Tetrahedron Vol. 49, No. 32, pp. 7063-7076, 1993
Printed in Great Britain

0040-4020/93 $6 00+.00

Preparation of Nitramine-Nitrates by Ring-Opening Nitration of Aziridines by Dinitrogen Pentoxide (N_2O_5)[1]

Peter GOLDING[2], Ross W MILLAR*, Norman C PAUL and David H RICHARDS†

Defence Research Agency, Fort Halstead, Sevenoaks, Kent TN14 7BP

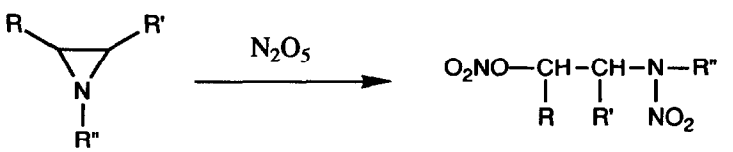
(*Received in UK* 28 *April* 1993; *accepted* 11 *June* 1993)

Abstract: Thirteen aziridines, bearing various types of substituents on the ring nitrogen, were treated with N_2O_5 in chlorinated solvents at sub-ambient temperature and formed 1,2-nitramine-nitrate products by a novel ring-opening nitration reaction analogous to that established for the corresponding oxygen heterocycles (epoxides). A wide variety of classes of aziridine underwent the reaction (N-alkyl, N-(nitroaryl), N-acyl and N-imidyl), the yields in many cases being high (70-82%), although in one category (the N-(alkylcarbonyl)aziridines) competing deacylation reactions resulted in reduced yields. Also, aziridines bearing groups capable of liberating nitric acid with N_2O_5 (i.e. those with O-H, N-H or unsubstituted aryl groups) gave rise to greatly reduced yields of the nitramine-nitrates owing to competing reactions, principally polymerisation/ oligomerisation.

INTRODUCTION

The reactions of epoxides and oxetanes with dinitrogen pentoxide (N_2O_5) in chlorinated hydrocarbon solvents to yield nitrate ester products have already been described[3-5]. Recent studies have been directed towards the extension of such ring-cleavage reactions to include the corresponding 3- and 4-membered nitrogen heterocycles, namely aziridines and azetidines[6], which were expected to yield nitramine products, materials which are of great utility in propellant and explosive technology[7]. In the present paper, the behaviour of aziridines towards N_2O_5 is described, whilst the azetidines are presented separately[8].

The utility of recent synthetic methods for the preparation of nitramines has been assessed[9], and several shortcomings are evident in the methods currently used, either in the laboratory or in processes, *viz* problems with by-product disposal, particularly of acyl nitrates, expense of reagents, and handling of intermediates or by-products which are sometimes highly toxic, eg nitrosamines. We hoped that, by employing strained-ring nitrogen heterocycles, in the present instance aziridines (**I**), as precursors, a ring-opening additive nitration would occur analogously to the reactions with the oxygen heterocycles described earlier, yielding 1,2-nitramine-nitrates (**II**, Eqn. 1). Such compounds have proven of value in the energetic materials field[10].



I **II**

---------- 1

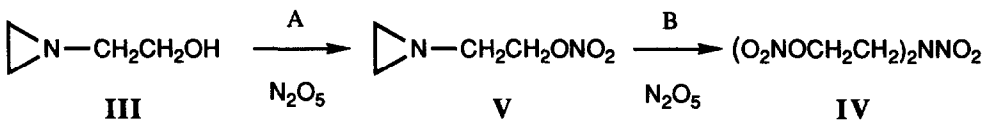
* Author to whom correspondence should be addressed. † Deceased

With the aziridine starting materials, derivatives may be formed by substitution either on the ring carbon atoms or on the nitrogen atom. Substituents of the latter type have been found to affect the course of the reaction in a much more fundamental way than the former; thus, for instance, if the nitrogen substituent (R", Eqn. 1) is hydrogen then no nitramine-nitrate product is isolated and dinitrates are obtained instead[11]. For this reason, the subsequent discussion is subdivided according to the nature of the substituent carried on the aziridine nitrogen, namely alkyl, aryl, acyl and imidyl. Each is now dealt with in turn.

RESULTS AND DISCUSSION

N-Alkylaziridines

Because of its ready availability, the first N-alkylaziridine to be studied was 2-aziridineethanol (**III**). When this compound was treated with N_2O_5 (2.5 mol) in dichloromethane, it gave only a low (<10%) yield of the nitramine-nitrate, N-nitrodiethanolamine dinitrate (DINA, **IV**), Eqn 2 (see Table). The bulk of the starting

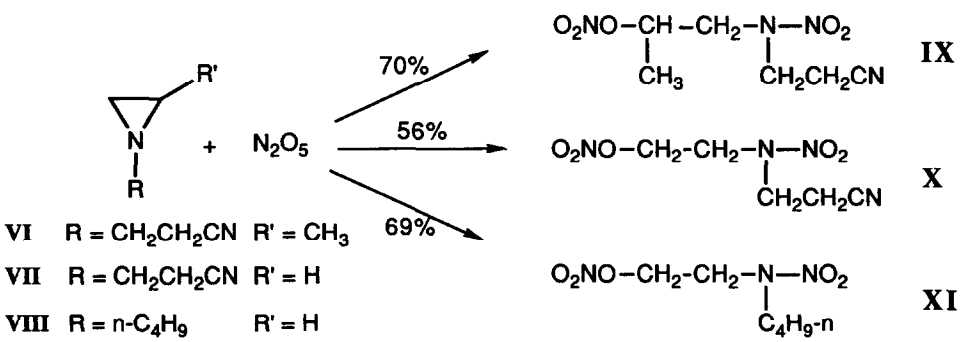


-------- 2

material appeared to have polymerised to an intractable oil, in keeping with the general behaviour of aziridines under acid conditions[12], despite precautions taken to prevent this mode of reaction, i.e. addition of the substrate to N_2O_5 rather than *vice-versa*[3,4] and low temperature of reaction[12]. This starting material was therefore not an ideal candidate for study owing to its bifunctionality, the hydroxyl group complicating the reaction by liberating free nitric acid upon formation of nitrate ester intermediate **V** (Eqn 2, step A). For this reason attention was turned to simple N-alkylaziridines possessing inert substituents.

The reactions of three other N-alkylaziridines (**VI, VII & VIII**) were studied, and these compounds reacted smoothly with N_2O_5 (mol ratio 1.1 to 1.25:1) to give the corresponding nitramine-nitrates in yields of around 70% (see Eqn 3). Compound **VII** gave a somewhat lower yield (56%) of **X** owing to the loss of some material through polymerisation, an intractable oil separating during the reaction.

