AFOSR-TR- 87-1596

AD-A187 518

NEW NITRATION CONCEPTS

DTIC FILE COPY
DTIC
ELECTE
NOV 18 1987
S D

September 1987

Final Report

By: Robert J. Schmitt and Jeffrey C. Bottaro

Prepared for:

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
Directorate of Chemical Sciences
Building 410
Bolling Air Force Base
Washington, DC 20332-6448

Contract No. F49620-86-K-0011

SRI Project PYU-2099

Approved for public release; distribution unlimited.

The findings in this report are not to be construed as an official Department of the Air Force position unless so designated by other authorized documents.

SRI International
333 Ravenswood Avenue
Menlo Park, California 94025-3493
(415) 326-6200
TWX: 910-373-2046
Telex: 334486

Approved for public release,
distribution unlimited

87 10 23

AD-A187 518

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: Unclassified	1b. RESTRICTIVE MARKINGS: N/A
2a. SECURITY CLASSIFICATION AUTHORITY: N/A	3 DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE: N/A	
4 PERFORMING ORGANIZATION REPORT NUMBER(S): SRI Project PYU-2099	5. MONITORING ORGANIZATION REPORT NUMBER(S): AFOSR-TR- 87-1598
6a. NAME OF PERFORMING ORGANIZATION: SRI International; 6b. OFFICE SYMBOL (If applicable):	7a. NAME OF MONITORING ORGANIZATION: AFOSR/NC
6c. ADDRESS (City, State, and ZIP Code): 333 Ravenswood Avenue, Menlo Park, CA 94025	7b. ADDRESS (City, State, and ZIP Code): Bldg 410 Bolling AFB DC 20332-6448
8a. NAME OF FUNDING/SPONSORING ORGANIZATION: Office of Scientific Res.; 8b OFFICE SYMBOL (If applicable): NC	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: ~~Contract~~ No. F49620-86-K-0011
8c. ADDRESS (City, State, and ZIP Code): Directorate of Chemical Sciences, Bolling Air Force Base, Washington, DC 20332	10 SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO. 61102F; PROJECT NO 2303; TASK NO B2; WORK UNIT ACCESSION NO

11 TITLE (Include Security Classification): New Nitration Concepts

12. PERSONAL AUTHOR(S): Robert J. Schmitt and Jeffrey C. Bottaro

13a TYPE OF REPORT	13b. TIME COVERED	14 DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM 860501 TO 870930	870930	17

16. SUPPLEMENTARY NOTATION

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Chemistry, synthesis, polynitro compounds, nitroacetylenes, nitramines, nitroolefins
19	01		
07	03		

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

The objective of the current study was to explore the reaction of nitroacetylenes and to synthesize trinitroethyl and fluorodinitroethyl derivatives of heteroaryl aromatics. Below we summarize the results of these research areas:

(1) Reactions of Nitroacetylenes. We have successfully prepared the two new cycloadducts from the reaction of a nitroacetylene with diazomethane and trimethylsilylazide: 4-nitro-5-(trimethylsilyl)triazole and 3-nitro-4-(trimethylsilyl) pyrazole.

(2) Synthesis of Polynitroheteroaromatic Explosives. We have synthesized a new class of polynitroheteroaromatic explosives designed to meet Air Force mission requirements. These include N,N'-bis(trinitroethyl)-1,4-diaminotetrazene, N,N'-bis(fluorodinitroethyl)-1,4-diaminotetrazene as well as the fluorodinitro and trinitroethyl esters of 2,3-pyrazine-dicarboxylic acid, 3,4-pyridinedicarboxylic acid, and 3,5-pyridine dicarboxylic acid.

20 DISTRIBUTION/AVAILABILITY OF ABSTRACT	21 ABSTRACT SECURITY CLASSIFICATION
☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	unclassified
22a NAME OF RESPONSIBLE INDIVIDUAL: Anthony Matuszko	22b. TELEPHONE (Include Area Code): (202) 767-4963; 22c. OFFICE SYMBOL: NC

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

CONTENTS

Accesion For
NTIS CRA&I ☑
DTIC TAB ☐
Unannounced ☐
Justification
By
Distribution/
Availability Codes
Dist | Avail and/or Special
A-1

DTIC COPY INSPECTED 6

COMPLETED PROJECT SUMMARY

TITLE: New Nitration Concepts

PRINCIPAL INVESTIGATORS: Dr. Robert J. Schmitt and Dr. Jeffrey C. Bottaro
SRI International
333 Ravenswood Avenue
Menlo Park, CA 94025

INCLUSIVE DATES: May 1, 1986, to September 30, 1987

CONTRACT NUMBER: F49620-86-K-0011

COSTS AND FY SOURCE: $108,599 FY86

SENIOR RESEARCH PERSONNEL: Dr. Ripudaman Malhotra
Dr. Clifford D. Bedford

PUBLICATIONS:

"Nitroacetylenes: Synthesis of 1-Nitro-2-Trialkylsilyl-Acetylenes via Nitrodesilylation of Bis-Silylacetylenes," Robert J. Schmitt, Jeffrey C. Bottaro, and Clifford D. Bedford, J. Org. Chem., 1987, 52, 2294.

"Nonacidic Nitration of Secondary Amines," Jeffrey C. Bottaro, Robert J. Schmitt, and Clifford D. Bedford, J. Org. Chem., 1987, 52, 2292.

PRESENTATIONS:

"New Polynitroheteroaromatic Explosive," Robert J. Schmitt and Jeffrey C. Bottaro. Presented at the Working Group Meeting on Synthesis of High Energy Dense Materials, ARDEC, Concord Hotel, NY, 1987.

"New Polynitroheteroaromatic Explosive," Robert J. Schmitt and Jeffrey C. Bottaro, Presented at the Office of Naval Research meeting on Explosives Synthesis, Great Oak Landing, Chestertown, Maryland, 1987.

"Development of Nitration Synthesis Methodologies: Nonacidic Amine Nitration and Nitroacetylene Synthesis", Clifford D. Bedford, Jeffrey C. Bottaro, and Robert J. Schmitt, ADPDA Meeting, Queen Mary, Long Beach, CA, October 27-29, 1986.

ABSTRACT OF OBJECTIVES AND ACCOMPLISHMENTS

Our high-density, high-energy explosives program, funded by AFOSR, focused on two major areas, all of which involve energetic heterocycles. The first type of materials we explored were the cycloadducts of nitroacetylenes, of which the azide adduct is the most promising. To date, we have achieved the cycloaddition of trimethylsilyl azide to trimethylsilyl nitroacetylene, giving 4-nitro-5-(trimethylsilyl) triazole. Preliminary attempts to nitrodesilylate this material to give 4,5-dinitrotriazole have not yet met with success. We have attempted to substitute nitroso for silicon by reaction of the silylated compound with nitrosonium fluoroborate but time and funding did not permit completion of this study. The cycloaddition reaction of nitroacetylenes with diazomethane gives the 3-nitro-4-(trimethylsilyl)pyrazole, and studies of the reaction of nitrile oxides to give nitrated isoxazoles have been done and will be written up in manuscript form.

The type class of materials we explored were the N-trinitroethyl and N-(fluorodinitroethyl)heteroaryl amines. Thus far, we have been most successful in derivatizing 1,4-diaminotetrazine, giving both the N,N'-bis(trinitroethyl) derivative and the corresponding N,N'-bis (fluorodinitroethyl) compound.

The properties of the tetrazines are of interest; the bis(fluorodinitroethyl)-1,4-diaminotetrazine melts over 220°C and detonates at 240°C. It is also highly colored, inviting the possibility of photo initiation. Preliminary efforts to trinitroethylate or fluorodinitroethylate melamine and guanazole in the same manner as 1,4-diaminotetrazine have not yet been successful.

In all cases, the melting points are moderate (100°-160°C), the densities are well in the range of acceptability (1.7 to 1.8), and the thermal stabilities are excellent (DSC decomposition > 200°C). Six

pyridine and pyrazine dicarboxylic acid ester derivatives have been prepared, with trinitroethanol and fluorodinitroethanol. The attempted syntheses of the corresponding N-oxide was not as successful; only one N-oxide could be prepared and purified successfully.

In conclusion, we have examined two novel types of potential high-energy, high-density explosives, and we have derived useful examples in each category. One compound, N,N'-bis(fluorodinitroethyl)-1,4-diamino-tetrazine, satisfies most, if not all, of the military criteria for a successful explosive.

AFOSR Program Manager: Dr. Anthony Matuszko

INTRODUCTION AND SUMMARY OF RESULTS ON CURRENT PROGRAM

Under AFOSR contract F49620-86-K-0011, we have investigated the synthesis of C-nitro and N-nitro groups in nonpolar, aprotic solvent systems. This work has resulted in the synthesis of a new class of polynitroheterocyclic aromatic explosives, the development of new methods for preparing nitro compounds in nonacid-base solvent systems, and the generaliration of the synthesis of nitroacetylenes. Of immediate interest to the explosives community are the good properties of the polynitroheteroaromatic compounds synthesized under this program.

