloride will proceed readily in high yield, while similar conversions of tetrachloropyridine-2-thiol (6) or the disulphide (14) are difficult.

Previously [4] we prepared 4,6,7-trichloro-3-methylthieno[3,2-*c*]pyridine (27) by cyclisation of (2,3,6-trichloro-4-pyridylthio)acetone with polyphosphoric acid. By analogy with the synthesis of diethyl 4,5,6,7-tetrafluorobenzo[*b*]thiophen-2,3-dicarboxylate,[25] dimethyl 4,6,7-trichlorothieno[3,2-*c*]pyridine-2,3-dicarboxylate (28) was prepared by successive addition of n-butyl-lithium



(27) $R^1 = H, R^2 = Me$
(28) $R^1 = R^2 = CO_2Me$

and dimethyl acetylenedicarboxylate to tetrachloropyridine-4-thiol in tetrahydrofuran. The low yield (24%) of product (28) reflects the difficulty with which a β-chlorine atom is displaced by nucleophiles in polychloropyridines.

EXPERIMENTAL

Molecular weights were determined by mass spectrometry with an A.E.I. MS902S or MS12 instrument. All new compounds gave mass spectra with correct isotopic abundance ratios. I.r. spectra were recorded with a Perkin-Elmer 257 instrument and n.m.r. spectra with a Varian A60 spectrometer (tetramethylsilane as internal standard).

Light petroleum had b.p. 60—80°. n-Butyl-lithium was

[24] R. E. Banks, R. N. Haszeldine, and D. R. Karsa, personal communication.

[25] G. M. Brooke and Md. Abul. Quasem, *J. Chem. Soc.* (*C*), 1967, 865; *J.C.S. Perkin I*, 1973, 429; G. M. Brooke, W. K. R. Musgrave, and Md. Abul. Quasem, B.P. 1,187,671/1970 (*Chem. Abs.*, 1970, **72**, 132,502).

purchased as a solution in hexane from Pfizer, and reactions with it were carried out under dry, oxygen-free nitrogen. Solvents and reagents were dried by literature procedures.

Pentachloropyridine *N*-oxide,[11] tetrachloro-2-nitropyridine,[18] tetrachloro-2-phenylsulphonylpyridine,[21] tetrachloropyridine-4-thiol,[2] tetrachloropyridine-4-sulphonyl chloride,[2] and bis(tetrachloro-4-pyridyl) disulphide [2] were prepared as described previously.

2-*Aminotetrachloropyridine*.—(a) *From tetrachloro-2-fluoropyridine*. Aqueous ammonia (*d* 0·88; 2 ml) was added to a stirred solution of tetrachloro-2-fluoropyridine (1·13 g, 4·8 mmol) in dimethylformamide (10 ml) and the mixture was stirred at room temperature for 2 h. Water (50 ml) was added and the precipitate was filtered off to give 2-aminotetrachloropyridine (1·0 g, 90%), m.p. 171—171·5° (from ethanol) (lit.,[18] 174—175°), identical (i.r.) with an authentic sample.

(b) *From pentachloropyridine* N-*oxide*. (i) Aqueous ammonia (*d* 0·88; 10 ml) was added to a stirred solution of the *N*-oxide (2·0 g, 7·5 mmol) in dimethylformamide (50 ml) and the mixture was stirred overnight at room temperature. It was then poured into water (50 ml), concentrated hydrochloric acid (15 ml) was added with vigorous stirring, and the mixture was filtered to remove residual pentachloropyridine *N*-oxide (1·8 g, 90% recovery). Treatment of the filtrate with 30% w/v aqueous sodium hydroxide (20 ml) gave 2-*aminotetrachloropyridine* N-*oxide* (0·1 g, 54% based on pentachloropyridine consumed), m.p. 192—192·5° (from ethanol) (Found: M^+, 245·8906. $C_5H_2Cl_4N_2O$ requires *M*, 245·8919). This compound is a pink solid which darkens rapidly on exposure to air. It was not possible to obtain satisfactory elemental analyses and in subsequent experiments the compound was used immediately following its isolation.

