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NITROXIDE CHEMISTRY XXII.*

OXIDATION OF N,N-BIS(TRIFLUOROMETHYL)HYDROXYLAMINE

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SUMMARY

A number of cheap oxidising agents have been found to be effective for the conversion of N,N-bis(trifluoromethyl)hydroxylamine into bis(trifluoromethyl)nitroxide. The best of these are cerium(IV) salts either in the solid state or in aqueous acid solution. Efficient, self-indicating processes have been developed using either catalytic amounts of silver(II) picolinate and aqueous potassium persulphate solutions, or electrochemical oxidation with cerium(III) nitrate and sodium nitrate in dilute nitric acid.

INTRODUCTION

One of the most important reactions of N,N-bis(trifluoromethyl)-hydroxylamine is its oxidation to the stable bis(trifluoromethyl)-nitroxide radical [1]. Previous reagents used for this conversion include a solution of $KMnO_4$ in acetic acid at 60 - 70 °C [2,3]; Ag_2O at high temperature [4,5]; fluorine at -70 °C [4]; sodium fluoride at 170 °C for 3 days [5]; electrolysis in KOH solution with Pt electrodes [6]; and an excess of silver(II) oxide at, or below, room

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* For part XXI see B.L.Booth, R.F.Browne, R.N.Haszeldine and J.S.Varley, J.Fluorine Chem., 24 (1984) 485.

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temperature [7]. Very recently bis(polyfluoroalkyl)nitroxides have been prepared from polyfluorodiacyl peroxides by electron transfer reactions with carbanions derived from secondary nitroalkanes [8,9], and by reactions of nitrites with polyfluoroalkyl iodides and sulphonyl bromides [10]. While some of these methods are suitable for small scale preparations they are either too expensive or too slow for large scale application.

We now report a systematic study of various cheap oxidising agents for this reaction and the development of methods suitable for continuous production of the nitroxide radical.

RESULTS AND DISCUSSION

For a variety of reasons, including the fact that $(CF_3)_2NO$ is a highly reactive radical which is insoluble in water, and that $(CF_3)_2NOH$ is unstable in aqueous alkaline solutions [11], the redox potential of the $(CF_3)_2NO/(CF_3)_2NOH$ couple cannot easily be established by conventional methods. In a series of preliminary experiments $(CF_3)_2NOH$ was mixed with cheap, solid oxidants and heated in Pyrex tubes sealed under vacuum. From the results given in Table 1 it can be seen that for oxidation to occur at moderate temperatures a reasonably powerful oxidizing agent is required. Weak oxidising agents, such as CuO, require forcing reaction conditions which lead to appreciable decomposition. The stronger oxidising agents CrO_3, $Ce(SO_4)_2$, PbO_2 and NiO_2 showed promising results, although with NiO_2 the yield of $(CF_3)_2NO$ decreases with increasing reaction time. A control experiment between $(CF_3)_2NO$ and NiO_2 suggests that this may be due to competing reaction of the radical with NiO_2 as at room temperature only 76% of the nitroxide could be recovered after 6 h. The best oxidising agents under these conditions were cerium(IV) sulphate and lead(IV) oxide. We have also examined a variety of cheap oxidising agents suitable for use in aqueous solution at room temperature (Table 2). From these data it appears that the $(CF_3)_2NO$ radical has a similar oxidising power to that of chlorine ($E° = 1{\cdot}36v$), and oxidation of $(CF_3)_2NOH$ does not occur below an E° threshold of 1.38 - 1.40v. The most effective oxidising

TABLE 1

Oxidation of $(CF_3)_2NOH$ using solid oxidants

Oxidant/g	$(CF_3)_2NOH$/g	Time/h	Temp/°C	$(CF_3)_2NO$/%
CuO (10)	0.98	24	146	48
Fe_2O_3(20)	1.21	24	146	-
CrO_3(1)	0.45	19	110	68
PbO_2(4)	0.92	20	128	75
PbO_2(5)	0.94	3	60	24
$Ce(SO_4)_2$(6)	1.04	17	21	71
NiO_2(6)	1.36	3	21	64
NiO_2(6)	0.87	6	21	45

agents were $Ce(SO_4)_2$, PbO_2 and $KBrO_3$ under acidic conditions. A control experiment has established that $(CF_3)_2NO$ is unaffected by 2M H_2SO_4 even after 5 days at room temperature. In our hands the most reliable oxidising agent for $(CF_3)_2NO$ production on a laboratory scale is $Ce(SO_4)_2$ in aqueous 2M sulphuric acid. Reaction is rapid, clean, and virtually quantitative. Also reaction can be followed easily by the colour changes involved.

$$\underset{\text{colourless}}{(CF_3)_2NOH(aq)} + \underset{\text{orange}}{Ce(IV)(aq)} \longrightarrow \underset{\text{purple}}{(CF_3)_2NO(g)} + \underset{\text{colourless}}{Ce(III)(aq)}$$

While HOCl and HOBr have some attractions as cheap oxidising agents, in practice, the rate of oxidation with these reactants is slow and

TABLE 2

Oxidation of $(CF_3)_2NOH$ in aqueous solution.