In summary, the major features of our work include the following:

- Synthesis of several promising polynitroheteroaromatic oxidizers.
- A generalization of our preparative route to nitroacetylenes and a study of the Diels-Alder reactions of nitroacetylenes (see Appendix A).
- New neutral lipophilic "nitrophores," which are reagents capable of delivering nitro groups to selected substrates.

We summarize below the results obtained in our research for AFOSR. Whenever possible, the details are given in the appendices.

Polynitroheterocyclic Aromatic Explosives

We have recently prepared several interesting high energy materials that are based on a heteroaromatic ring system. The advantages of using heteroaromatic rings instead of aromatic rings are that heteroaromatic rings have a higher (more positive) heat of formation[2] and they will generate more gas, in the form of nitrogen, than aromatic ring systems. Additionally, less oxygen is required to completely oxidize the compound because nitrogen replaces carbon or a carbon-hydrogen group. Table 1 summarizes the results obtained with these compounds. The detonation

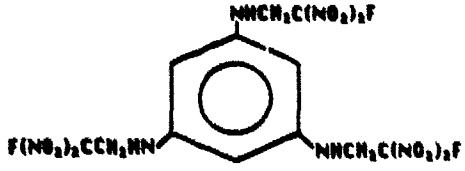
pressures (P_{cj}) and detonation velocity (D_{vel}) were calculated using the KJSM method. Table 2 gives the measured and calculated values of known oxidizers for comparison.

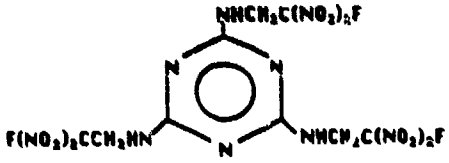
The most interesting compounds that we have prepared are derivatives of the diaminotetrazene. The tetrazene ring is interesting because of the high nitrogen content (four nitrogens and only two carbons). Also, very few tetrazene derivatives are known, and no one has prepared energetic tetrazenes.

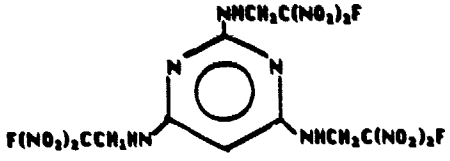
We have prepared two tetrazenes substituted with fluorodinitroethyl (FDNE) or trinitroethyl (TNE) groups at the amines, bis(N,N-fluorodinitroethyl)-1,4-diaminotetrazene (BFDDT) and bis(N,N-trinitroethyl)-1,4-diaminotetrazene (BTDT). We are particularly excited about BFDDT, which is balanced to $CO/HF/H_2O/N_2$ and calculates to have a heat of formation of approximately -13 kcal/mole, a detonation pressure (P_{cj}) of 315 kbar, and a detonation velocity of 8.5 mm/μs. Most important, BFDDT has excellent thermal stability with a melting point of 221°C and a decomposition onset at 232°C (DSC). All qualitative tests done on impact sensitivity indicate that this is a stable material, with either the same or better stability than RDX.

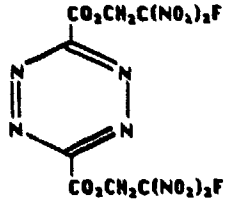
We have also prepared several FDNE and TNE derivatives of pyridine and pyrazine, as well as a TNE derivative of the N-oxide of pyridine (Table 1). The N-oxides were prepared because we believed the N-oxide would increase the oxygen content, the heat of formation, and, most important, the density of the molecule. The oxygen content and heat of formation certainly were increased, but unfortunately, as seen from the table, the density was lowered. Because of this negative result, we did not pursue further the synthesis of any other N-oxides.

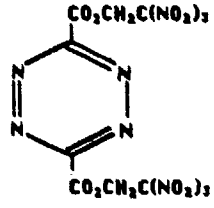
In summary, we have found the preparation of heterocyclic aromatic derivatives to be a viable approach for the synthesis of interesting energetic molecules. The materials prepared thus far all show good thermal properties as well as reasonable densities.

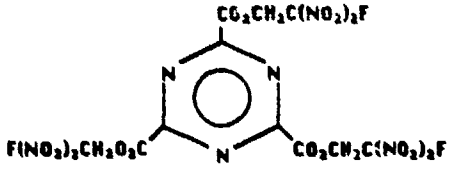












Nitroacetylene Synthesis and Reaccions (Appendix A)

Five nitroacetylenes have been reported previously,[3-7] and all are reported to be thermally unstable. As part of a study to develop new synthesis routes to energetic materials precursors, we developed a general synthesis route to 1-nitro-2-trialkylsilyl acetylenes, 10.[8,9] The synthesis is achieved by treating a bis-substituted trialkylsilylacetylene with a nitronium ion source (i.e., nitronium tetrafluoroborate, nitronium hexafluorophosphate, or nitryl fluoride) and a fluoride source in acetonitrile or nitromethane to give the desired nitroacetylenes in fair to excellent yields, as shown in equation (1).

Table 1

PROPERTIES OF POLYNITRO AROMATIC HETEROCYCLES

Compound	mp (°C)	Density (g/cm^3)	Decomposition Onset (°C)	D_{vel} (mm/μs)	P_{cj} (kbar)	ΔH_f (kcal/mole)
Pyridine-3,5-di(TNE-carbonyl)	135.3	1.8	180	8.3	305.6	-99.1
Pyridine-3,4-di(TNE-carbonyl)	132	1.74	175	8.3	305.6	-99.1
Pyridine-N-oxide-3,4-di(TNE-carbonyl)	106	1.7	180			
Pyrazine-2,3-di(TNE-carbonyl)	142	1.69	180	8.4	314	-85.7
Pyrazine-2,3-di(FDNE-carbonyl)	103	1.7		7.9	280.3	-158.9
N,N'-Bis(FDNE)-1,4-diaminotetrazene	221	>1.73	232	8.5	315	-13
N,N'-Bis(TNE)-a,4-diaminotetrazene	None	1.8	160	8.8	344	+60.2

TNE = $CH_2C(NO_2)_3$
FDNE = $CH_2C(NO_2)_2F$
THF from Ref 2.

Table 2

PROPERTIES OF KNOWN OXIDIZERS

Compound	D_{vel} (mm/μs)	P_{cj} (kbar)	H_{rxn} (kcal/mole)	$H_{f,Prod}$ (kcal/mole)	$H_{f,SM}$ (kcal/mole)	Density (g/cm^3)
Calculated Values for Known Oxidizers						
HMX	9.3	392.0	-354.7	-336.8	17.9	1.9
RDX	8.8	341.0	-267.3	-252.6	14.7	1.8
TNT	7.6	241.6	-228.3	-236.9	-8.6	1.6
Measured Values for Known Oxidizers[a]						
HMX	9.11	387	-354.7	-336.8	17.9	1.9
RDX	7.25	338	-267.3	-252.6	14.7	1.77
TNT	6.93	190	-228.3	-236.9	-8.6	1.64

[a]From Reference 1.

$$R_3Si\text{-}C{\equiv}X\text{-}SiR_3 \xrightarrow[F^-]{NO_2^+} R_3Si\text{-}C{\equiv}C\text{-}NO_2 \qquad (1)$$

CH_3CN/CH_3NO_2

where R = alkyl, $Si(CH_3)_3$, $Si(CH_3)_2(t\text{-}Bu)$, $Si(CH_3)_2(i\text{-}Pr)$, or $Si(i\text{-}Pr)_3$.

The reaction is an improvement over our previously reported synthesis of nitro-trimethylsilyl acetylene[8] by the reaction of nitronium tetrafluoroborate with bis-trimethylsilylacetylene in methylene chloride. The best yields (30%-70%, see Table 3), are obtained when R contains another silyl group, either trimethylsilyl, $Si(CH_3)_2(t\text{-}Bu)$, $Si(CH_3)_2(i\text{-}Pr)$, or $Si(i\text{-}Pr)_3$. Only the trimethylsilyl nitro acetylene was reported previously.