(ii) A mixture of 2-aminotetrachloropyridine *N*-oxide (0·3 g, 1·22 mmol) and phosphorus trichloride (2 ml) in chloroform (20 ml) was heated under reflux for 1 h. Work-up in the usual way gave 2-aminotetrachloropyridine (0·2 g, 71%), m.p. 170—170·5° (from ethanol), identical (m.p. and i.r.) with an authentic sample.

Tetrachloropyridine-2-ol.—(*a*) (i) A stirred mixture of pentachloropyridine *N*-oxide (2·0 g, 7·5 mmol), anhydrous sodium acetate (2·0 g, 24·4 mmol), and acetic anhydride (10·2 g, 100·0 mmol) was heated under reflux for 24 h. Water (50 ml) was added and the mixture was stirred overnight at room temperature. The precipitate was filtered off and washed with water to give tetrachloropyridin-2-ol *N*-oxide (1·4 g, 74%), m.p. 186° (decomp.) (from methanol) (lit.,[26] 180°), identical (i.r.) with an authentic sample.

(ii) A mixture of pentachloropyridine *N*-oxide (2·0 g, 7·5 mmol), sodium hydroxide (2·0 g), ethanol (50 ml), and water (50 ml) stirred at room temperature for 48 h gave a precipitate of tetrachloropyridin-2-ol *N*-oxide (1·2 g, 63%), identical (m.p. and i.r.) with the sample described in (i).

(*b*) A mixture of tetrachloropyridin-2-ol *N*-oxide (1·2 g, 4·8 mmol), phosphorus trichloride (2 ml), and chloroform (20 ml) was heated under reflux for 30 min. Work-up in the usual way gave a solid (1·0 g) which was treated with 2N-sodium hydroxide (10 ml). Filtration of this mixture gave pentachloropyridine (0·2 g, 17%), m.p. 176—177°, identical (i.r.) with an authentic sample, while addition of 2N-hydrochloric acid (10 ml) to the filtrate gave a precipitate of tetrachloropyridin-2-ol (0·75 g, 70%), m.p. 223—224° (from aqueous ethanol) (lit.,[26] 224°), identical (i.r.) with an authentic sample.

Tetrachloropyridine-2-thiol.—(a) *By reduction of bis-(tetrachloro-2-pyridyl) disulphide*. A mixture of the disulphide (2·5 g, 5·1 mmol), granulated zinc (2·0 g), and acetic acid (25 ml) was heated under reflux for 2 h. It was then cooled, filtered, and poured into water (100 ml). Extraction with chloroform gave *tetrachloropyridine-2-thiol* (2·3 g, 92%), $\nu_{max.}$ (Nujol) 2590 cm^{-1} (SH) [Found (for a freshly prepared sample): C, 25·4; H, 0·6; N, 5·6%; M^+, 246·8582. C_5HCl_4NS requires C, 24·1; H, 0·4; N, 5·6%; *M*, 246·8588].

(b) *By reaction of tetrachloro-2-pyridyl-lithium with sulphur*. A solution of n-butyl-lithium (45·0 mmol) in hexane (20 ml) was added dropwise to a stirred solution of pentachloropyridine (10·0 g, 40·0 mmol) in anhydrous methylcyclohexane (400 ml) at −70°, and the mixture was allowed to warm to 0° during 30 min. It was kept at 0° for 30 min, then recooled to −70°, and dry, powdered sulphur (2·0 g, 62·5 mmol) was added in one portion. The mixture was stirred at −70° for a further 1 h, then at room temperature overnight, and finally was heated under reflux for 2 h. Water (50 ml) was added followed by 20% w/v aqueous potassium hydroxide (50 ml), the mixture was filtered, and addition of concentrated hydrochloric acid (25 ml) to the filtrate gave the thiol (2·8 g, 28%), identical (i.r.) with the sample prepared in (a).