The products bearing α-cyanoethyl substituents (**IX & X**) were both crystalline solids, while **XI** was an oil. The identity of product **IX** was confirmed by comparison with an authentic sample, prepared by nitration



--------- 3

Table: Reactions of Aziridines with N_2O_5

Entry	Aziridine	Mol N_2O_5: Substrate	Solvent	Temp. °C	Nitramine-Nitrates		Notes
					Compound	Yield (%)	
1	**III**	2.5:1	CH_2Cl_2	-5±5	**IV**	<10	Identified by hplc
2	**VI**	1.25:1	CH_2Cl_2	-10 to -5	**IX**	70	M.pt. 85-86.5°C
3	**VII**	1.1:1	CH_2Cl_2	-5±5	**X**	56	M.pt. 61°C. Polymeric by-product
4	**VIII**	1:1	$CDCl_3$	0±2	**XI**	69	Oil
5	**XII**	1.13:1	$CDCl_3$	0±2	**XIII**	76	Identified by mixed m.pt.
6a	**XVI**	1.1:1	$CDCl_3$	-5 to 0	**XVII**	82	Contained *ca* 10% of acyl nitrate (**XVIII**)
6b	"	1:1	$CDCl_3$	-5 to 0	"	67	Contained <5% of acyl nitrate (**XVIII**)
7	**XIX**	1.3:1	CCl_4	-5 to 0	**XXI**	*ca* 20	Multicomponent mixture
8	**XX**	1.15:1	CH_2Cl_2	0±5	**XXIII**	83	Oil
9	**XXIV**	2.2:1	$CDCl_3$	-10 to -5	**XXV**	50	Unstable: hydrolyses readily
10	**XXVI**	1.3:1	CH_2Cl_2	5 to 10	**XXVIII**	14	Multicomponent mixture
11	**XXVII**	1.3:1	CH_2Cl_2	5 to 10	**XXIX**	<20	ditto
12	**XXXI**	1.28:1	CCl_4	-5 to 0	**XXXIII**	<10	Intractable oil
13	**XXXII**	2.2:1	$CDCl_3$	-5±5	**XXXIV**	few %	Multicomponent gum

of the corresponding amino-alcohol (see Experimental, Section 3). **IX** showed a strong absorbance in the i.r. attributable to nitramine asymmetric stretching [ν_{max} (>N-NO_2)] at 1523 cm^{-1}; strong absorbance at ν_{max} 1636 cm^{-1} and a broad band at 1285-1277 cm^{-1} also indicated the respective asymmetric and symmetric stretching of nitrate ester (-ONO_2). The remaining two compounds exhibited corresponding bands at ν_{max}

1520-1515, 1639-1630 and 1288-1270 cm^{-1}, which correlate well with those of the known nitramine-nitrate DINA (**IV**) (corresponding absorptions 1522, 1637 and 1281 cm^{-1})[13].

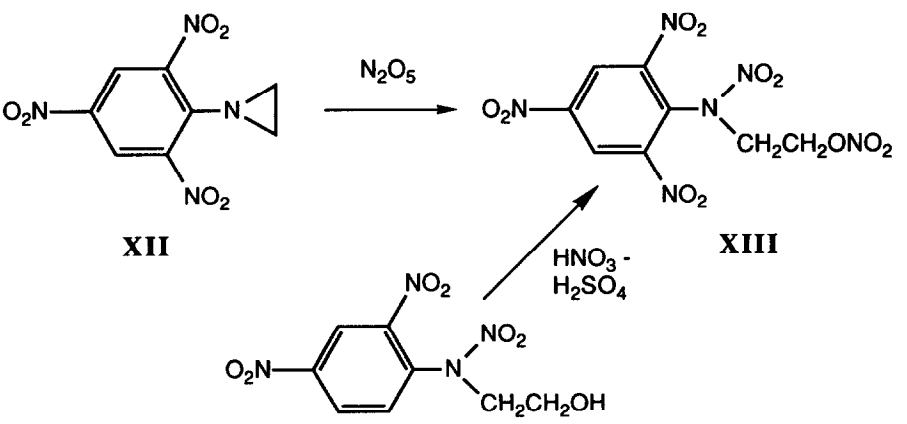
Chemical shifts in the ^1H nmr of **IX** were at the expected positions and the multiplicities were also in agreement with the assigned structure. The methylene protons adjacent to the nitramine function gave signals in the range δ 3.5-4.5 ppm (**X** & **XI**: δ 3.65-4.23, DINA (**IV**) δ 4.15 ppm), whilst the methine proton adjacent to the nitrate ester function resonated at δ 5.40 ppm. The value of this shift confirms that the methyl substituent is on the carbon atom α to the nitrate ester group, i.e. that the product possesses a secondary nitrate ester structure, which is also substantiated by the ^{13}C nmr experiments (see below). The remaining compounds (**X** & **XI**) have primary nitrate ester functions and gave shifts of δ 4.69-4.80 ppm (cf DINA (**IV**) δ 4.80 ppm).

The ^{13}C nmr spectra of the three compounds without methyl substitution (**IV**, **X** & **XI**) showed shifts for the carbon α to the nitrate ester of δ 69.75 ±0.75 ppm. In the compound with an α-methyl group (**IX**) this signal moved downfield by 9.25 ppm to *ca* δ 79.0 ppm. By contrast, the carbons α to the nitramine function were much less affected by methyl substitution, giving signals at δ 51.1 + 0.8 ppm in **IV**, **X** & **XI** and δ 54.9 ppm in **IX**. Other nitramine-nitrates showed similar patterns in their shifts. Finally, **IX** showed a molecular ion at the expected m/z value in the chemical ionisation mass spectrum, and a breakdown pattern consistent with the assigned structure (see ref. 35).

Thus nitramine-nitrates are formed from N-alkylaziridines, in the limited number of cases studied, cleanly and in good to high yield. An exception to this general rule is the difunctional aziridine, 2-aziridineethanol (**III**); here a competing reaction on the hydroxyl group liberates nitric acid which promotes competing polymerisation reactions and little of the simple nitration product, DINA (**IV**), is formed. The extension of this methodology to N-aryl and N-heteroarylaziridines is now considered.

N-Arylaziridines

The nitroaniline derivative **XII**, which is easily prepared from 2,4,6-trinitroanisole[14], gave the tetryl derivative **XIII** (known as "Pentryl"[15,16]) in good (76%) yield, thus demonstrating the applicability of the reaction to N-arylaziridines. The identity of this product was established by comparison with an authentic sample prepared by mixed acid nitration of N-(2'-hydroxyethyl)-2,4-dinitrobenzene (**XIV**; Eqn 4). Although



XII **XIII** **XIV**

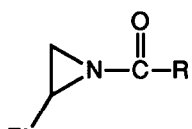
---------- 4

the yield of pentryl and its purity, as assessed by hplc, were acceptable, further improvement may be possible by judicious choice of solvent - the product precipitated from solution in the solvent used ($CDCl_3$).

Hence reactions of an aziridinyl polynitrobenzene give the corresponding nitramine-nitrate in high yield. This result is in line with the behaviour of the s-triazine derivatives, triethylenemelamine and tripropylene-melamine, already described[17], which gave yields of the corresponding nitramine-nitrates of 95 and 78% respectively. Therefore the reduced basicity of aryl aziridines does not appear to affect adversely their susceptibility to electrophilic attack by the N_2O_5 molecule; indeed the yields are significantly higher than those obtained with the more basic N-alkylaziridines, a trend which is continued throughout the acyl series (see below) and which may be explained by the increased propensity of the more basic (alkyl) aziridines to undergo polymerisation reactions, thus reducing the yield of nitramine-nitrate products.