Table 3

NITROACETYLENE YIELDS

Starting Material	Nitronium Salt	Nitroacetylene Product	Yield (%)
$TMS\text{-}C{\equiv}C\text{-}TMS$	NTFB	$TMS\text{-}C{\equiv}C\text{-}NO_2$	70[a]
$TMS\text{-}C{\equiv}C\text{-}SiMe_2iPr$	NHFP	$SiMe_2i\text{-}Pr\text{-}C{\equiv}C\text{-}NO_2$ $TMS\text{-}C{\equiv}C\text{-}NO_2$	34[b] 6[b]
$TMS\text{-}C{\equiv}C\text{-}SiMe_2t\text{-}Bu$	NHFP	$SiMe_2t\text{-}Bu\text{-}C{\equiv}C\text{-}NO_2$ $TMS\text{-}C{\equiv}C\text{-}NO_2$	59[a] 29[a]
$TMS\text{-}C{\equiv}C\text{-}Si(i\text{-}Pr)_3$	NHFP	$Si(i\text{-}Pr)_3\text{-}C{\equiv}C\text{-}NO_2$ $TMS\text{-}C{\equiv}C\text{-}NO_2$	57[a] 0[b]
$TMS\text{-}C{\equiv}C\text{-}CH_3$	NHFP	$CH_3\text{-}C{\equiv}C\text{-}NO_2$	c,d
$TMS\text{-}C{\equiv}C\text{-}(CH_2)_4CH_3$	NHFP	$CH_3(CH_2)_4\text{-}C{\equiv}C\text{-}NO_2$	0
$TMS\text{-}C{\equiv}C\text{-}t\text{-}Bu$	NHFP	$t\text{-}Bu\text{-}C{\equiv}C\text{-}NO_2$	0
$TMS\text{-}C{\equiv}C\text{-}C_6H_5$	NHFP	$C_6H_5\text{-}C{\equiv}C\text{-}NO_2$	0
$TMS\text{-}C{\equiv}C\text{-}(CH_2)_4\text{-}C{\equiv}C\text{-}TMS$	NHFP	$TMS\text{-}C{\equiv}C\text{-}(CH_2)_4\text{-}C{\equiv}C\text{-}NO_2$	0

[a]Isolated yield.
[b]Yield determined from internal standard.
[c]Rapidly decomposes.
[d]Trace yield, observed by GC/MS.

When R is an alkyl group, methyl, butyl, hexyl or t-butyl, the yields are considerably lower. We estimate from qualitative measurements that the nitroacetylenes resulting from these mono-substituted trialkylsilyl acetylenes range from 2%-10% yields. 1-Nitropropyne, 1-nitrohexyne, and 1-nitrooctyne are all new compounds (see Table 3).

Two products can result from the nitrodesilylation of bis-trialkylsilylacetylene substrates: one resulting from replacement of the trimethylsilyl group, the other from replacement of the more sterically crowded trialkylsilyl group. In general, the ease of desilylation, and consequently the relative proportion of the two nitroacetylene products, follow the order observed for the elimination of trialkylsilyl moieties:[10] $Si(CH_3)_3 > Si(CH_3)_2(i\text{-}Pr) > Si(CH_3)_2(t\text{-}Bu) > Si(i\text{-}Pr)_3$. This high degree of regioselectivity (entries 2-4, Table 3) results from the ease of attack by fluoride ion on the trialkylsilyl moiety. The steric crowding encountered in the triisopropylsilyl case resulted in exclusive fluoride-ion-assisted displacement of the trimethylsilyl group. Mixtures of nitroacetylenes were obtained when less bulky silyl substituents were studied.

The yield of the nitroacetylene is considerably enhanced when a bis-trialkylsilylacetylene is used as the acetylene substrate rather than a mono-trialkylsilylacetylene. The higher yields are attributed to the intrinsic properties of the silicon atom. Silicon generally stabilizes beta-carbonium ions better than carbon. Furthermore, silicon enhances alpha-carbonium ion stability due to hyperconjugation and induction. Consequently, any intermediate carbonium ion formed during the reaction of nitronium ion with a bis-trialkylsilyl acetylene is more stable than the corresponding carbonium ion generated from a mixed silyl-alkylacetylene. This extra stabilization in the transition state of the bis-silylated acetylenes significantly improves the yield of the target nitro-trialkylsilylacetylene product.

The nitroacetylenes readily undergo Diels-Alder reactions with cyclopentadiene, cyclohexadiene, and furan. The structure of the products was confirmed by a combination of field ionization mass

spectrometry, proton NMR, infrared spectra, and elemental analysis. We are continuing to explore the chemistry associated with these unique materials.

Nonacidic Amine Nitration (Appendix B)

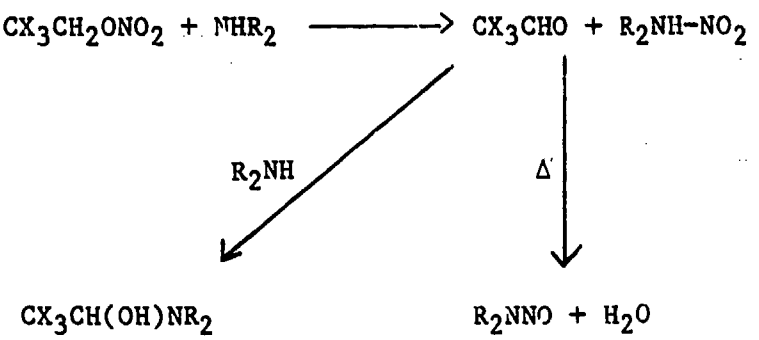
The N-nitration of secondary amines under neutral conditions poses a problem of N-nitrosation as a competing side reaction. When nitrogen dioxide,[11] nitryl chloride, nitrogen pentoxide, nitryl fluoride,[12] nitronium fluoroborate,[13] and tetranitromethane[14] are used in the N-nitration of amines, they all result in substantial yields (> 30%) of nitrosamine side-products, which are extremely toxic and difficult to separate from the target nitramine. The production of nitrosamines is a result of the redox reaction between secondary amines and nitrating agent.

To overcome the problems associated with N-nitrosation, we studied novel covalent nitrating agents. The oxidizing power of the nitrating agent was attenuated by varying the electronegativity of the leaving group. Since ordinary nitrate esters fail to nitrate secondary amines and nitryl fluoride reacts rapidly even at -78°C, we concluded that the viable range of electronegativities for the nitro transfer reaction lay somewhere between alkoxide (the leaving group on a nitrate ester) and fluoride (the leaving group on nitryl fluoride). Thus, we examined a series of electron-deficient nitrate esters as our target category of neutral nitrating agents for secondary amines.

This approach was originally attempted by Emmonds and Freeman,[11] who studied some electron-deficient nitrate esters and found that acetone cyanohydrin nitrate[12,15] does nitrate amines at elevated temperatures. Unfortunately, this reagent releases acetone and hydrogen cyanide, which react with amines to give aminonitriles, rendering this method low-yielding with respect to the amine substrate.

Our initial efforts to overcome this potential problem focused on the use of polyfluoroalkyl nitrates, such as hexafluoroisopropyl nitrate and trifluoroethyl nitrate. These compounds were synthesized by direct

nitration of the corresponding alcohols in fuming nitric/sulfuric acid. Treating these materials with piperidine yielded predominantly elimination products, Scheme I. In the case of trifluoroethyl nitrate, a small amount of nitramine was formed in competition with the elimination products. Only elimination products were detected in the case of hexafluoroisopropyl nitrate, along with small amounts of nitrosation products resulting from the thermal decomposition of the nitrite salt.



Scheme I. Amine-Induced Elimination of Nitrous Acid

The trend established by these nitrate esters prompted us to design alkyl nitrates that were less electron-poor and, if possible, endowed with structural attributes that preclude the elimination reaction shown in Scheme I, which ultimately leads to nitrosation by self-condensation of the resulting nitrite salt. Candidates (13 and 14) for a new generation of nitrate-transfer reagents are shown below. Both these structures preclude the elimination side reaction shown in Scheme I.

$CF_3C(CH_3)_2ONO_2$ $\qquad$ $(ClCH_2)_2C(CH_2ONO_2)_2$

13 $\qquad$ 14

The pentaerythritol nitrate derivate 14 has a high degree of steric hindrance to base attack on the protons alpha to the nitrate ester, and the fluorinated t-butyl nitrate 13 is devoid of such protons entirely.

The new compounds were synthesized by direct nitration of the corresponding protic compound. Thus compound 13, 2-trifluoromethyl-2-propyl nitrate, was synthesized by nitration of 2-trifluoromethyl-2-propanol in nitric acid/trifluoroacetic anhydride. Compound 14, 2,2-bis(chloromethyl)propane-1,3-diol dinitrate, was prepared by hydrolysis and nitration of 3,3-bis(chloromethyl)oxetane in nitric acid/oleum. Compounds 13 and 14 both nitrate secondary amines under mild conditions (room temperature to 55°C) without nitrosation, except in isolated cases. In general, 13 is a more convenient, cleaner, and efficient nitrating agent, which allows for a facile workup. The results obtained with selected amines for both reagents are shown in Table 4.

Table 4

NITRATION OF SECONDARY AMINE WITH NITRATE ESTERS

	2-Trifluoromethyl-2-Propyl Nitrate		2,2-Bis(chloromethyl)propane-1,3-diol Dinitrate	
Amine	Yield of Nitramine (%)	Yield of Nitrosamine (%)	Yield of Nitramine (%)	Yield of Nitrosamine (%)
Piperidine	75	0[a]	65	0
Morpholine	72	0	40	Trace
Pyrrolidine	100	0	86	0
Diethylamine[b]	58	0	17	4
N-Benzylmethyl-amine	75	0	42	6
Dimethylamine	--	--	55	0

[a]As detected by TLC.
[b]Probable loss of product during isolation due to high volatility.