(c) *By reaction of tetrachloro-2-nitropyridine with potassium hydrogen sulphide*. A solution of potassium hydroxide (0·3 g, 5·3 mmol) in methanol (50 ml) was saturated with hydrogen sulphide and added dropwise to a stirred solution of the nitro-compound (0·7 g, 2·7 mmol) in methanol (25 ml) at 50°. The mixture was heated at 50° for a further 1 h and the methanol was distilled off under reduced pressure. 4N-Potassium hydroxide (50 ml) was added to the residue, the resulting solution was filtered, and concentrated hydrochloric acid (10 ml) was added to the cooled (0°) filtrate. Extraction with ether gave the thiol (0·3 g, 45%), identical (i.r.) with the sample prepared in (a).

(d) *By deoxygenation of tetrachloropyridine-2-thiol* N-*oxide*. A mixture of the *N*-oxide (1·0 g, 4·0 mmol) (see below), phosphorus trichloride (2 ml), and chloroform (20 ml) was heated under reflux for 1 h. It was then cooled and water (50 ml) was added followed by 4N-potassium hydroxide (20 ml). Addition of concentrated hydrochloric acid to the aqueous layer gave tetrachloropyridine-2-thiol (0·65 g, 69%), identical (i.r.) with the samples prepared above.

Bis(tetrachloro-2-pyridyl) Disulphide.—(a) *By reaction of pentachloropyridine* N-*oxide with thiourea*. A mixture of the *N*-oxide (2·67 g, 10·0 mmol), thiourea (0·76 g, 10·0 mmol), and ethanol (50 ml) was heated under reflux for 2 h, then cooled and filtered, to give the *disulphide* (2·1 g, 85%), m.p. 230—232° (from acetic acid) (Found: C, 24·6; N, 5·2%. $C_{10}Cl_8N_2S_2$ requires C, 24·2; N, 5·65%). Evaporation of the filtrate gave a brown oil (0·8 g) which t.l.c. showed to be a complex mixture, and was not examined further.

(b) *By reaction of pentachloropyridine* N-*oxide with* NN′-*diethylurea*. This reaction was carried out as in (a) and gave a 65% yield of the disulphide, m.p. 231—232° (from acetic acid). The filtrate yielded a brown oil (1·6 g) which t.l.c. showed to be a complex mixture, and was not examined further.

(c) *By oxidation of tetrachloropyridine-2-thiol*. Bromine (1·0 g, 6·3 mmol) was added to a freshly prepared sample

[26] F. Binns and H. Suschitzky, *J. Chem. Soc.* (*C*), 1971, 1223.

of the thiol (2·5 g, 10·0 mmol) in acetic acid (25 ml) at 20°, and the resulting mixture was stirred at ambient temperature for 4 h. It was then poured into water (100 ml) and the disulphide (2·5 g, 99%), m.p. 230—232° (from acetic acid), identical (i.r.) with the samples prepared in (a) and (b), was filtered off.

Tetrachloro-2-methylthiopyridine.—Freshly prepared tetrachloropyridine-2-thiol (2·5 g, 10·0 mmol) was dissolved in a solution of potassium hydroxide (0·5 g) in water (20 ml) and the resulting solution was filtered. Dimethyl sulphate (1·39 g, 11·0 mmol) was added to the filtrate and the mixture was stirred at room temperature for 1 h. The precipitate was filtered off and washed successively with 2N-ammonium hydroxide (20 ml) and water (20 ml) to give *tetrachloro-2-methylthiopyridine* (2·3 g, 88%), m.p. 99—100° (from ethanol), τ ($CDCl_3$) 7·43 (s, Me) (Found: C, 27·8; H, 1·25; N, 5·4%; M^+, 261. $C_6H_3Cl_4NS$ requires C, 27·4; H, 1·15; N, 5·3%; *M*, 261).

Tetrachloro-2-methylsulphonylpyridine.—A mixture of tetrachloro-2-methylthiopyridine (0·3 g, 1·1 mmol), acetic acid (15 ml), and hydrogen peroxide (30%; 3 ml) was stirred overnight at room temperature and then poured into water (50 ml) to give a precipitate of *tetrachloro-2-methylsulphonylpyridine* (0·3 g, 90%), m.p. 170·5—172° (from aqueous ethanol) (Found: C, 24·55; H, 1·1; N, 4·7%; M^+, 293. $C_6H_3Cl_4NO_2S$ requires C, 24·4; H, 1·0; N, 4·75%; *M*, 293).