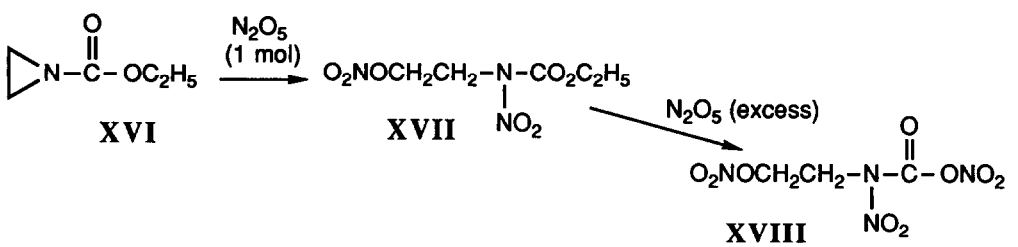
N-Acylaziridines

These compounds, of general structure **XV**, are divided into three broad classes - a) carbamates (R = OR"), b) ureas (R = NR"R"') and c) amides (R = alkyl). These are now considered in turn.



XV

a) Carbamates. One compound of this type was examined, ethyl N,N-(ethylene)carbamate (**XVI**). This reacted smoothly with N_2O_5 (10% molar excess) to give ethyl N-(2-hydroxyethyl)-N-nitrocarbamate nitrate (**XVII**), together with a small amount, detected by ^{13}C nmr and hplc, of the acyl nitrate (**XVIII**) formed by a



XVI **XVII** **XVIII**

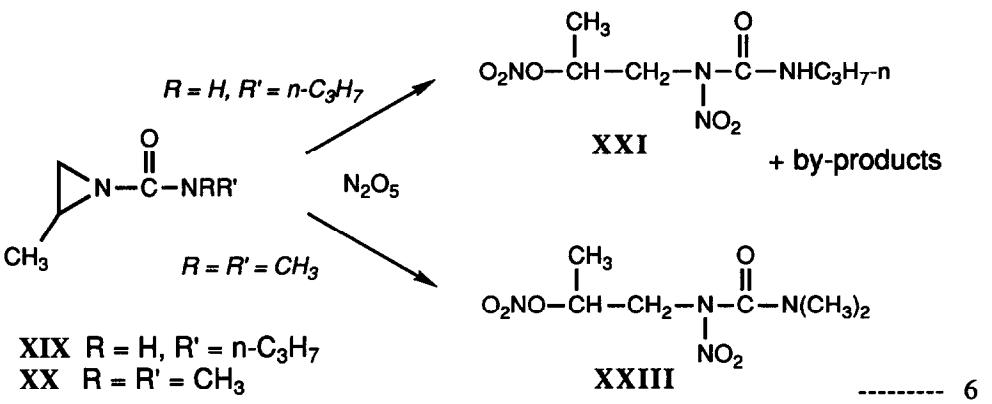
------- 5

trans-esterification reaction[18] with excess N_2O_5 (Eqn 5). Reduction of the N_2O_5 stoichiometry to exactly 1:1 appeared to reduce but not eliminate the proportion of acyl nitrate contaminant. (N.B. The stoichiometric ratio is difficult to measure accurately in practice owing to condensation of atmospheric moisture during weighing.) Although purification of the product, eg by distillation, was not attempted because of the risk of explosion from this labile contaminant, the spectra and hplc indicated high purity and hence, taking the isolated product to comprise entirely **XVII**, the yield was high at 82%. This indicates that the attachment of an electron-withdrawing moiety does not reduce the susceptibility of the aziridine nitrogen atom to electrophilic attack.

The i.r., ^1H and ^{13}C nmr spectra of **XVII** also merit comment. The ν_{max}(>N-NO_2), asymmetric stretching, was observed at 1581 cm^{-1}, which correlates closely with other structurally similar nitramine-nitrates and agrees with the value of 1580 cm^{-1} reported for other nitrocarbamates[19]. In addition, the carbonyl stretching frequencies of 1777 and 1742 cm^{-1} were in good agreement with those at 1770 & 1740 cm^{-1} reported for methyl

N-(isobutyl)nitrocarbamate[19], where the reasons for the observation of two peaks are also explained. The ^1H nmr signals were consistent with the assigned structure, and likewise the ^{13}C nmr shifts correlated closely with those of related compounds, showing a significant upfield shift to δ 46.23 ppm for the carbon α to nitramine.

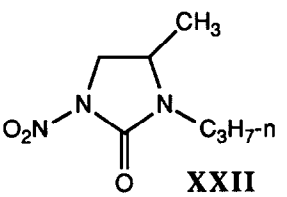
b) Ureas. Three compounds in this class were examined, two monopropyleneureas (**XIX** & **XX**) and a dipropyleneurea (**XXIV**). Compound **XIX**, when reacted with 1.3 mol N_2O_5, gave a complex mixture of products as observed by ^{13}C nmr, although this apparently contained at least some of the nitramine-nitrate (**XXI**; Eqn 6). The reaction is complicated by the presence of the N-H function, which liberates nitric acid



XIX R = H, R' = n-C_3H_7
XX R = R' = CH_3

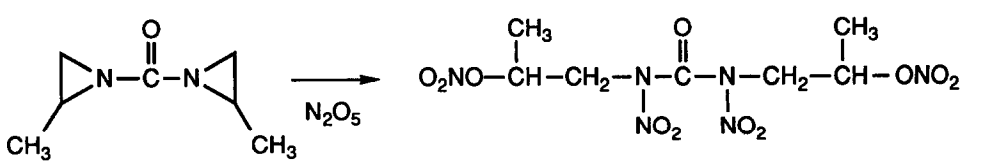
XXI **XXIII** --------- 6

rapidly with concomitant N-nitration in a competing reaction, whilst a further complication arises from the possibility of a ring-closure reaction occurring under acid conditions to form a 2-imidazolidone (**XXII**), behaviour which is characteristic of monoethyleneureas[20]. For all of these reasons the reaction was not studied further, and attention was focussed on **XX** and **XXIV**, which possess no labile hydrogen atoms.



XXII

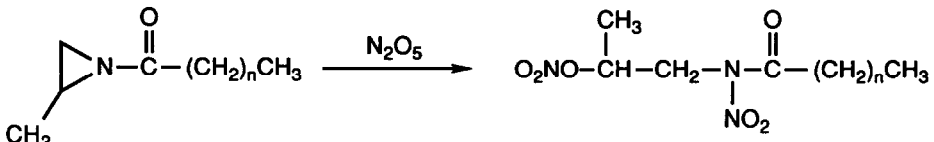
With the N,N-dimethyl derivative (**XX**) and the dipropyleneurea (**XXIV**), the interfering reactions mentioned above were not possible, and reaction took place smoothly to give the nitrourea derivatives **XXIII** and **XXV** (Eqns 6 & 7). The dinitrourea **XXV** was somewhat unstable, both thermally and hydrolytically, and had to be characterised immediately after preparation. The instability of dinitroureas has been noted in the



XXIV **XXV** --------- 7

literature[21-23]. **XXV** and **XXIII** showed nitramine stretching bands at 1600 and 1550 cm^{-1} respectively, in a similar region to that reported[24] for mononitroureas (ν_{max} (>N-NO_2) 1587-1575 cm^{-1}), and correspondingly lowered carbonyl stretching frequencies at 1723 and 1720 cm^{-1} respectively. The ^1H nmr signals were in the expected positions, and the ^{13}C nmr shifts (of **XXV**) were consistent with the assigned structure.

c) Amides. The N-propionyl and N-butyryl derivatives (**XXVI** & **XXVII**) gave only low (typically *ca* 15%) yields of the ring-opened products (**XXVIII** & **XXIX**, Eqn 8). The predominant pathway in these reactions therefore appears to be nitro-deacylation on the ring nitrogen, behaviour typical of aliphatic amines[25].