CONCLUSIONS

In conclusion, we have had considerable success in preparing new and interesting polynitro derivatives of aromatic heterocyclic compounds. Several of these materials have excellent mechanical properties and should be considered for use in energetic formulations. We have also found several new reactions for the nitroacetylenes which we had prepared in a previous contract. Finally, we have developed a new group of lipophilic nitrating agents which are useful for the nitration of acid sensitive compounds.

REFERENCES

1. B. M. Dobratz and P. C. Crawford, LLNL Explosives Handbook: Properties of Chemical Explosives and Explosive Simulants, UCRL-52997 Change 2 (January 31, 1985).

2. S. Benson, Thermochemical Kinetics, 2nd Edition (John Wiley and Son, 1976).

3. K. B. Rall, A. I. Vil'davskaya, and A. A. Petrov, Russ. Chem. Rev., 1975, 44, 373; Translated from Uspekhi Khimii, 1975, 44, 744.

4. A. N. Kashin, N. A. Bumagin, M. P. Bessonova, I. P. Belteskaya, and O. A. Reutov, J. Org. Chem. USSR, 1980, 16, 1153; Translated from Zur. Organ. Khimii, 1980, 16, 1345.

5. V. Jager and H. G. Viehe, Angew. Chem. Int. Ed., 1969, 8, 273.

6. V. Jager, J. C. Motte, and H. G. Viehe, Chimica, 1975, 29, 516.

7. J. C. Motte and H. G. Viehe, Chimica, 1975, 29, 515.

8. R. J. Schmitt, J. C. Bottaro, and C. D. Bedford, Synthesis, 1986, 1320.

9. R. J. Schmitt, J. C. Bottaro, and C. D. Bedford, J. Org. Chem., 1987.

10. W. P. Weber, Silicon Reagents for Organic Synthesis: Reactivity and Structure Concepts in Organic Chemistry, Vol., 14 (Springer-Verlag, Berlin, 1983), pp. 391-404 and references therein.

11. W. D. Emmonds and J. P. Freeman, J. Am. Chem. Soc., 1965, 77, 4387.

12. W. D. Emmonds, K. S. McCallum, and J. P. Freeman, J. Org. Chem., 1952, 19.

13. M. A. Ilyushin, E. L. Golod, and B. V. Gidaspov, Zh. Org. Khim., 1977, 13, 8.

14. a) J. F. Riordan and B. L. Vallee, Method Enzymol., 1972, 25 (part B), 515; b) A. Castonguay and H. VanVunakis, Toxicol. Let., 1979, 4, 475; c) C. Lagercrantz, Acta. Chem. Scand., 1964, 18, 382; d) T. C. Bruice, M. J. Gregory, and S. L. Walters, J. Amer. Chem. Soc., 1968, 90, 1612; e) T. C. Bruice and S. L. Walters, J. Amer. Chem. Soc., 1971, 93, 2269.

15. J. P. Freeman and I. Shepherd, Org. Syn. Colle. 1973, 5, 839.

APPENDIX A

Reprinted from The Journal of Organic Chemistry, Vol. 52, page 2294
Copyright © 1987 by the American Chemical Society and reprinted by permission of the copyright owner.

Nitroacetylenes: Synthesis of 1-Nitro-2-(trialkylsilyl)acetylenes via Nitrodesilylation of Bis(trialkylsilyl)acetylenes

Robert J. Schmitt,* Jeffery C. Bottaro, Ripudaman Malhotra, and Clifford D. Bedford*†

Energetic Materials Program, Chemistry Laboratory, SRI International, Menlo Park, California 94025

Received September 30, 1986

As part of a study to develop a new synthetic route to nitroacetylenes, this report describes a general synthesis of 1-nitro-2-(trialkylsilyl)acetylenes 1. The method in-

$$\underset{\mathbf{1}}{R_3SiC{\equiv}CNO_2}$$

volves direct reaction between a nitronium ion source [i.e., nitronium tetrafluoroborate (NTFB), nitronium hexafluorophosphate (NHFP), or nitryl fluoride], bis(trialkylsilyl)acetylene, and a fluoride ion source. Only five nitroacetylenes have been reported previously,[1-6] and all are reported to be thermally unstable. The synthesis routes to known nitroacetylenes are shown in eq 1 and 2.

$$RC{\equiv}CSnMe_3 + N_2O_5 \xrightarrow{\text{inert solvent}} RC{\equiv}CNO_2 \quad (1)$$

R = Ph, Me_3Si, *n*-Pr, *i*-Pr

$$RC{\equiv}CH + NO_2I \rightarrow R(I)C{=}C(H)NO_2 \xrightarrow{\text{base/heat}} RC{\equiv}CNO_2 \quad (2)$$

R = *t*-Bu

We report here a general synthesis method for preparing 1-nitro-2-(trialkylsilyl)acetylenes. This unique one-step procedure allows for the preparation of numerous nitroacetylenes not accessible through the known synthesis methods.

Recently, we reported[7] an improved, one-step synthesis of 1-nitro-2-(trimethylsilyl)acetylene by treating bis(trimethylsilyl)acetylene with NTFB in methylene chloride (eq 3). When freshly triturated NTFB is used, a 70%

$$Me_3SiC{\equiv}CSiMe_3 + NO_2BF_4 \xrightarrow{CH_2Cl_2} Me_3SiC{\equiv}CNO_2 \quad (3)$$

yield of the nitroacetylene is obtained. The effects of alkyl substituents on both the acetylene and silyl substrate, the nitronium ion source, and reaction solvents have been studied. A special feature of this one-step nitrodesilylation reaction is the regioselectivity observed with bis(trialkylsilyl)acetylene substrates, allowing for the preparation of numerous 1-nitro-2-(trialkylsilyl)acetylenes, not easily

† Present address: Naval Surface Weapons Center, Code R-11, White Oak Laboratory, Silver Spring, MD 20910.

0022-3263/87/1952-2294$01.50/0 © 1987 American Chemical Society

Table I. Nitroacetylene Yields

starting material	nitronium salt	nitroacetylene product	yield, %
$Me_3SiC{\equiv}CSiMe_3$	NTFB	$Me_3SiC{\equiv}CNO_2$	70[a]
$Me_3SiC{\equiv}CSiMe_2$-*i*-Pr	NHFP	*i*-$PrMe_2SiC{\equiv}CNO_2$	34[b]
		$Me_3SiC{\equiv}CNO_2$	6[b]
$Me_3SiC{\equiv}CSiMe_2$-*t*-Bu	NHFP	*t*-$BuMe_2SiC{\equiv}CNO_2$	59[a]
		$Me_3SiC{\equiv}CNO_2$	29[a]
$Me_3SiC{\equiv}CSi(i\text{-}Pr)_3$	NHFP	$(i\text{-}Pr)_3SiC{\equiv}CNO_2$	57[a]
		$Me_3SiC{\equiv}CNO_2$	0
$Me_3SiC{\equiv}CCH_3$	NHFP	$CH_3C{\equiv}CNO_2$	c,d
$Me_3SiC{\equiv}C$-*t*-Bu	NHFP	*t*-$BuC{\equiv}CNO_2$	0
$Me_3SiC{\equiv}CC_6H_5$	NHFP	$C_6H_5C{\equiv}CNO_2$	0
$Me_3SiC{\equiv}C(CH_2)_4C{\equiv}CSiMe_3$	NHFP	$Me_3SiC{\equiv}C\text{-}(CH_2)_4C{\equiv}CNO_2$	0

[a] Isolated yield. [b] Yield determined from internal standard. [c] Rapidly decomposes. [d] Trace yield, observed by GC/MS.

accessible by known preparative routes.

One aspect of the synthesis study centered on generalizing the reaction of 1-alkyl-substituted silylacetylenes with nitronium ion sources. Purified NTFB in anhydrous acetonitrile or nitromethane and methylene chloride solvents proved to be an effective medium for the nitrodesilylation reaction, giving 1-alkyl-2-nitroacetylene compounds in low yield (Table I). Treatment of 1-phenyl-2-(trimethylsilyl)acetylene with nitronium ion sources failed to yield the desired nitroacetylene product. The nitronium salt, either NTFB or NHFP, must be thoroughly pure as impurities lead to reaction difficulties.

Good to excellent yields of nitroacetylenes were obtained when the R of eq 4 was a trialkylsilyl group. The presence

$$RC{\equiv}CSiMe_3 \xrightarrow[\text{acetonitrile/nitromethane}]{\text{NTFB/NHFP}} RC{\equiv}CNO_2 \quad (4)$$

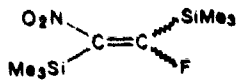
of a silicon atom α to the triple bond provides extra stabilization to the nitronium ion/acetylene transition state. Table I gives the yield of nitroacetylenes from the various bis(trialkylsilyl)acetylene substrates. Note that particularly high yields of the nitroacetylene products were obtained when bis(trialkylsilyl)acetylene substrates were used compared with the low nitroacetylene yields for the monosilylacetylene substrates.