(*Tetrachloro-2-pyridylthio*)*acetone.*—(*a*) Dry chlorine was passed through a stirred solution of bis(tetrachloro-2-pyridyl) disulphide (0·5 g, 0·9 mmol) and anhydrous aluminium chloride (0·5 g, 3·7 mmol) in anhydrous carbon tetrachloride (50 ml) for 1 h at room temperature. The resulting orange solution of tetrachloropyridine-2-sulphenyl chloride was filtered and the excess of chlorine was removed by evaporation of the solvent under reduced pressure. Anhydrous acetone (50 ml) was added to the residue and the mixture was stirred at room temperature for 30 min. Evaporation of the excess of acetone under reduced pressure gave the *product* (0·2 g, 36%), m.p. 94—95° (from methanol–carbon tetrachloride), $\nu_{max.}$ (Nujol) 1735 cm^{-1} (C:O) (Found: C, 31·8; H, 1·9; N, 4·5%; M^+, 303. $C_8H_5Cl_4NOS$ requires C, 31·5; H, 1·65; N, 4·6%; *M*, 303).

(*b*) A mixture of potassium tetrachloropyridine-2-thiolate (1·0 g, 3·6 mmol) and chloroacetone (10 ml) was stirred for 4 h at room temperature and then poured into stirred water. The resulting oil solidified after 2 h, to give (tetrachloro-2-pyridylthio)acetone (0·8 g, 75%), identical (m.p. and i.r.) with the sample prepared in (*a*).

Tetrachloropyridine-2-sulphonyl Chloride.—Freshly prepared tetrachloropyridine-2-thiol (1·6 g, 6·5 mmol) was dissolved quickly in anhydrous acetic acid [27] (100 ml) and dry chlorine was bubbled through the stirred solution for 1 h. The mixture was then poured on crushed ice (500 g) to precipitate *tetrachloropyridine-2-sulphonyl chloride* (0·3 g, 15%), m.p. 75—76·5° (from light petroleum) (Found: C, 19·5; N, 4·4%; M^+, 313. $C_5Cl_5NO_2S$ requires C, 19·0; N, 4·5%; *M*, 313).

Tetrachloropyridine-2-sulphonamide.— Tetrachloropyridine-2-sulphonyl chloride (0·2 g, 0·6 mmol) was added at room temperature in small portions to stirred aqueous ammonia (*d* 0·88; 10 ml), and the resulting mixture was stirred for 1 h at room temperature. It was then filtered and concentrated hydrochloric acid (10 ml) was added to the filtrate, to give the *sulphonamide* (0·1 g, 55%), m.p. 180—180·5° (from ethanol), $\nu_{max.}$ (Nujol) 3260 and 3350 cm^{-1} (NH) (Found: C, 20·5; H, 0·8; N, 9·2%, M^+, 294. $C_5H_2Cl_4N_2O_2S$ requires C, 20·3; H, 0·7; N, 9·5%; *M*, 294).

(*Tetrachloro-2-pyridylthio*)*acetic Acid.*—A stirred mixture of potassium tetrachloropyridine-2-thiolate (1·0 g, 3·6 mmol), chloroacetic acid (1·5 g, 15·9 mmol), and water (5 ml) was heated on a water-bath for 1 h. The resulting yellow precipitate was filtered off and washed with water to give the *product* (0·3 g, 27%), m.p. 156·5—157·5° (from chloroform–light petroleum); $\nu_{max.}$ (Nujol) 1715s cm^{-1} (C:O) (Found: C, 27·7; H, 1·3; N, 4·7. $C_7H_3Cl_4NO_2S$ requires C, 27·4; H, 1·0; N, 4·6%).