XXVI n = 1 **XXVII** n = 2 **XXVIII** n = 1 **XXIX** n = 2 + by-products

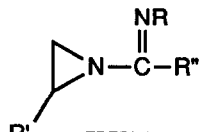
---------- 8

In the case of the aziridines, however, the N-nitroaziridine co-product is unstable and exists only transiently, and hence it is not observed as such in the product mixture. The presence of acyl nitrate species in the product mixture as evinced from i.r. bands at 1777 and 1742 cm^{-1} also supports this assumption, and this deacylative behaviour thus parallels that of the N-acylazetidines[11].

In conclusion, acylnitramines were preparable in good yield by the action of N_2O_5 on aziridinyl compounds and product classes include nitrocarbamates (eg **XVII**) and nitroureas (**XXIII** & **XXV**). However, the nitramides examined, **XXVIII** & **XXIX**, were not formed in adequate yield or purity by the action of N_2O_5 on the corresponding aziridine precursor, and this route is therefore unsuitable for their preparation.

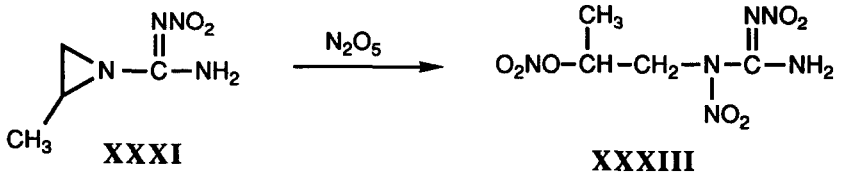
N-Imidylaziridines

These compounds, of general structure **XXX**, were substituted such that R" = a nitrogen function, thus giving ethyleneguanidine derivatives (**XXXI** and **XXXII**) as starting materials. These compounds were of particular interest because their expected products from reaction with N_2O_5 (Eqns 9 and 10) are the dinitroguanidines **XXXIII** and **XXXIV**, a novel class of compounds of which but a few members are known[26-28].



XXX

When compound **XXXI** was treated with N_2O_5 under the standard reaction conditions it reacted completely to give a mixture of products which was insoluble in the reaction medium in agreement with the known insolubility of **XXXIII** in methanol[26] (Eqn 9). The i.r. and ^1H nmr spectra of the viscous, hygroscopic oil which was isolated were complex, although the i.r. spectrum did show two bands at 1577 and 1532 cm^{-1} in the region attributable to nitramine asymmetric stretching, consistent with the formation of some nitramine-nitrate, **XXXIII**. The free amino group in the starting material is believed to complicate the reaction owing to the

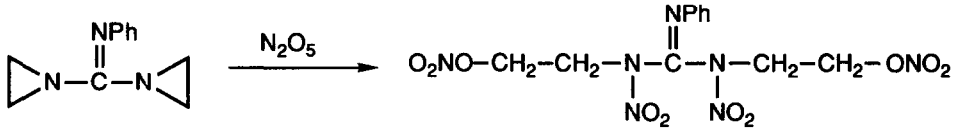


XXXI **XXXIII**

---------- 9

liberation of nitric acid during its nitration, akin to the situation prevailing with the monopropyleneurea (**XIX**, above).

In order to suppress these side-reactions, the diethyleneguanidine **XXXII**, which possesses no N-H groups, was reacted with N_2O_5 (Eqn 10). The product was a viscous red oil which contained, from its hplc,



XXXII **XXXIV**

---------- 10

no fewer than ten components. I.r. and ^{1}H nmr spectral evidence showed the following: (i) aromatic nitration had taken place as shown by i.r. bands at 1524 and 1344 cm^{-1}, and ^{1}H nmr signals downfield from those of the starting material in the aromatic region, and (ii) new peaks had appeared corresponding to the nitrate ester and nitramine asymmetric stretching regions in the i.r. spectrum at 1650 and 1589 cm^{-1} respectively, as well as a symmetric stretching band for these substituents at 1277 cm^{-1}. In the ^{1}H nmr new signals appeared in the midfield region also consistent with the formation of nitramine-nitrates. The fact that this aromatic system readily undergoes ring nitration may be explained by the greatly enhanced electron density on the aromatic ring in the arylguanidine series. This results from the presence of the electron-rich guanidino substituent, and renders the system probably more susceptible to electrophilic attack than aniline; thus it is hardly surprising that aromatic nitration takes place so readily.

Therefore neither of the ethyleneguanidines reacted cleanly with N_2O_5, and although there was spectral evidence, particularly in the i.r., of the formation of α-nitroxyethylnitroguanidines (i.e. nitramine-nitrates), none could be isolated in a pure state. The reactions are complicated by the generation of free nitric acid from side-reactions; hence the employment of alternative starting materials without such labile groups would be advantageous, but unfortunately time did not permit such studies.

Conclusions

N-Substituted aziridines yield the expected nitramine-nitrates in a reaction analogous to that already reported for epoxides[3,4], with yields in the range 70-82% for the majority of the examples studied, except where the aziridines bore reactive substituents such as N-H groups, or strongly deactivating substituents such as N-(alkylcarbonyl) groups. The reaction is general for the aziridines and is, with the above proviso, largely independent of the nature of the substituent on the ring nitrogen, be it alkyl, aryl, heteroaryl, acyl or, to a more limited extent, imidyl. The reaction is, however, affected by the presence of other potentially reactive groups such as N-H, O-H or even unsubstituted aromatic nuclei. The behaviour in this last category is in contrast to

the epoxide reaction[4]; care must therefore be taken when choosing substrates for this novel nitramine-nitrate synthesis to avoid the deleterious effects such groups would introduce.

EXPERIMENTAL

1. Materials and apparatus

All materials were used as received unless otherwise stated. Commercially available aziridines were supplied as follows:- Propyleneimine by Fluka AG ("purum" grade), and 2-aziridineethanol by Aldrich Chem. Co. (reagent grade).

The following aziridines were prepared by literature procedures: ethyleneimine by the method of Wystrach & Schaefer[29], N-(2-cyanoethyl)-2'-methylaziridine (**VI**), N-(2-cyanoethyl)aziridine (**VII**), N-(2,4,6-trinitrophenyl)aziridine (**XII**), ethyl N,N-(ethylene)carbamate (**XVI**), and N,N,N',N'-di-(propylene)urea (**XXIV**) by the method of Bestian[14] (modified in the case of N-(2-cyanoethyl)-2'-methylaziridine (**VI**), b.p. 95-97°C/ 95 mbar); N-(n-butyl)aziridine (**VIII**) by the method of Elderfield & Hageman[30]; N-(n-propyl)-N',N'-(propylene)urea (**XIX**), N-propionyl-2-methylaziridine (**XXVI**) and N-butyryl-2-methylaziridine (**XXVII**) by the method of Stephens[31]; N-nitro-N,N'-(propylene)guanidine (**XXXI**) by the method of Lowe *et al*[32]; N-phenyl-N',N',N'',N''-di-(ethylene)guanidine (**XXXII**) by the method of Dehmlow *et al*[33].