Two products can result from the nitrodesilylation of bis(trialkylsilyl)acetylene substrates: one resulting from replacement of the Me_3Si group, the other from replacement of the more sterically crowded trialkylsilyl group (eq 5). In general, the ease of desilylation, and consequently

$$Me_3SiC{\equiv}CSiRR'R'' \xrightarrow{\text{NHFP/CH}_3\text{CN}} NO_2C{\equiv}CSiRR'R'' + Me_3SiC{\equiv}CNO_2 \quad (5)$$

the relative proportion of the two nitroacetylene products, follow the order generally observed for elimination of trialkylsilyl moieties:[8] $Me_3Si > Me_2$-*i*-PrSi > Me_2-*t*-BuSi > $(i\text{-}Pr)_3Si$. This high degree of regioselectivity (entries 2–4) results from the ease of attack by fluoride ion on the trialkylsilyl moiety. The steric crowding encountered in the triisopropylsilyl case results in exclusive fluoride ion assisted displacement of the Me_3Si group, whereas mixtures of nitroacetylenes were obtained when the bulky silyl substituents were studied entries 2 and 3, Table I.

In addition to the target nitroacetylene compounds, two other minor products were isolated from many of these nitrodesilylation reactions. They resulted from cis and trans addition of NO_2F across the triple bond, **2**.



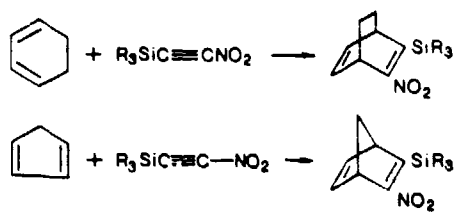
2

The nitroacetylenes were characterized by a combination of GC/MS and GC/FTIR observations (Tables II and III; see paragraph at end of paper about supplementary material). All nitroacetylenes show the characteristic acetylene stretching frequency band between 2150 and 2250 cm^{-1} in the infrared. Furthermore, in all compounds the characteristic asymmetric and symmetric NO_2 stretching frequencies were observed in the infrared spectra near 1525 and 1350 cm^{-1}, respectively.

The 1-nitro-2-(trialkylsilyl)acetylenes frequently gave a molecular ion ($M^{+\cdot}$) under electron impact mass spectrometry (70 eV). Other characteristic fragmentations are loss of an alkyl group from the silyl moiety ($M - R^+$) and complete loss of the silyl group ($M - SiR_3^+$).[8] The general fragmentation pathways for nitroacetylenes are shown in eq 7. Additional simple fragmentations are observed from the alkyl or other functional groups.

$$R_3SiC{\equiv}CNC_2 \rightarrow \begin{array}{l}[R_3SiC{\equiv}CNO_2]^{+\cdot}\ (M^{+\cdot}) \\ [R_2SiC{\equiv}CNO_2]^+ + R^\cdot\ (M^+ - R) \\ [C{\equiv}CNO_2]^\cdot + R_3Si^+ \\ R_3SiC{\equiv}C^+ + NO_2\ (M^+ - NO_2)\end{array} \quad (7)$$

The nitroacetylenes readily undergo Diels–Alder reactions with various cyclic dienes (eq 8). The structures of



(8)

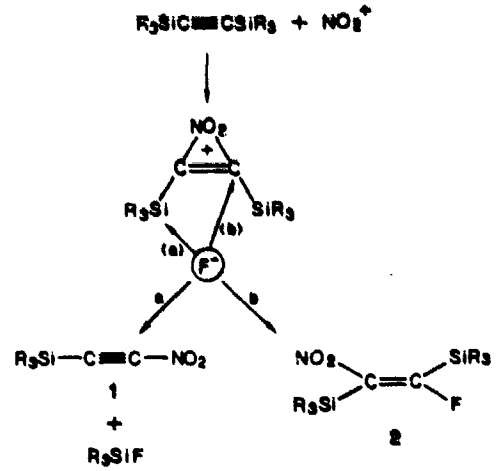
these products were confirmed by a combination of field ionization mass spectrometry, ^1H NMR, infrared, and elemental analysis.

Two possible mechanisms may account for the dramatic differences in the yields of nitroacetylenes formed when bissilyl- and monosilylacetylene substrates are used in the nitrodesilylation reaction. The first results from electrophilic attack of nitronium ion on the triple bond, followed by fluoride attack at silicon or carbon to give silyl fluoride and nitroacetylene or cis/trans fluoronitro olefin products. The second mechanism arises from initial fluoride displacement of the silyl group to give silylfluoride and the acetylide anion, followed by nitronium ion addition to the carbanion (Schemes I and II, respectively). The driving force for either mechanism is the formation of the strong Si–F bond resulting from attack of fluoride ion at silicon.[9]

We postulate that the first mechanism is the most probable. The contrast in reactivity between mono- and bissilylacetylenes is due to the ability of silicon to stabilize the carbonium ion intermediates over that of carbon.[10-13]

(1) Petrov, A. A.; Zavgorodinii, V. S.; Rall, K. B.; Vil'davskaya, A. I.; Bogoradovskii, E. T. *J. Gen. Chem. USSR (Engl. Transl.)* **1978**, *48*, 865.
(2) Jager, V.; Motte, J.-C.; Viehe, H. G. *Chimica* **1975**, *29*, 516.
(3) Jager, V.; Viehe, H. G. *Angew. Chem., Int. Ed. Engl.* **1969**, 273.
(4) Rall, K. B.; Vil'davskaya, A. I.; Petrov, A. A. *Russ. Chem. Rev. (Engl. Transl.)* **1975**, *44*, 373.
(5) Kashin, A. N.; Bumagin, N. A.; Bessonova, M. P.; Beletskaya, I. P.; Reutov, O. A. *J. Org. Chem. USSR (Engl. Transl.)* **1980**, *16*, 1153.
(6) Stevens, T. E.; Emmons, W. D. *J. Am. Chem. Soc.* **1958**, *80*, 338.
(7) Schmitt, R. J.; Bedford, C. D. *Synthesis* **1986**, 493.
(8) Pierce, A. E. *Silylation of Organic Compounds*; Pierce Chemical Co.: Rockford, IL, 1982; pp 1–39.
(9) McMillen, D. F.; Golden, D. M. *Annu. Rev. Phys. Chem* **1982**, 493.
(10) Weber, W. P. *Silicon Reagents for Organic Synthesis; Reactivity and Structure Concepts in Organic Chemistry, 14*; Springer-Verlag: Berlin, 1983; and references therein.

Scheme I. Cyclic Nitronium Ion Intermediate



Scheme II. Acetylide Ion Intermediate

$$Me_3SiC{\equiv}CR + F^- \rightarrow RC{\equiv}C^- + Me_3SiF$$
$$RC{\equiv}C^- + NO_2^+ \rightarrow RC{\equiv}CNO_2$$

Silicon is known to stabilize β-carbonium ions through hyperconjugation significantly better than alkyl groups. A second factor supporting the first mechanism is the observation of the small amounts of NO_2F addition products that would not be expected from the second reaction mechanism. Third, alkyl groups more readily undergo carbonium ion rearrangements, for example, to give a tertiary carbonium ion, than do silicon systems. This propensity of carbonium ions to rearrange may in part explain why we cannot synthesize *tert*-butylnitroacetylene from *tert*-butyl(trimethylsilyl)acetylene. Finally, addition of nitronium ion salts to a lithioacetylene does not give any nitroacetylene product.

Experimental Section

CAUTION! All nitroacetylene compounds are considered toxic and potentially explosive and should be handled with appropriate precautions.

Materials. Nuclear magnetic resonance spectra were recorded on a Varian Associates EM-360 or a JEOL FXQ-90. Infrared spectra were obtained on a Digilab-20 GC/FTIR (HP5980 GC). Mass spectra were obtained on a HP mass selective detector 5790B with gas chromatographic separation on a HP5970 GC. The reaction progress was monitored by gas chromatography using a Varian Model 3700 equipped with a SE-54, 50-m capillary column. High-quality NHFP and NTFB were obtained from Ozark-Mahoning. NHFP was used as obtained. NTFB was purified by triturating with nitromethane, decanting away the residual nitric acid components, and then rotoevaporating the wet NTFB to dryness. This step was repeated several times, resulting in NTFB free of acidic impurities. The silicon compounds were generally obtained from Petrarch Systems, Inc., or from Aldrich Chemical Co.