Reactions of Pentachloropyridine N-Oxide with Potassium Hydrogen Sulphide.—(*a*) A solution of potassium hydrogen sulphide (0·72 g, 10·0 mmol) in ethylene glycol (5 ml) (prepared by saturation with hydrogen sulphide of a warm solution of potassium hydroxide in the solvent [4]) was added dropwise to a stirred solution of pentachloropyridine *N*-oxide (2·67 g, 10·0 mmol) in ethylene glycol (100 ml) at room temperature, and the resulting mixture was stirred overnight at ambient temperature. The mixture was then poured into water (100 ml) and filtered, and addition of 4N-hydrochloric acid to the cooled (0°) filtrate gave tetrachloropyridine-2-thiol *N*-oxide (1·0 g, 38%). This compound was unstable in air and it was not possible to record its m.p. or to analyse it. It was characterised by conversion into its methylthio-derivative (see below). Treatment with boiling ethanol (50 ml) of the solid which remained after filtration of the mixture left a polymeric residue (0·75 g). Evaporation of the ethanol under reduced pressure gave starting material (0·64 g, 24%).

(*b*) A solution of potassium hydrogen sulphide (1·8 g, 25·0 mmol) in ethylene glycol (12·5 mmol) [prepared as in (*a*)] was added to a solution of the *N*-oxide (2·67 g, 10·0 mmol) in ethylene glycol (100 ml) at room temperature and the reaction was then carried out as described in (*a*). Work-up gave an inseparable mixture (2·45 g) of tetrachloropyridine-2-thiol *N*-oxide and trichloropyridine-2,6-dithiol *N*-oxide together with polymeric material (0·8 g).

The thiol mixture was dissolved quickly in a solution of potassium hydroxide (1·0 g) in water (20 ml), dimethyl sulphate (2·52 g, 20·0 mmol) was added, and the resulting mixture was stirred at room temperature for 1 h. The product (3·5 g) was filtered off, washed with water, dried, and dissolved in chloroform (25 ml). Phosphorus trichloride (5 ml) was added and the mixture was heated under reflux for 1 h. It was then cooled and poured onto crushed ice (50 g). Extraction with chloroform gave a solid (3·0 g) which was chromatographed on silica. Light petroleum eluted tetrachloro-2-methylthiopyridine (0·94 g, 35%), m.p. 99·5—100° (from ethanol) (i.r. spectrum identical with that of the sample prepared above), and *trichloro-2,6-bismethylthiopyridine* (0·66 g, 24%), m.p. 165—167° (from ethanol), τ ($CDCl_3$) 7·36 (s, Me) (Found: C, 30·5; H, 2·3; N, 5·1%; M^+, 273. $C_7H_6Cl_3NS_2$ requires C, 30·6; H, 2·2; N, 5·1%; *M*, 273).

(*c*) A solution of potassium hydrogen sulphide (2·88 g, 40·0 mmol) in ethylene glycol (20 ml) [prepared as in (*a*)] was added to a solution of the *N*-oxide (2·67 g, 10·0 mmol) in ethylene glycol (100 ml) at room temperature and the reaction was then carried out as described in (*a*). Work-up gave trichloropyridine-2,6-dithiol *N*-oxide (2·52 g, 96%). This compound was unstable in air and it was

[27] W. L. Orr and N. Kharasch, *J. Amer. Chem. Soc.*, 1953, **75**, 6030.

not possible to record its m.p. or to analyse it. It was characterised by conversion into its bismethylthio-derivative (see below).

Tetrachloro-2-methylthiopyridine N-oxide (79%), m.p. 142·5—143° (from aqueous ethanol) (Found: C, 26·1; H, 1·25; N, 4·75%; M^+, 277. $C_6H_3Cl_4NOS$ requires C, 25·8; H, 1·1; N, 5·0%; *M*, 277) and *trichloro-2,6-bismethylthiopyridine N-oxide* (73%), m.p. 208—208·5° (from ethanol), τ ($CDCl_3$) 7·33 (s, Me) (Found: C, 29·0; H, 2·1; N, 4·9%; M^+, 289. $C_7H_6Cl_3NOS_2$ requires C, 28·9; H, 2·1; N, 4·8%; *M*, 289) were prepared by treatment of the appropriate thiol with dimethyl sulphate according to the procedure described before for the synthesis of tetrachloro-2-methylthiopyridine.