N,N-(Propylene)-N',N'-dimethylurea (**XX**) was prepared as follows: propyleneimine (7.98 g, 0.14 mol) was added dropwise over 15 min. with stirring at 15±2°C (ice bath) to a mixture of N,N-dimethylcarbamyl chloride (15.05 g, 0.14 mol) and N,N,N',N'-tetramethylguanidine (17.71 g, 0.154 mol) in dichloromethane (100 ml). After a further 30 min. stirring at room temperature the mixture was filtered, concentrated under reduced pressure, filtered again and distilled (Kugelrohr) to give N,N-(propylene)-N',N'-dimethylurea (**XX**) (6.6 g, 74%), b.pt. 65-70°C/ 2.5 mm. ^{1}H nmr: δ ($CDCl_3$) 1.30 (d,3); 1.82 (m,1); 2.35 (m,2); 3.05 (d,6) ppm; ν_{max} (film) 1665 (CO) cm^{-1}.

Solvents and the remaining inorganic reagents were all supplied by BDH (reagent grade) with the following exceptions: dichloromethane was hplc grade (BDH); methanol, acetonitrile and water used in hplc separations were Fisons hplc grade (acetonitrile was "Far u.v." grade); 95% ethanol was supplied by Burroughs Ltd; $CDCl_3$ by Aldrich (99.5% isotopic purity); fuming nitric acid (95-98% assay) by BDH Ltd. N_2O_5 was prepared by ozonation of N_2O_4[34] and was storable for short periods at -40 to -80°C. Dichloromethane was dried by passage through a column of chromatographic silica gel (BDH), and $CDCl_3$ was allowed to stand over 4A molecular sieves (BDH) before use. Acetic anhydride was supplied by Fisons plc (reagent grade). All other reagents were used as received.

^{1}H nmr spectra were recorded on a Varian Associates EM 360A nmr spectrometer equipped with an EM 3630 homonuclear lock-decoupler operating at 60 MHz (except where marked thus: # - Varian XL 200 spectrometer operating at 200 MHz). Chemical shifts are reported in ppm downfield from tetramethylsilane (TMS) used as internal standard. ^{13}C nmr spectra were run on a Jeol FX-90Q pulse Fourier transform nmr spectrometer operating at 22.6 MHz under the following conditions: solvent - $CDCl_3$, ^{1}H nuclei wide-band noise decoupled, pulse angle 40°, pulse delay 2 sec. (where marked #, a Varian XL 200 spectrometer was used operating at 50 MHz). Chemical shifts are reported in ppm from the TMS position, calculated using the solvent signal (centre peak) as internal standard (XL 200 shifts are referenced to TMS). Infra-red spectral measurements were carried out using either a Nicolet 5SX Fourier transform i.r. spectrometer operating in transmittance mode and equipped with DTGS detector, or a Perkin-Elmer 157G i.r. spectrometer.

Glc analyses were carried out on a Pye Unicam 204 Series gas chromatograph equipped with a flame-ionisation detector, a temperature programmer and a Spectra-Physics 4100 computing integrator. Samples were run throughout this work on a 2.4 m x 3 mm i.d. glass column packed with 2-3% OV101 on Chromosorb, and conditions were chosen to provide optimum peak sharpness and separation with minimim peak tailing. Hplc separations were performed on a Kontron 600 Series gradient system controlled by a 205 series programmer with monitoring by Uvikon 720 or Pye-Unicam PU4021 u.v. spectrophotometers, operating at 210 nm unless otherwise stated, outputting to either a Uvikon Recorder 20 or a Pye-Unicam 4850 Video Chromatography Control Centre. Columns used measured 22 cm x 5 mm with Lichrosorb 10 RP18, RP8 or nitrile packings (Merck GmbH). All columns were supplied pre-packed by HPLC Technology Ltd, Macclesfield.

Mass spectral measurements were performed on a VG 7070EQ system with quadrupole attachment for examination of daughter ions. Nitrate ester samples, which did not show molecular ion peaks under electron-bombardment conditions (source temp. 210°C, 50 eV electron energy) were therefore studied using the chemical ionisation (CI) mode (inert gas: isobutane). Accurate mass measurements were performed in real time by the data system against perfluorokerosene at 10,000 resolution (10% valley definition).

Elemental analyses were carried out on either Perkin-Elmer 2400 or Carlo Erba 1106 micro elemental analysers at Ministry of Defence (P.E.) DQA/TS Explosive Division, Chorley, Lancs. by Miss S. Jones. Melting points were determined in open capillaries on a Büchi 510 apparatus using a heating rate of 3°C/min. and are uncorrected.

CAUTION: All reactions utilising N_2O_5 were carried out in armoured cupboards.

2. Reactions of aziridines with N_2O_5

General, and Description of Standard Method. Thirteen N-substituted aziridines were submitted to reaction with N_2O_5; six were reacted by the method described below, and in all but one instance (compound **VI**) yielded liquid products. With a further compound (**VII**), the conditions were modified only slightly to give crystalline products and these modifications are described in full later in this section. The remaining six substrates required special reaction conditions and each is described separately below. Details of quantities of reagents and condit-ions employed in this and the following section, where not specifically mentioned, are as indicated in the Table.

The following compounds were treated by the standard method:

a) N-(2-Cyanoethyl)-2'-methylaziridine (**VI**)

b) N-(n-Butyl)aziridine (**VIII**)

c) Ethyl N,N-(ethylene)carbamate (**XVI**)

d) N,N,N',N'-Di(propylene)urea (**XXIV**)

e) N-(n-Propyl)-N',N'-(propylene)urea (**XIX**)

f) N,N-(Propylene)-N',N'-dimethylurea (**XX**)

The substrate (20 mmol) was dissolved in the appropriate solvent (10-15 ml) and added dropwise with stirring and cooling to a solution of N_2O_5 in the same solvent (20-40 ml). After addition was complete (usually 10-15 min.) the mixture was stirred for a further 0.5-1 hr at the temperature of addition. Thereafter the mixture was allowed to warm to room temperature and stirred at this temperature for an additional period of 1-2 hr, or until completion of reaction was indicated (gc, tlc, hplc or ^1H nmr). The reaction mixture was then drowned in ice-water (30-40 ml) and the organic layer separated. The aqueous layer was extracted with dichloromethane

and the combined extracts were washed further with saturated sodium bicarbonate solution, dried over anhydrous $MgSO_4$ and evaporated under water-pump vacuum below 30°C. The product, in the form of an oil [compounds b) - f)] or white solid [compound a)] was then identified by spectroscopy and, in certain cases, examined by gc or hplc to assess its purity.