General Synthesis Procedure for the Synthesis of Nitroacetylenes Using Nitronium Hexafluorophosphate or Nitronium Tetrafluoroborate. NHFP (1 equiv) or purified NTFB (1 equiv) suspended in anhydrous acetonitrile, nitromethane, or nitromethane/methylene chloride was added to 1 equiv of the (trimethylsilyl)acetylene in acetonitrile, nitromethane, or nitromethane/methylene chloride with rapid stirring for 1 h at room temperature. The crude nitroacetylenes were purified by simple column chromatography using a silica gel column and chloroform as the eluting solvent. The reaction mixture was quickly passed through a chloroform-saturated plug of silica gel, applying suction at the effluent port and rinsing with 100 mL of chloroform. The effluent was typically concentrated to 10 mL in vacuo and quickly utilized in subsequent synthetic transformations. *NOTE*: Do not wash with brine or bicarbonate solutions; they cause rapid decomposition of the nitroacetylenes. Nitroacetylenes will generally decompose rapidly if concentrated and allowed to stand. Decomposition can be slowed by dilution in an inert solvent and storing in a freezer. However, both (triisopropylsilyl)nitroacetylene and (dimethyl-*tert*-butylsilyl)nitroacetylene are stable for a few hours at room temperature when concentrated. The stability of the nitroacetylenes goes up dramatically with increasing size of the silyl group attached to the nitroacetylene. For example, we find no decomposition of (triisopropylsilyl)- or (dimethyl-*tert*-butylsilyl)nitroacetylenes when dissolved in methylene chloride at room temperature over several weeks. Characterization of the new nitroacetylene compounds are shown in Tables II and III (available as supplementary material).

2-Nitro-3-(triisopropylsilyl)bicyclo[2.2.1]hepta-2,5-diene. (Triisopropylsilyl)nitroacetylene (70 mg, 0.4 mmol, with 30 mg of (triisopropylsilyl)acetylene as impurity) was dissolved in 10 mL of CCl_4 and treated with cyclopentadiene (300 mg, 5 mmol). This mixture was stirred for 3 days at room temperature, concentrated, and chromatographed over silica gel, eluting with 90% heptane/10% dichloromethane to give 70 mg (75%) of the expected adduct, an oil: ^1H NMR (CCl_4) δ 1.07 (d, 18 H, CH_3), 1.32 (m, 3 H, CH), 2.15 (m, 2 H, CH_2), 4.10 (m, 2 H, CH), and 6.90 (m, 2 H, CH); IR (neat) 2925, 2850, 1500, 1465, 1340 cm^{-1}. Anal. Calcd for $C_{16}H_{27}NO_2Si$: C, 65.90; H, 9.35; N, 4.82. Found: C, 65.41; H, 9.54; N, 4.73.

2-Nitro-3-(trimethylsilyl)bicyclo[2.2.2.]octa-2,5-diene. Nitronium fluoroborate (1.3 g, 10 mmol) was suspended in 10 mL of nitromethane and stirred under argon at 0 °C with ice cooling. Bis(trimethylsilyl)acetylene (1.7 g, 10 mmol) was then added, and the reaction became homogeneous and amber in color. The entire reaction was filtered through a 3 in. × 1 in. plug of chloroform-saturated silica gel and was eluted with 150 mL of chloroform, by using a vacuum aspirator to hasten elution rate. The product was concentrated to 10 mL, treated with 1,3-cyclohexadiene (2 g, 25 mmol) and allowed to stand at room temperature overnight. The reaction mixture was then chromatographed over silica gel, eluting with 1:1 hexane/chloroform, collecting the R_f 0.5 material. Concentration of the effluent in vacuo yielded 600 mg (27% overall, from bis(trimethylsilyl)acetylene of yellow crystals, mp 53–55 °C: IR (CCl_4 smear) 3085 (w, vinyl C–H), 2960 (m, C–H), 1520 (s, NO_2), 2360 (s, NO_2) cm^{-1}; ^1H NMR (CCl_4) δ 1.4 (m, 4 H, CH_2), 4.1 (m, 1 H, CH), 4.6 (m, 1 H, CH), 6.3–6.6 (m, 2 H, CH). Anal. Calcd for $C_{11}H_{17}NO_2Si$: C, 59.19; H, 7.62; N, 6.28. Found: C, 59.14; H, 7.45; N, 6.28.

2-Nitro-3-(trimethylsilyl)norbornadiene. The reaction of nitronium fluoroborate and bis(trimethylsilyl)acetylene was carried out exactly as described in the previous sequence involving cyclohexadiene. The resulting 10 mL of solution containing (trimethylsilyl)nitroacetylene was treated with 5 mL of cyclopentadiene and was stored under argon for 15 h. The reaction mixture was concentrated and chromatographed over silica gel, eluting with chloroform, collecting the R_f 0.7 material. The effluent was concentrated and distilled in vacuo to give 1.0 g (50%) of yellow oil, bp 44 °C (0.1 torr): IR (neat smear) 3080 (w, vinyl C–H), 2960 (m, C–H), 1505 (s, nitro), 1350 (s, nitro) cm^{-1}; ^1H NMR (CCl_4) δ 2.2 (m, 2 H, CH_2), 4.0 (m, 2 H, CH), 6.8 (m, 1 H, CH), 7.1 (m, 1 H, CH). Anal. Calcd for $C_{10}H_{15}NO_2Si$: C, 57.42; H, 7.18; N, 6.70. Found: C, 56.73; H, 7.43; N, 6.39.

Acknowledgment. We thank Dr. Anthony Matuszko of the Air Force Office of Scientific Research (Contract F49620-83-K-0023) for his encouragement and support of this work.

Registry No. NTFB, 13826-86-3; NHFP, 19200-21-6; $Me_3SiC{\equiv}CSiMe_3$, 14630-40-1; $Me_3SiC{\equiv}CSiMe_2$-*i*-Pr, 107474-00-0; $Me_3SiC{\equiv}CSiMe_2$-*t*-Bu, 107474-01-1; $Me_3SiC{\equiv}CSi(i\text{-}Pr)_3$, 107474-02-2; $Me_3SiC{\equiv}CCH_3$, 6224-91-5; $Me_3SiC{\equiv}$-*t*-Bu, 14630-42-3; $Me_3SiC{\equiv}CC_6H_5$, 2170-06-1; $Me_3SiC{\equiv}C(CH_2)_4C{\equiv}CSiMe_3$, 63873-32-5; *t*-$BuMe_2SiC{\equiv}CNO_2$, 107474-04-4; $Me_3SiC{\equiv}CNO_2$,

(11) Apeloig, Y.; Stanger, A. *J. Am. Chem. Soc.* **1985**, *107*, 2806.
(12) Wierschke, S. G.; Chandrasekhar, J.; Jorgensen, W. L. *J. Am. Chem. Soc.* **1985**, *107*, 1496.
(13) Shiner, V. J., Jr.; Ensiger, M. W.; Kriz, G. S. *J. Am. Chem. Soc.* **1986**, *108*, 842.

67177-80-4; *i*-PrMe$_2$C—C≡CNO$_2$, 107474-03-3; (*i*-Pr)$_3$SiC≡CNO$_2$, 107474-05-5; CH$_3$C≡CNO$_2$, 107474-06-6; **2**, 107474-09-9; (*i*-Pr)$_3$SiC≡CH, 89343-06-6; cyclopentadiene, 542-92-7; 1,3-cyclohexadiene, 592-57-4; 2-nitro-3-(triisopropylsilyl)norbornadiene, 107474-07-7; 2-nitro-3-(trimethylsilyl)bicyclo[2.2.2]octa-2,5-diene, 107494-77-9; 2-nitro-3-(trimethylsilyl)norbornadiene, 107474-08-8.

Supplementary Material Available: IR spectral data for all new nitroacetylenes (Table II) and MS fragmentation patterns for nitroacetylenes and (trimethylsilyl)acetylenes (Table III) (3 pages). Ordering information is given on any current masthead page.

APPENDIX B

Reprinted from The Journal of Organic Chemistry, Vol. 52, page 2292
Copyright © 1987 by the American Chemical Society and reprinted by permission of the copyright owner.

Nonacidic Nitration of Secondary Amines

Jeffrey C. Bottaro,* Robert J. Schmitt, and Clifford D. Bedford*†

Energetic Materials Program, Chemistry Laboratory, Physical Sciences Division, SRI International, Menlo Park, California 94025

Received September 30, 1986

The N-nitration of secondary amines under neutral conditions poses a unique problem of N-nitrosation as a competing side reaction. When nitrogen dioxide,[1] nitryl chloride,[2] nitrogen pentoxide, nitryl fluoride, nitronium fluoroborate,[3] and tetranitromethane[4] are used in the N-nitration of amines, they all result in substantial yields (≥30%) of nitrosamine side products, which are extremely toxic and difficult to separate from the target nitramines. Nitramines are potentially useful as explosives, biocides, and pharmaceuticals, necessitating a high-yielding synthesis devoid of carcinogenic nitrosamine byproducts.