Trichloro-2,6-bismethylsulphonylpyridine N-Oxide.—A mixture of trichloro-2,6-bismethylthiopyridine *N*-oxide (1·0 g, 3·4 mmol), acetic acid (20 ml), concentrated sulphuric acid (10 ml), and hydrogen peroxide (30%, 5 ml) was stirred at room temperature for 8 h. Work-up in the usual way gave the *product* (1·0 g, 82%), m.p. 217—218·5° (from ethanol) (Found: C, 24·1; H, 1·8; N, 4·0%; M^+, 353. $C_7H_6Cl_3NO_5S_2$ requires C, 23·7; H, 1·7; N, 4·0%; *M*, 353).

Reaction of Tetrachloro-2-methylthiopyridine N-Oxide with Phosphorus Trichloride.—A mixture of the *N*-oxide (1·0 g, 3·6 mmol) and phosphorus trichloride (2 ml) in chloroform (20 ml) was heated under reflux for 1 h. It was then cooled, water (50 ml) was added, and extraction with chloroform gave tetrachloro-2-methylthiopyridine (0·9 g, 95%), m.p. 100—100·5° (from ethanol), with an i.r. spectrum identical with those of the samples prepared above.

Reaction of Trichloro-2,6-bismethylthiopyridine N-Oxide with Phosphorus Trichloride.—This *N*-oxide (1·0 g, 3·4 mmol) was treated with phosphorus trichloride (2 ml) in chloroform (20 ml) according to the procedure in the preceding experiment and gave trichloro-2,6-bismethylthiopyridine (0·75 g, 85%) m.p. 165—166° (from ethanol), identical (i.r.) with the sample prepared before.

Reaction of Trichloropyridine-2,6-dithiol N-Oxide with Phosphorus Trichloride.—A mixture of the 2,6-dithiol *N*-oxide (1·0 g, 3·8 mmol), phosphorus trichloride (2 ml), and chloroform (30 ml) was heated under reflux for 30 min. It was then cooled to 0° and poured carefully into water (100 ml), to give a high molecular weight product which we believe to be a poly(trichloropyridine-2,6-diyl disulphide). A mixture of this product and 4N-sodium hydroxide (50 ml) was heated under reflux for 30 min. The resulting yellow solution was filtered, cooled to room temperature, and dimethyl sulphate (2·0 g, 16·0 mmol) was added. The resulting mixture was stirred at ambient temperature for 4 h to give a precipitate which was filtered off, washed with water, and recrystallised from ethanol, to give trichloro-2,6-bismethylthiopyridine (0·79 g. 72%), m.p. 164·5—165·5°, identical (i.r.) with the samples prepared before.

Bis(tetrachloro-2-pyridyl) Disulphide Bis-N-oxide.—A sample (99%), decomp. 160—162°, no sharp m.p. <320° (from acetic acid–dimethyl sulphoxide) (Found: C, 22·25; N, 5·4%; M^+, 524. $C_{10}Cl_8N_2O_2S_2$ requires C, 22·75; N, 5·3%; *M*, 524) was prepared from tetrachloropyridine-2-thiol *N*-oxide (9·0 mmol) according to the procedure described before for the synthesis of bis(tetrachloro-2-pyridyl) disulphide.

Reduction of Bis(tetrachloro-2-pyridyl) Disulphide Bis-N-Oxide.—Reduction of this bis-*N*-oxide (4·8 mmol) according to the procedure described before for the reduction of bis-(tetrachloro-2-pyridyl) disulphide gave tetrachloropyridine-2-thiol *N*-oxide, which with dimethyl sulphate gave tetrachloro-2-methylthiopyridine *N*-oxide (87%), m.p. 142—144° (from aqueous ethanol), with an i.r. spectrum identical with that of the sample prepared above.