The products from reactions a) to f) were characterised as follows (yields shown in parentheses):-

a) *N-(2-cyanoethyl)nitraminopropan-2-ol nitrate* (**IX**) (70 %), straw-coloured needles, m.pt. 85-86.5°C; ^1H nmr and i.r. spectra were identical to the material prepared in Section 3 below; ^{13}C nmr: δ($CDCl_3$) 15.88, 16.25, 49.19, 54.88, 79.04, 118.26 ppm; C.I. mass spectrum[35]: m/z $(M+H)^+$ 219.0734 (calculated for $C_6H_{11}N_4O_5$: 219.0729. Found: C, 32.93%; H, 4.60%; N, 25.54% (calculated for $C_6H_{10}N_4O_5$: C, 33.03%; H, 4.62%; N, 25.68%). The m.pt. was not depressed on admixture with an authentic sample (Section 3).

b) *N-(n-Butyl)nitraminoethanol nitrate* (**XI**), (69%), colourless oil; ^1H nmr: δ ($CDCl_3$) 1.0 (d,3); 1.1-1.85 (m,4); 3.65-4.15 (m,4); 4.80 (t,2) ppm; ^{13}C nmr: δ($CDCl_3$) 19.63, 28.35, 48.78, 52.57, 69.98 ppm; ν_{max} (film) 1639, 1515 (NO_2 asymm.); 1288, 1273 (NO_2 symm.) cm^{-1}. C.I. mass spectrum[35]: m/z $(M+2H-NO_2)^+$ 163.015 (calculated for $C_6H_{15}N_2O_3$: 163.018).

c) *Ethyl N-(2-hydroxyethyl)-N-nitrocarbamate nitrate* (**XVII**) (run 1 - 82%, run 2 - 67%), colourless oil; ^1H nmr: δ ($CDCl_3$) 1.37 (t,3); 4.2-4.8 (m,6) ppm; ^{13}C nmr: δ ($CDCl_3$) 13.56, 46.23, 65.13, 68.76, 149.70 ppm; ν_{max} (film) 1777, 1742 (CO); 1642, 1581 (NO_2 asymm.); 1278 (NO_2 symm.) cm^{-1}.

d) *N,N-Bis(2-hydroxypropyl)-N',N'-dinitrourea dinitrate* (**XXV**) (50%), pale yellow oil; ^1H nmr: δ ($CDCl_3$) 1.48 (d,6); 4.42 (m,4); 5.45 (m,2) ppm; ^{13}C nmr: δ($CDCl_3$) 16.00, 51.16, 76.73, 147.75 ppm; ν_{max} (film) 1723 (CO); 1639, 1600 (NO_2 asymm.); 1288, 1277 (NO_2 symm.) cm^{-1}.

e) *N-(n-Propyl)-N'-(2-hydroxypropyl)-N'-nitrourea nitrate* (**XXI**) (*ca* 20 %), component of product mixture (oil); ^1H nmr: δ (CCl_4) 0.8-1.9 (m,8); 4.0-4.4 (m,4); 5.3 (m,1) ppm; ^{13}C nmr: δ($CDCl_3$) 16.00, 48.02, 77.38 ppm + other unassigned signals; ν_{max} (film) 1719 (CO); 1633, 1594 (NO_2 asymm.); 1283 (NO_2 symm.) cm^{-1}.

f) *N-(2-Hydroxypropyl)-N-nitro-N',N'-dimethylurea nitrate* (**XXIII**) (83%), colourless oil; ^1H nmr: δ ($CDCl_3$) 1.45 (d,3); 3.12 (br.s,6); 4.15 (m,2); 5.4 (m,1) ppm; ν_{max} (film) 1720 (CO); 1635, 1550 (NO_2 asymm.); 1275 (NO_2 symm.) cm^{-1}.

The following compound required additional treatment to facilitate isolation of the nitrated product, having yielded a viscous glass by the standard method: g) N-(2-cyanoethyl)aziridine (**VII**).

It was treated by further solvent removal using acetone to entrain residual dichloromethane: this yielded *N-(2-cyanoethyl)nitraminoethanol nitrate* (**X**, 56%) as a white fused solid, m.pt. 61°C, which upon being broken up, was used to seed further batches of the glassy product. ^1H nmr: δ ($CDCl_3$) 2.85 (t,2); 4.12 (m,4); 4.69 (t,2) ppm; δ (D_6-acetone) 2.90 (t,2); 4.23 (m,4); 4.85 (t,2) ppm; ^{13}C nmr: δ($CDCl_3$) 16.09, 49.19, 50.20, 70.50, 118.32 ppm; ν_{max} (mull) 2249 (CN); 1632, 1519 (NO_2 asymm.); 1277, 1270 (NO_2 symm.) cm^{-1}. Found: C, 29.21%; H, 3.69%; N, 27.18% (calculated for $C_5H_8N_4O_5$: C, 29.42%; H, 3.95%; N, 27.45%).

Other Methods. The following compounds were reacted with N_2O_5 under the standard conditions, but j) and k) yielded products which were insoluble in the reaction medium, and m), n), p) and q) yielded multicomponent products:

j) N-(2,4,6-Trinitrophenyl)aziridine (**XII**)

k) N-Nitro-N',N'-(propylene)guanidine (**XXXI**)

m) 2-Aziridineethanol (**III**)

n) N-Phenyl-N',N',N'',N''-diethyleneguanidine (**XXXII**)

p) N-Propionyl-2-methylaziridine (**XXVI**)

q) N-Butyryl-2-methylaziridine (**XXVII**)

These were treated as follows:

j) The product precipitated immediately as a yellow oil which crystallised after *ca* 30 min. The supernatant liquid was decanted and the *N-(2,4,6-trinitrophenyl)-nitraminoethanol nitrate* (**XIII**, 76%) was collected on a filter paper and washed with water. M.pt. was 114-119°C (lit.[16] 126°C) which was not depressed on admixture with an authentic sample. ^{1}H nmr: δ (D_6-acetone) 4.59 (m,2); 4.90 (m,2); 9.42 (s,2) ppm; ν_{max} (mull) 1639, 1572 (NO_2 asymm., nitrate ester/ nitramine); 1547 (NO_2 asymm., arom. nitro); 1340 (NO_2 symm., arom. nitro); 1288, 1277 (NO_2 symm., nitrate ester/ nitramine) cm^{-1}.

k) The product separated as a viscous oil. Decantation of the solvent (in which no solute remained) furnished *N-(2-hydroxyethyl)-N,N'-dinitroguanidine nitrate* (**XXXIII**) as a hygroscopic solid (<10%) which was immediately characterised spectroscopically. ^{1}H nmr: δ ($CDCl_3$) 1.5 (d,3); 4.45 (m,2); 5.50 (m,1) ppm; ν_{max} (film) 1632, 1577, 1532 (NO_2 asymm.); 1288, 1277 (NO_2 symm.) cm^{-1}.

m) The product separated as a pale yellow oil which was pipetted out of the reaction vessel and examined by hplc (conditions: RP18 column, acetonitrile-water 45:55 eluant, flow rate 4 ml/min, λ 210 nm). The product contained a small amount (probably < 10%) of *N-nitrodiethanolamine dinitrate* (DINA, **IV**), identified by comparison (hplc, ^{1}H & ^{13}C nmr and i.r. spectra) with an authentic sample. ^{1}H nmr: δ ($CDCl_3$) 4.15 (t,4); 4.80 (t,4) ppm; ^{13}C nmr: δ($CDCl_3$) 50.39, 70.54 ppm; ν_{max} (mull) 1638, 1523 (NO_2 asymm.); 1283 (NO_2 symm.) cm^{-1} [lit.[10a] 1637, 1522, 1281 cm^{-1}].