To overcome the problems associated with N-nitrosation, we studied a series of novel covalent nitrating agents and examined the effect of amine blocking groups on the outcome of the nitration reaction. The use of amine protecting groups on the nitro/nitrosamine product distribution proved futile. When the *N*-trimethylsilyl, *N*-trimethoxysilyl, *N*-trichlorosilyl, and *N*-difluoroboryl derivatives of piperidine (our model amine substrate) were treated with the conventional nitrating agents mentioned above, they all produced products contaminated with nitrosamine byproducts. Nitrations with nitryl fluoride were complicated by unavoidable contamination of NO_2F with NO_2, which occurred as a result of contact of NO_2F with glass, air, and organic solvents. This approach was abandoned in favor of developing novel nonacidic nitrating agents.

The production of nitrosamines is a result of the redox reaction between secondary amines and nitrating agent. We sought to attenuate the oxidizing power of the nitrating agent by varying the electronegativity of the leaving group. For example, when nitryl fluoride was reacted with secondary amines, it gave unacceptable yields of nitrosamines (≃50%). In our hands similar results were obtained with tetranitromethane, *N*-nitrocollidinium fluoroborate,[10] and nitryl chloride. In response to this problem, we chose to examine nitrating agents with leaving groups that were less electronegative than fluorine. Since ordinary nitrate esters failed to nitrate secondary amines at all, we concluded that

Scheme I. Amine-Induced Elimination of Nitrous Acid

$$CX_3CH_2ONO_2 + HNR_2 \rightarrow \begin{array}{l} CX_3CHO \xrightarrow{R_2NH} CX_3CH(OH)NR_2 \\ + \\ R_2NH_2^+NO_2^- \xrightarrow{\Delta} R_2NNO + H_2O \end{array}$$

the viable range of electronegativities for the nitro transfer reaction lay somewhere between alkoxide (the leaving group on a nitrate ester) and fluoride (the leaving group on nitryl fluoride). Thus, we examined a series of electron-deficient nitrate esters as our target category of neutral nitrating agents for secondary amines.

This approach was attempted by Emmonds and Freeman,[5] who studied some electron-deficient nitrate esters and found that acetone cyanohydrin nitrate[6,7] does indeed produce the nitration of amines at elevated temperatures. Unfortunately, this reagent releases acetone and hydrogen cyanide, which react with amines to give amino nitriles, rendering this method low yielding with respect to the amine substrate. The use of trichloroethyl nitrate[6] also did not solve this problem: the nitrate ester suffered an elimination of nitrous acid to give a mixture of dialkylammonium nitrite and trichloroacetaldehyde, which itself reacted with 1 equiv of the amine to form the hemiaminal side product (Scheme I).

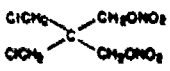
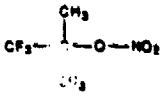
We sought to design nitrating agents that could achieve the desired acyl transfer (here, acyl = nitro) without any undesirable side reactions. Our initial efforts focused on the use of polyfluoroalkyl nitrates. Hexafluoroisopropyl nitrate and trifluoroethyl nitrate were synthesized by direct nitration of the corresponding alcohols in fuming nitric/sulfuric acid. Treating these materials with piperidine, our preliminary test amine, yielded predominantly elimination products as depicted in Scheme I. In the case of trifluoroethyl nitrate, a small amount of nitramine was formed in competition with the elimination products. Only elimination products were detected in the case of hexa-

† Present address: Naval Surface Weapons Center, Code R-11, White Oak Laboratory, Silver Spring, MD 20910.

(1) (a) Challis, B. C.; Kyrtopoulos, S. A. *J. Chem. Soc., Perkin Trans. 2* **1978**, 1296. (b) Williams, D. L. H. *Adv. Phys. Org. Chem.* **1983**, *19*, 381.
(2) Shineman, R. S. Thesis Ohio State University, 1957; University Microfilms, Ann Arbour, MI, Card No. M.C. 58-2104.
(3) Ilyushin, M. A.; Golod, E. L.; Gidaspov, B. V. *Zh. Org. Khim.* **1977**, *13*, 8.
(4) (a) Riordan, J. F.; Vallee, B. L. *Methods Enzymol.* **1972**, 25 (part B), 515. (b) Castonguay, A.; VanVunakis, H. *Toxicol. Lett.* **1979**, *4*, 475. (c) Lagercrantz, C. *Acta, Chem. Scand.* **1964**, *18*, 382. (d) Bruice, T. C.; Gregory, M. J.; Walters, S. L. *J. Am. Chem. Soc.* **1968**, *90*, 1612. (e) Bruice, T. C.; Walters, S. L. *J. Am. Chem. Soc.* **1971**, *93*, 2269.
(5) Emmonds, W. D.; Freeman, J. *J. Am. Chem. Soc.* **1965**, *77*, 4587.
(6) Emmonds, W. D.; McCallum, K. S.; Freeman, J. P. *J. Org. Chem.* **1952**, *19*, 1472.
(7) Freeman, J.; Shepherd, I. *Organic Synthesis*; Wiley: New York, 1973; Collect. Vol. V, p 839.

0022-3263/87/1952-2292$01.50/0 © 1987 American Chemical Society

Table I. Candidate Nitrate-Transfer Reagents

compd	structure	yield, %	properties
1		5	mp 62 °C; dec >150 °C
2		80	bp 98 °C; slight dec at bp; stable for weeks at room temp
3		80[a]	mp 93 °C

[a] Reference 9.

Table II. Nitration of Amines with 2-(Trifluoromethyl)-2-propyl Nitrate

amine	yield, % nitramine	nitrosamine
piperidine	75	0[a]
morpholine	72	0
N-benzylmethamine	75	0
pyrrolidine	100	0
diethylamine	58	0

[a] As detected by TLC which is consistently sensitive to ≤1% yields of nitrosamines and/or nitramines.

fluoroisopropyl nitrate. Also detected were small amounts of nitrosation products resulting from the thermal decomposition of the nitrite salts.

The trend established by hexafluoroisopropyl nitrate (no nitration) and trifluoroethyl nitrate (low yield of nitration) prompted us to design alkyl nitrates that were less electron poor and, if possible, endowed with structural attributes that precluded the elimination reaction shown in Scheme I, which ultimately leads to nitrosamines by self-condensation of the resulting nitrite salts.

Candidates for this new generation of nitrate-transfer reagents are shown in Table I. All these structures preclude the elimination side reaction shown in Scheme I. The pentaerythritol dinitrate derivative **1** has a degree of steric hindrance to base attack on the protons α to the nitrate esters, and fluorinated *tert*-butyl nitrate (**2**) is devoid of such protons entirely. *N*-Nitropyrazole (**3**) also enjoys an immunity to elimination reactions.

Compounds **1**–**3** were synthesized by direct nitration of the corresponding protic compound. Perfluoro-*tert*-butyl nitrate and hexafluoro-*tert*-butyl nitrate could not be prepared and were abandoned as potential targets. Compound **2** [2-(trifluoromethyl)-2-propyl nitrate] was synthesized by nitration of 2-(trifluoromethyl)-2-propanol in nitric acid/trifluoroacetic anhydride. Compound **1** [2,2-bis(chloromethyl)propane-1,3-diol dinitrate][8] was prepared by hydrolysis and nitration of 3,3-bis(chloromethyl)oxetane in nitric acid/oleum.

Both compounds **1** and **2** nitrate secondary amines under mild conditions (room temperature to 55 °C) without nitrosation, except in isolated cases. In general, **2** is a more convenient, cleaner, and efficient nitrating agent, which allows for a facile workup. The results obtained with selected amines for both reagents are shown in Tables II and III. *N*-Nitropyrazole (**3**) failed to transfer its nitro group to diethylamine even when refluxed in a solution with diethylamine as solvent. This compound was abandoned as a nitrating agent.

Table III. Nitration of Amines with 2,2-Bis(chloromethyl)propane-1,3-diol Dinitrate

amine	yields, % nitramine	nitrosamine
piperidine	65	0
morpholine[a]	40	tr
N-benzylmethanamine	42	6
pyrrolidine	86	0
diethylamine[a]	17	4
dimethylamine	55	0

[a] Probable loss in isolation due to high volatility. [b] As detected by TLC.

Attempts to nitrate primary amines and ethylenediamine derivatives met with difficulty. For example, attempted dinitration of piperazine with **2** resulted in a low yield of *N*-nitroso-*N'*-nitropiperazine. The same result was obtained with *N,N'*-dimethylethylenediamine, giving mixed nitro and nitroso compounds in poor yields. Furthermore, the nitration of 3-methyl-3-[(*N*-ethylamino)-methyl]oxetane, a highly hindered amine, gave only a poor yield of nitramine, with no nitrosation. Finally, nitrations of benzylamine and phenethylamine gave low yields of corresponding primary nitramines, which could not be purified to analytical specifications. Evidently, amines of diminished nucleophilicity due to inductive or steric encroachments yield nitrosation products through the slow decomposition of the nitrating agent. The poor performance of compound **2** in N-nitration of primary amines is probably due to decomposition of the product under the prolonged heating necessary to drive the nitro-transfer reaction.