Reaction of Pentachloropyridine N-Oxide with Phosphorus Pentasulphide.—A mixture of the *N*-oxide (1·3 g, 5·0 mmol) and phosphorus pentasulphide (1·1 g, 5·0 mmol) was intimately mixed and heated in a sealed tube at 60° for 10 min. The product was heated in boiling water (100 ml) until evolution of hydrogen sulphide had ceased, and the resulting solution was filtered and acidified by addition of 2N-hydrochloric acid (50 ml), to give a precipitate of tetrachloropyridine-4-thiol (0·7 g, 57%), m.p. 163—164° (from carbon tetrachloride) (lit.,[4] 164—165°), identical (i.r.) with an authentic sample.

Tetrachloropyridine-4-sulphonyl Chloride N-Oxide.—Aqueous hydrogen peroxide (85%; 15 ml) was added dropwise to a stirred solution of tetrachloropyridine-4-sulphonyl chloride (5·0 g, 16·0 mmol) in a mixtute of acetic acid (25 ml) and concentrated sulphuric acid (50 ml) at 0° and the resulting mixture was stirred for a further 24 h at room temperature. The mixture was then poured on ice (500 g) and the precipitate was filtered off, washed with water, and dried in air. The product was dissolved in acetone and reprecipitated with light petroleum to give *tetrachloropyridine-4-sulphonyl chloride N-oxide* (4·7 g, 90%), m.p. 148—150° (decomp.) (Found: C, 18·4; N, 3·7. $C_5Cl_5NO_3S$ requires C, 18·1; N, 4·2%).

Reactions of Tetrachloropyridine-4-sulphonyl Chloride N-Oxide.—(a) *With dimethylamine.* A mixture of the sulphonyl chloride *N*-oxide (1·0 g, 3·0 mmol), dimethylamine (0·27 g, 6·0 mmol), and acetone (10 ml) was stirred for 5 min at room temperature. The mixture was acidified with 4N-hydrochloric acid, water (50 ml) was added, and the precipitate was filtered off and washed with water to give NN-*dimethyltetrachloropyridine-4-sulphonamide 1-oxide* (0·7 g, 67%), m.p. 231—233° (decomp.) (from acetone–dimethylformamide) (Found: C, 25·1; H, 1·7; N, 8·5%; M^+, 338. $C_7H_6Cl_4N_2O_3S$ requires C, 24·7; H, 1·8; N, 8·2%; *M*, 338).

(b) *Thermolysis.* A solution of the sulphonyl chloride *N*-oxide (0·5 g, 1·5 mmol) in acetic acid (5 ml) was heated under reflux for 20 min. Distillation of the solvent under reduced pressure gave pentachloropyridine *N*-oxide (0·38 g, 95%), identical (m.p. and i.r.) with an authentic sample, and a trace (t.l.c.) of starting material.

Dimethyl 4,6,7-Trichlorothieno[3,2-c]pyridine-2,3-dicarboxylate.—A solution of n-butyl-lithium (24·0 mmol) in hexane (10 ml) was added dropwise to a stirred suspension of tetrachloropyridine-4-thiol (5·0 g, 20·1 mmol) in anhydrous tetrahydrofuran (100 ml) at −70°. Dimethyl acetylenedicarboxylate (3·0 g, 21·1 mmol) was then added slowly at −70°, the resulting mixture was allowed to warm slowly to room temperature, and it was then heated under reflux for 4 h. 4N-Sulphuric acid (50 ml) was added and extraction with chloroform gave a product which was chromatographed on silica gel. Light petroleum–chloroform (1 : 1) eluted tetrachloro-4-methylthiopyridine (1·0 g, 19%),* m.p. 58·5—59° (from ethanol), identical (i.r.) with an authentic sample,[4] and *dimethyl 4,6,7-trichlorothieno[3,2-c]pyridine-2,3-dicarboxylate* (1·7 g, 24%), m.p. 111—112° (from methanol), τ (CCl_4) 6·00 (s, Me) (Found:

* This presumably arises through cleavage of the Me—O bond in the ester by the tetrachloropyridine-4-thiolate anion.

C, 37·4; H, 1·8%; M^+, 353. $C_{11}H_6Cl_3NO_4S$ requires C, 37·25; H, 1·7%; M, 353).

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