n) The reaction solution, which was yellow, was treated in the usual manner to yield a viscous red oil after evaporation. Examination of this oil by hplc (conditions: RP8 column, acetonitrile-water 1:1 eluant, flow rate 3 ml/min, λ 270 nm) showed that it contained sixteen components. Detailed identification was not attempted, although spectra suggested that the mixture contained a small amount (<5%) of the desired product, *N,N'-bis-(2-hydroxyethyl)-N,N'-dinitro-N''-phenylguanidine dinitrate* (**XXXIV**), together with derivatives nitrated on the aromatic ring: ^{1}H nmr: δ ($CDCl_3$) 3.8-4.9 (m,8); 7.2-8.4 (m,4) ppm; ν_{max} ($CDCl_3$ solution) 1650, 1589 (NO_2 asymm., nitrate ester/ nitramine); 1524 (NO_2 asymm., arom. nitro); 1344 (NO_2 symm., arom. nitro); 1277 (NO_2 symm., nitrate ester/ nitramine) cm^{-1}.

p) A near colourless oil was isolated which showed complex ^{1}H nmr and i.r. spectra; examination of this oil by hplc (RP18 column, acetonitrile-water 3:2, λ 210 nm) showed several components, one of which corresponded to the nitramine-nitrate (**XXVIII**). Quantitative hplc analysis using di-(n-propyl) phthalate as an internal standard indicated that the oil contained 24% by weight of *N-(2-hydroxypropyl)-N-nitropropionamide nitrate* (**XXVIII**), and the yield was thus 14%.

q) Similar to p) above, a near colourless oil was isolated which from its ^{1}H nmr and i.r. spectra contained some (<20%) *N-(2-hydroxypropyl)-N-nitrobutyramide nitrate* (**XXIX**), together with unidentified co-products.

3. Preparation of authentic nitramine-nitrates

N-(2,4,6-Trinitrophenyl)nitraminoethanol nitrate (**XIII**, Pentryl) was prepared by the method of Clark[16] [m.pt. 114-116°C dec. (from benzene) (lit.[16] 128°C); found: C, 26.69%; H, 1.48%; N, 23.11% (calculated for $C_8H_6N_6O_{11}$: C, 26.53%; H, 1.67%; N, 23.20%)]. N-Nitrodiethanolamine dinitrate (**IV**, DINA) was prepared by the method of Wright *et al*[10a] but was utilised as crude product (m.pt. 38-41°C; lit.[10a] 51-52°C) owing to stability problems encountered during attempted purification.

N-(2-Cyanoethyl)aminopropan-2-ol[36] was nitrated to the nitramine-nitrate (IX) by N_2O_5 using the following procedure: the aminoalcohol, as a finely powdered solid (1.28 g, 10 mmol), was added slowly with stirring at -10°C (cardice-acetone bath) to a solution of N_2O_5 (3.5 g, *ca* 30 mmol) in the same solvent (12 ml). After an initial exotherm (temperature kept <-5°C), the resulting suspension was stirred at 0±5°C for 2 hr (solid still present) then kept at 4°C overnight. The resulting clear solution was worked up as described above to give, after evaporation, a brown sticky solid which was triturated with ethanol to give white crystals of *N-(2-cyanoethyl)nitraminopropan-2-ol nitrate* (IX, 0.67 g, 31%), m.pt. 81-83°C. ^{1}H nmr: δ ($CDCl_3$) 1.35 (d,3); 2.75 (t,2); 3.5-4.5 (m,4); 5.40 (m,1) ppm; δ (D_6-acetone) 1.40 (d,3); 2.90 (t,2); 4.2 (m,4); 5.5 (m,1) ppm; ν_{max} (mull) 2250 (CN); 1636, 1523 (NO_2 asymm.); 1285, 1277 (NO_2 symm.) cm^{-1}.

N-(2-Hydroxypropyl)propionamide[37] was nitrated to the nitramine-nitrate (XXVIII) in a manner similar to that described above except that the reaction mixture was kept at 4°C for 2.5 days. Workup in the usual manner gave *N-(2-hydroxypropyl)-N-nitropropionamide nitrate* (XXVIII) as a colourless oil (77%), ^{1}H nmr: δ ($CDCl_3$) 1.23 (t,3); 1.40 (d,3); 3.02 (qr,2); 4.60 (m,2); 5.45 (m,1) ppm; ν_{max} (film) 1727 (CO); 1640, 1577 (NO_2 asymm.); 1288, 1273 (NO_2 symm.) cm^{-1}.

Ethyl N-(2-hydroxyethyl)carbamate[38] was nitrated to the nitrocarbamate-nitrate (XVII) using acetyl nitrate as follows: Acetyl nitrate solution was prepared[39] by dropwise addition of fuming nitric acid (0.55 ml, 11.25 mmol) with vigorous stirring at a temperature not exceeding 12°C (but >5°C) to acetic anhydride (3 ml). The resulting solution was kept at 12 to 15°C for 10 min., then the carbamate, as a neat liquid (0.46 g, 3.5 mmol), was added dropwise over 1 min. with rapid stirring to the acetyl nitrate solution at 20±5°C (cardice-acetone cooling), and stirring was continued at 15 to 20°C for a further 20 min. The mixture was then poured into water (10 ml) and stirred for 1 hour at room temperature. The pale yellow oil which separated was transferred by pipette to a separating funnel containing ether (10 ml) and the ethereal solution was washed with saturated $NaHCO_3$ solution, dried over $MgSO_4$ and evaporated to yield *ethyl N-(2-hydroxyethyl)-N-nitrocarbamate nitrate* (XVII) as a pale yellow oil (0.475 g, 60%). ^{1}H nmr#: δ ($CDCl_3$) 1.385 (t,3; J = 7.2 Hz); 4.396 (q,4; J = 7.2 Hz); 4.485 (t,3; J = 4.9 Hz); 4.742 (t,3; J = 4.9 Hz) ppm; ^{13}C nmr#: δ($CDCl_3$) 13.92, 46.38, 65.44, 68.75, 149.96 ppm; ν_{max} (film) 1775, 1745 (CO); 1640, 1580 (NO_2 asymm.); 1280 (NO_2 symm.).

Acknowledgements

The authors wish to thank Dr A. V. Cunliffe and Mr R. Morrell for assistance with nmr spectroscopy, Mr J. A. Rowley for mass spectral measurements, Miss S. Jones (DQA/TS Chorley) for performing elemental analyses, and the following for assisting in the synthesis of precursor compounds: Mr I. Bird and Mr I. Brown. One of us (R. W. M.) also thanks Prof. J. H. Ridd and the authorities of University College London for the provision of laboratory facilities and the use of the Varian XL-200 nmr spectrometer.