In conclusion, we have developed two effective reagents, 2-(trifluoromethyl)-2-propyl nitrate and 2,2-bis(chloromethyl)propane-1,3-diol dinitrate, for the neutral nitration of secondary amines. These materials have complementary properties, the first being useful for volatile substrates and the second for nonvolatile substrates. The 2-(trifluoromethyl)-2-propyl nitrate will enjoy a broader application in synthesis because it reacts in a cleaner manner and in higher yield than 2,2-bis(chloromethyl)propane-1,3-diol dinitrate for the nonacidic nitration of basic amines.

Experimental Section

General Methods. ^{1}H NMR spectra were determined on a Varian T-60 NMR spectrometer as solutions in $CDCl_3$ or CCl_4. IR spectra were determined on a Perkin-Elmer 1420 IR spectrophotometer.

Synthesis of Hexafluoroisopropyl Nitrate. Oleum (100 g of 30% SO_3) was cooled to 0 °C under argon and treated with 25 mL of 90% nitric acid (*Caution*! *Exotherm*!) followed by addition of hexafluoroisopropyl alcohol (35 g, 210 mmol). The reaction was stirred under argon for 1 h, warming to room temperature over that time. The crude product was distilled out of the biphasic reaction mixture at ~30 Torr, trapping the product in a dry ice/acetone bath. The crude product was stirred over 4 g of Na_2CO_3, treated with 2 mL of H_2O, and decanted. It contained some free alcohol and was stored at 0 °C. Even at 0 °C, it slowly decomposed, giving off NO_2 gas: ^{1}H NMR (CCl_4) δ 5.8 (septet, J = 6 Hz).

Synthesis of Trifluoroethyl Nitrate. Oleum (360 g of 30% SO_3) was cooled to 0 °C under argon and was carefully treated with 80 mL of 90% nitric acid. After this mixture had cooled, trifluoroethanol (77 g, 0.77 mol) (Aldrich) was added, and the reaction mixture was allowed to warm to room temperature over 1 h. The resulting biphasic reaction mixture was then distilled, under an aspirator vacuum, into a dry ice cooled receiver, neutralized by stirring over 2 g of Na_2CO_3/4 mL of H_2O, followed

(8) German Patents 638432 and 638433, Westfälisch-Anhaltische Sprengstoff A.G. Nov 14, 1936 (Cl.78c.18).
(9) Huttel, R.; Böchele, F. *Chem. Ber.* **1955**, *88*, 1586.
(10) Ho, T.-L.; Olah, G. A. *J. Org. Chem.* **1977**, *42*, 3097.

by addition of 5 g of Na_2CO_3 to remove H_2O. The supernatant liquid was decanted and found to be sufficiently pure for synthesis. The yield of clear colorless liquid was 101 g (85%): ^1H NMR (CCl_4) δ 4.9 (quart., J = 8 Hz); IR (neat) 1400, 1430, 1680 cm^{-1}.

Synthesis of 2-(Trifluoromethyl)-2-propyl Nitrate. Trifluoroacetic anhydride (16 g, 75 mmol) was cooled to 0 °C with stirring under argon, in a 50-mL round-bottomed flask. Nitric acid (4.5 g, 75 mmol) was carefully added over 5 min to avoid excessive heating. After the addition was complete, the mixture was stirred for 20 min at 0 °C, 2-(trifluoromethyl)-2-propanol (6.5 g, 50 mmol) was added, and the reaction mixture was stirred for an additional 30 min. The reaction mixture was diluted with 25 mL of dichloromethane, extracted with 100 mL of ice–water, dried over Na_2CO_3, and distilled at ~400 Torr. The yield of clear, colorless liquid was 5.3 g (62%): bp 60 °C (400 torr); ^1H NMR (CCl_4, 60 MH_z) δ 1.7 (s); IR (neat) 1660 cm^{-1}. The neat compound gave off traces of NO_x gas after 1 month of storage at room temperature, but its NMR spectrum was unchanged. At low temperatures (0 °C) no decomposition has been observed, even after 1 year.

Reaction of 1,1,1-Trifluoroethyl Nitrate with Piperidine. Piperidine (4.3 g, 50 mmol) was dissolved in 50 mL of diethyl ether and the resultant mixture treated with trifluoroethyl nitrate (9 g, 60 mmol). An exotherm ensued, causing the solvent to reflux. After 1 h, the exotherm had subsided, and a solid had precipitated from the reaction mixture. The solid was isolated by filtration, and the filtrate was freed of acidic and basic compounds by extraction with aqueous base and acid, respectively. The ether layer was found to contain approximately 600 mg (~10% yield) of *N*-nitropiperidine, as determined by IR, NMR, and TLC in comparison with those of an authentic sample. The solid (2.3 g) was unstable, degrading to *N*-nitrosopiperidine on standing. The solid had an NMR spectum identical with that of piperidine·HNO_3, but its IR spectrum was different from that of an authentic sample. On this basis, and due to its tendency to degrade to *N*-nitrosopiperidine, the solid was assumed to be piperidine·HNO_3.

Reaction of 2-(Trifluoroethyl)-2-propyl Nitrate with Secondary Amines. The secondary amine (1 mmol) was mixed neat with 2-(trifluoromethyl)-2-propyl nitrate (250 mg, 1.5 mmol) and kept at 50 °C for 7 days. Volatiles including 2-(trifluoromethyl)-2-propanol were evaporated in vacuo, and the crude product was filtered through a short plug of silica gel to give pure *N*-nitramines. The products were identical with known materials in their spectroscopic and physical properties. The yields were not further optimized (see Table II).

Synthesis of 2,2-Bis(chloromethyl)propane-1,3-diol Dinitrate. Fuming nitric acid (90%) (100 mL) was saturated with $NaNO_3$ at room temperature. Next, 3,3-bis(chloromethyl)oxetane (20 g, 130 mmol) was added. A mild exotherm was observed, and ice cooling was applied. The mixture was stirred at 0–15 °C for 5 h, with gradual warming from 0 to 15 °C over that interval. The reaction mixture was cooled to 0 °C and was carefully treated with 40 mL of 30% fuming H_2SO_4, stirring and adding the acid in 2-mL aliquots. The resulting mixture was warmed to room temperature over 15 min and poured over ice, giving a white solid. The solid was collected by filtration, dissolved in 150 mL of warm carbon tetrachloride, and crystallized to give 25 g (73%) of large, colorless prisms: mp 63 °C; ^1H NMR ($CDCl_3$, Me_4Si) δ 3.7 (s), 4.6 (s); IR (CCl_4 smear) ν_{max} 1670, 1300 cm^{-1}. Anal. Calcd for $C_5H_8Cl_2N_2O_6$: C, 22.83; H, 3.07; N, 10.65; Cl, 26.95. Found: C, 22.90; H, 2.98; N, 10.60; Cl, 26.78.

Reaction of 2,2-Bis(chloromethyl)propane-1,3-diol Dinitrate with Secondary Amines. The amine (10 mmol) was mixed with 2,2-bis(chloromethyl)propane-1,3-diol dinitrate (1.3 g, 5 mmol) and the resultant mixture heated in a sealed vial at 55 °C for 3 days. Unreacted nitrate ester was destroyed by adding 5 mL of ethyl alcohol and 2 mL of hydrazine and heating at 80 °C for 1 h. The reaction mixture was partitioned between 100 mL of ether and 100 mL of water. The ether layer was concentrated and chromatographed, eluting chloroform over silica gel, yielding the pure nitramines, which were visualized by UV. The products were chromatographically and spectroscopically identical with known samples of the target compounds (see Table III).

Acknowledgment. We thank Dr. Anthony Matuszko of the Air Force Office of Scientific Research (Contract No. F49620-83-K-0023) for his encouragement and support of this work.

Registry No. $(F_3C)_2CHOH$, 920-66-1; $(F_3C)_2CHONO_2$, 107149-24-6; F_3CCH_2OH, 75-89-8; $F_3CCH_2ONO_2$, 461-38-1; $F_3CC(CH_3)_2OH$, 507-52-8; $F_3CC(CH_3)_2ONO_2$, 107149-25-7; $C_6H_5CH_2NHCH_3$, 103-67-3; $NH(CH_3)_2$, 124-40-3; $H_3CN(NO_2)CH_2C_6H_5$, 36239-05-1; $O_2NN(CH_2CH_3)_2$, 7119-92-8; $O_2NN(CH_3)_2$, 4164-28-7; $C_6H_5CH_2N(NO)CH_3$, 937-40-6; $O_2NOCH_2C(CH_2Cl)_2CH_2ONO_2$, 107149-26-8; piperidine, 110-89-4; morpholine, 110-91-8; pyrrolidine, 123-75-1; *N*-nitropiperidine, 7119-94-0; *N*-nitromorpholine, 4164-32-3; *N*-nitropyrrolidine, 3760-55-2; 3,3-bis(chloromethyl)oxetane, 78-71-7.