Oxidant	E°/v[a]	Time/h	Temp/°C	$(CF_3)_2NO$/%
$CuSO_4/H_2SO_4(aq)$	0.158	1	90	0
Br_2/H_2O	0.25	24	21	0
$KBrO_3/H_2O$	0.61	24	21	0
$KBrO_3/OH(aq)$	0.61	24	21	0
$Fe(NO_3)_3/H_2O$	0.77	1	90	0
$NaOCl/H_2O$	0.90	18	21	0
$NaVO_3/H_2SO_4(aq)$	1.0	1	90	0
$HClO_4$	1.19	24	21	0
$HClO_4/2MH_2SO_4$	1.37	24	21	0
$Na_2Cr_2O_4/H_2SO_4$	1.3	1.5	90	0
$Ca(OCl)_2(aq)$		24	21	33
$Ca(OCl)_2/KBr(aq)$		24	21	35
$NaOCl/KBr(aq)$		0.5	21	50
$Br_2(aq)/HgO/H^+$	1.6?	1	21	35
$Br_2(aq)/NaOH$ (pH 8-9)		1	21	66
$Br_2(aq)/Ca(OCl)_2$		0.5	21	50
$NaOCl/KBr(aq)$		0.5	21	50

(continued)

TABLE 2 (cont.)

Oxidant	E°/v	Time/h	Temp/°C	$(CF_3)_2NO$/%
$HOCl(pH_2)$	1.49	1	21	70
Cl_2/H_2O	1.5	29d	21	71
$Ce(SO_4)_2/10\%H_2SO_4$	1.46	2	21	90
$PbO_2/10\%H_2SO_4$	1.46	5	21	90
$KBrO_3/2MH_2SO_4$	1.52	1	21	98
$KBrO_3/2MHNO_3$	1.52	1	21	98
$K_2S_2O_8(aq)$	2.0	4	85	61

[a] 'Handbook of Chemistry and Physics', CRC Press,Cleveland,56th edn, 1976, D141-146.

yields of the nitroxide are variable due to the difficulty of maintaining constant high concentrations of the active agents in solution.

It has been known for many years [7] that silver(II) oxide is an efficient oxidising agent for $(CF_3)_2NOH$, but to achieve high conversion it is necessary to use an excess of the expensive silver salt and the $(CF_3)_2NOH$ must be dry. The use of a silver(II) salt may be a possible alternative to cheaper oxidising agents if it could be used in catalytic quantities, preferably in a cheap solvent such as water. The square planar complex, silver(II) picolinate, is readily prepared by oxidation of a silver(I) salt with an aqueous solution of potassium persulphate [12-14]. Although silver(II) picolinate is insoluble in water and organic solvents, the silver(I) salt is sparingly water soluble and can, therefore, be reoxidised to silver(II) by a suitable oxidising agent, such as potassium persulphate. Thus, an aqueous solution of a catalytic amount of silver(II) picolinate with an excess of potassium persulphate [Ag(II): $S_2O_8{}^{2-}$: $(CF_3)_2NOH$ 1 : 40 : 20] gave an 89% yield of $(CF_3)_2NO$ at room temperature. This compares with a yield of only 8% obtained using silver(II) oxide and potassium persulphate in the same ratio under similar conditions. The silver picolinate oxidation reactions are accompanied by a very useful colour change in which the orange-red colour of the silver(II) salt changes to the white silver(I) salt. Once oxidation is complete the orange-red colour reappears, indicating that the rate of oxidation of $(CF_3)_2NOH$ by silver(II) picolinate is much faster than the rate of oxidation of silver(I) picolinate by persulphate as expected from the respective oxidation potential.

$$(CF_3)_2NOH \rightleftharpoons (CF_3)_2NO + H^+ + e^- \qquad \underline{ca}.\ 1.40v$$

$$Ag^{2+} + e^- \rightleftharpoons Ag^+ \qquad 1.99v$$

$$S_2O_8{}^{2-} + 2e^- \rightleftharpoons 2SO_4{}^{2-} \qquad 2.0v$$

The rate of oxidation can be easily controlled by varying the amount of silver(II) picolinate, and is not only cheaper and more efficient than the previously reported reaction using an excess of silver(II) oxide [7], but, also, does not require the use of anhydrous $(CF_3)_2NOH$. Some attack by $(CF_3)_2NO$ on the picolinate ligand does occur during the oxidation, but this is a very minor side reaction which does not detract from the obvious advantages of this method.