REFERENCES AND NOTES

1. Part 8 of "Nitration by Oxides of Nitrogen"; Part 7: see preceding paper: Golding, P.; Millar, R. W.; Paul, N. C.; Richards, D. H., "Preparation of Di- and Polynitrates by Ring-opening Nitration of Oxetanes by Dinitrogen Pentoxide (N_2O_5)".
2. Present address: Ministry of Defence, A.W.E., Aldermaston, Berks RG7 4PR.
3. Golding, P.; Millar, R. W.; Paul, N. C.; Richards, D. H., *Tetrahed. Letts* **1988**, *29*(22), 2731-2734.
4. Golding, P.; Millar, R. W.; Paul, N. C.; Richards, D. H., "Preparation of Di- & Polynitrates by Ring-opening Nitration of Epoxides by Dinitrogen Pentoxide (N_2O_5)", *Tetrahedron* in press.
5. Golding, P.; Millar, R. W.; Paul, N. C.; Richards, D. H., "Preparation of Di- & Polynitrates by Ring-opening Nitration of Oxetanes by Dinitrogen Pentoxide (N_2O_5)", *Tetrahedron* in press.

6. Golding, P.; Millar, R. W.; Paul, N. C.; Richards, D. H., *Tetrahed. Letts* **1988**, *29*(22), 2735-2736.
7. a) Urbanski, T., *Chemistry and Technology of Explosives*, *3*, Pergamon Press, Oxford (1965); b) *ibid*, *4* Chapter 13 (1984); c) Grayson, M. (Ed.) *Kirk-Othmer Encyclopedia of Chemical Technology*, 3rd Edition, *9*, pp 581-587, Wiley-Interscience, New York, 1980.
8. Golding, P.; Millar, R. W.; Paul, N. C.; Richards, D. H., "Preparation of Nitramine-Nitrates by Ring-opening Nitration of Azetidines by Dinitrogen Pentoxide (N_2O_5)", *Tetrahedron*, paper in preparation.
9. See ref. 6 and references contained therein.
10. a) Chute, W. J.; Herring, K. G.; Toombs, L. E.; Wright, G. F., *Canad. J Res.* B **1948**, *26B*, 89-103; b) Stuart, R. S.; Wright, G. F.; *Canad. J Res.* **1948**, *26B*, 401-414.
11. Golding, P.; Millar, R. W.; Paul, N. C.; Richards, D. H., *Tetrahed. Letts* **1991**, *32*(37), 4985-4988.
12. Dermer, O. C.; Ham, G. E., *Ethyleneimine and Other Aziridines* (Academic Press, 1969) Ch. 4.
13. Pouchert, C. J. *Aldrich Library of Infra-red Spectra* 2nd Edition (Aldrich Chemical Co. Inc., Milwaukee, Wis., USA, 1975).
14. Bestian, H., *Liebig's Annalen* **1950**, *566*, 210-244.
15. See reference 7 a), p 70.
16. Clark, L. V., *Ind. Eng. Chem.* **1933**, *25*, 1385-1390.
17. Millar, R. W.; Paul, N. C.; Richards, D. H.; Bunyan, P.; Golding, P.; Rowley, J. A., *Prop. Explos. Pyrotech.* **1993**, *18*, 55-61; also Millar, R. W.; Colclough, M. E.; Golding, P.; Honey, P. J.; Paul, N. C.; Sanderson, A. J.; Stewart, M. J., *Phil. Trans. Roy. Soc. London A* **1992** *339* 305-319.
18. Golding, P.; Millar, R. W.; Paul, N. C.; Richards, D. H., Unpublished MoD (PE) Report 1986.
19. White, E. H.; Grisley, D. W., *J Am. Chem. Soc.* **1961**, *83*, 1191-1196.
20. Najer, H., Giudicelli, R.; Menin, J.; Morel, C., *Compt. Rend.* **1961**, 2369-2371.
21. Lamberton, A. H., *Chem. Soc. Quart. Rev.* **1951**, *5*, 75-98.
22. a) Denton, I. N.; Lamberton, A. H., *J Chem. Soc.* **1953**, 1998-2005; b) *ibid* **1955**, 1655-1657.
23. Boileau, J.; Emeury, J. M.; Longueville, Y.; Monteagudo, P., *Proc. Internat. Jahrestag. (I.C.T.)* 1-3 July 1981, pp 505-526 (Fraunhofer Institut für Treib- und Explosivstoffen, Karlsruhe, FRG, 1981).
24. Bellamy, L. J., *The Infra-Red Spectra of Complex Molecules, Vol 1* 3rd Edition p337-8 (Chapman and Hall, 1975).
25. a) Smith, P. A. S., *Open-chain Nitrogen Compounds*, Vol. 2, Ch. 15 (Benjamin, New York 1966); b) Gilbert, E. E.; Leccacorvi, J. R.; Warman, M., "The preparation of RDX from 1,3,5-triacylhexahydro-s-triazines" in *Industrial and Laboratory Nitrations* (Albright, L. F.; Hansson, C., Eds.), *A.C.S. Symp. Ser. no. 22*, Ch. 23 (American Chemical Society, Washington DC, 1975).
26. McKay, A. F.; Milks, J. E., *J Am. Chem. Soc.* **1950**, *72*, 1616-1620
27. Hall, R. H.; McKay, A. F.; Wright, G. F., *J Am. Chem. Soc.* **1951**, *73*, 2205-2208
28. Yongzhong, Y.; Zhuang, S.; Baoru, D.; Fubo, C., *Prop. Explos. Pyrotech.* **1989**, *14*(4), 150-152.
29. Wystrach, V. P.; Kaiser, D. W.; Schaefer, F. C., *J Am. Chem. Soc.* **1955**, *77*, 5915-5918; Wystrach, V. P.; Schaefer, F. C., *J Am. Chem. Soc.* **1956**, *78*, 1263.
30. Elderfield, R. C.; Hageman, H. A., *J Org. Chem.* **1949**, *14*, 605-637.
31. Stephens, W. D.; Moffett, L. R.; Vaughan, H. W.; Hill, W. E.; Brown, S. P., *J Chem. Eng. Data* **1963**, *8*, 625-6.
32. Lowe, J. U.; Oda, T. A.; Evans, R., *J Org. Chem.* **1963**, *28*, 1496-1498.
33. Dehmlow, E. V.; Westendorf, H-J., *Z Naturf. B* **1970**, *25*, 1191.
34. Harris, A. D.; Trebellas, J. C.; Jonassen, H. B., *Inorg. Synth.* **1967**, *9*, 83-88.
35. Rowley, J. A., *Org. Mass Spect.* **1989**, *24*, 997-1000.
36. Bell, J. A.; Kenworthy, C., *Synthesis* **1971**, 650-652.
37. Prepared from isopropanolamine (2 mol) and propionyl chloride: Sandler, S. R.; Karo, W., *Organic Functional Group Preparations*, *1*, Ch. 11, Academic Press, 1968; b.pt. (GKR) 170-185°C/ 1.5 mm; ^{1}H nmr: δ ($CDCl_3$) 1.10 (t,3); 1.12 (d,3); 2.27 (q,2); 3.2 (m,2); 3.85 (m,1); 4.85 (s,1); 7.05 (br.s,1) ppm; ν_{max} (film) 3303 (NH/OH); 1650 (CO) cm^{-1}.
38. a) Najer, H.; Chabrier, P.; Giudicelli, R., *Compt. Rend.* **1959**, 611-614. For ^{1}H nmr see: b) Soignet, D. M.; Boudreaux, G. J.; Berni, R. J.; Benerito, R. R., *Appl. Spectrosc.* **1974**, *28*(4), 350-353.
39. Curry, H. M.; Mason, J. P., *J Am. Chem. Soc.* **1951**, *73*, 5043-5046.