From the results reported in Table 1 and 2 it can be seen that lead(IV) oxide is quite an efficient oxidising agent for $(CF_3)_2NOH$. This led us to consider whether a lead acid accumulator might provide a cheap method of indirect electrochemical oxidation. Consequently the lead cathode and lead(IV) oxide anode of a 6v lead-acid accumulator were connected via a liquid bridge, and freshly-prepared sulphuric acid solution was used as the electrolyte. Whilst the cell was under change (0.3A) an aqueous solution of $(CF_3)_2NOH$ was added to the anode compartment and after 20 h a 90% yield of $(CF_3)_2NO$ was collected. However, the efficiency of the system decreased markedly over a period of time. A much better system is obtained on replacing the lead(IV) oxide anode by a platinum electrode with an electrolyte consisting of sodium nitrate in dilute nitric acid. Addition of cerium(III) nitrate to the anode compartment solution caused development of the purple vapour of $(CF_3)_2NO$, and electrolysis (150-200mA) over 24 h gave the nitroxide in 90% yield. No reaction occurs in the absence of cerium(III) nitrate, and, interestingly, the reaction is self-indicating. When oxidation of the hydroxylamine is proceeding the solution in the anode compartment is colourless, and the $(CF_3)_2NO$ vapour can be removed continuously by low temperature condensation. When all the hydroxylamine has been oxidised the anode solution becomes yellow due to the presence of cerium(IV) ions, and a fresh amount of hydroxylamine can be charged into the anode compartment. Thus, this represents a simple, continuous method for the production of $(CF_3)_2NO$ from $(CF_3)_2NOH$, which can be operated on a large laboratory scale.

EXPERIMENTAL

N,N-Bis(trifluoromethyl)nitroxide was prepared by a previously reported procedure [15]. Nickel peroxide (available oxygen content $0.23(\text{mol } O_2)g^{-1}$ and silver(II) picolinate [13,14] were prepared by literature methods, and all other reagents were commercial samples.

Oxidation with solid oxidants

An excess of pre-dried solid oxidant was loaded into a 70 cm^3 Pyrex tube, which was then evacuated and cooled in liquid nitrogen. A known weight of N,N-bis(trifluoromethyl)hydroxylamine was condensed into the tube which was then sealed, and agitated at a set temperature for the required reaction time. After reaction the volatile products were condensed in a vacuum system and separated by trap-to-trap condensation. The results are given in Table 1.

Oxidation in aqueous solution

The oxidising agent was placed in a three-necked flask (100 cm^3) containing a magnetic follower, and fitted with a cold-finger condenser connected to two external traps cooled to -78 °C. The hydroxylamine was added by means of a syringe through a serum cap with vigorous stirring, and a slow steady stream of nitrogen was maintained to flush the nitroxide into the external traps. The volatile products were separated by trap-to-trap condensation. The results are given in Table 2.

Catalytic oxidation with silver(II) picolinate

When hydroxylamine (1.70g, 10.06 mmol) was added to an orange solution of silver(II) picolinate (0.18g, 0.05 mmol) and aqueous potassium persulphate (5.04g, 20.0 mmol in 7.8 cm^3 water) at room temperature the purple vapour of $(CF_3)_2NO$ formed immediately and the solution became colourless. After 3.5 h the orange colour reappeared after bis(trifluoromethyl)nitroxide (1.51g, 8.99 mmol, 89%) had been collected.

Electrochemical oxidation

The apparatus consisted of two multi-necked, flanged reaction vessels (800 cm^3) connected via a conductance bridge (1cm. diameter). Each flask was fitted with a pressure-equalising dropping funnel, a thermometer, and a magnetic stirrer bar. The anode compartment contained a platinum foil electrode (48 cm^2), and the cathode was a rod of lead (ca. 1cm diameter). The electrodes were connected to a conventional mains-supply power pack unit. In addition the anode compartment was fitted with jacketed coil condenser maintained at 12 °C by pumping cold methylated spirits around it, and the outlet was connected to two external traps cooled at -78 °C.

The cell compartments were filled with an aqueous acid solution of sodium nitrate [1300 cm^3 containing HNO_3 (15g.l^{-1}) and $NaNO_3$(100g l^{-1})], and some of this was drawn by suction to fill the conductivity bridge. An aqueous solution of cerium(III) nitrate (2.57g in 50 cm^3 water) was added to the anode compartment. Then an aqueous solution of $(CF_3)_2NOH$ (11.63g, 68.9 mmol, in 50 cm^3 water) was added dropwise to the anode compartment, and simultaneously 50 cm^3 of aqueous electrolyte solution was added at the same rate to the cathode compartment while maintaining a current of 150-200 mA between the electrodes. After several minutes the purple vapour of $(CF_3)_2NO$ was observed above the anode compartment and the current was maintained until the colourless electrolyte solution in the anode compartment turned yellow (ca. 24 h). Bis(trifluoromethyl)nitroxide (10.29g, 61.2 mmol, 89%) was collected in the external trap.

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