THE NITROLYSIS OF HEXAMETHYLENETETRAMINE

VII. INTERMEDIATES IN THE NITROLYSIS[1]

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Abstract

The evidence presented by Vroom and Winkler that 3,5-dinitro-3,5-diazapiperidinium nitrate is an intermediate compound in the conversion of hexamine dinitrate to Cyclonite has been vitiated by the demonstration that it cannot survive the reaction conditions in which it supposedly was formed. Presumably the formation of 3,5-dinitropiperadinium nitrate occurs during dilution by decomposition of 1-dimethylolaminomethyl-3,5-dinitro-1,3,5-triazacyclohexane and/or 1-methylol-3,5-dinitro-1,3,5-triazacyclohexane. Evidence favoring the latter as the stable intermediate is afforded by demonstration that dimethylolnitramide also is present. When the cold nitrolysis mixture is treated with acetic anhydride rather than water the intermediate is esterified and nitrolyzed to 1-acetoxy-7-nitroxy-2,4,6-trinitro-2,4,6-triazaheptane and 1,7-diacetoxy-2, 4, 6- trinitro-2,4,6-triazaheptane.

It is obvious that the nitrolysis of hexamine, which involves at least three particles of nitric acid and one particle of the amine, must proceed to the eventual formation of Cyclonite (V) through intermediate steps. Because of the rapidity of reaction, intermediate compounds representing such steps could not be isolated in this laboratory. However, the isolation of 1,9-diethoxy-2,4,6,8-tetranitro-2,4,6,8-tetrazanonane by ethanolysis of a small amount of the dinitroxy analogue (III, R = NO_2) produced in the normal nitrolysis of hexamine with 99% nitric acid (5) indicated that 1-dimethylolaminomethyl-3,5-dinitro-1,3,5-diazacyclohexane (I) may have been an intermediate. Furthermore the formation of 1,7-dinitroxy-2,4,6-trinitro-2,4,6-triazaheptane (IV, R = NO_2) by nitrolysis of hexamine with nitric acid containing nitrogen pentoxide (5) indicated that 1-methylol-3, 5-dinitro-1, 3, 5-triazacyclohexane (II) was present in the reaction mixture as a derivative either of hexamine or of (I). The conversion of hexamine to Cyclonite has thus been considered as a series of tertiary amine nitrolyses following the sequence, hexamine → I → II → V.

Recently Vroom and Winkler (10) have presented a different interpretation of Cyclonite formation on the basis of the isolation of 3,5-dinitro-3,5-diazapiperidinium nitrate (VI). They consider VI to be an intermediate compound of appreciable life in the reaction mixture and they interpret the formation of Cyclonite as a combined nitrolysis and nitration following the sequence, hexamine → I → VI → V.

Neither the amount of nitric acid used for preparation of VI nor the yield using 97% nitric acid was reported by Vroom and Winkler. A ratio of 47-49 moles of nitric acid per mole of hexamine was chosen as intermediate in the ratios used in their kinetic work. Under these conditions it was found that a

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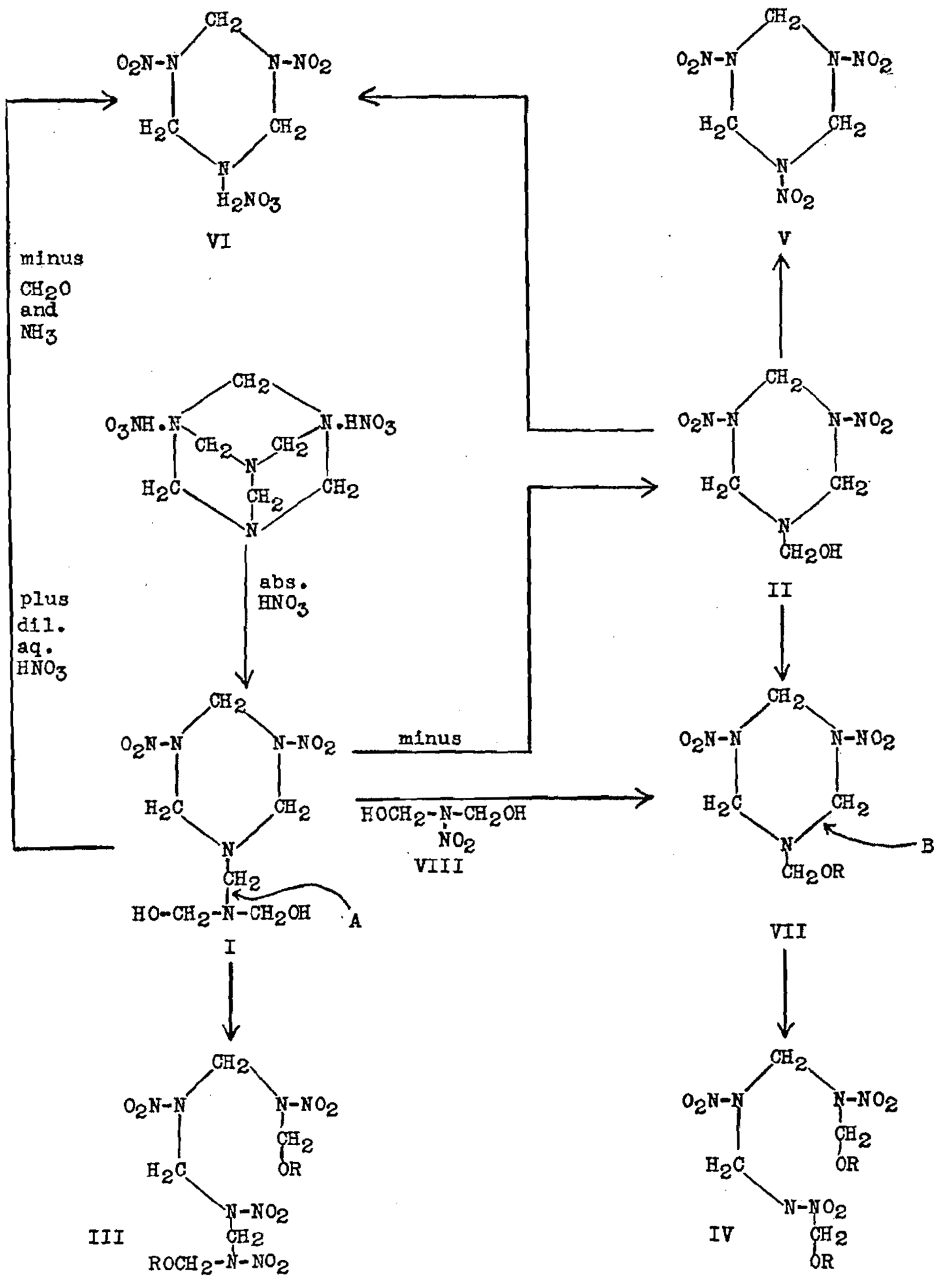
VI
V
minus
CH2O
and
NH3
abs.
HNO3
plus
dil.
aq.
HNO3
II
minus
HOCH2-N-CH2OH
NO2
VIII
B
A
I
VII
III
IV

yield of 0.5-2.5% of Cyclonite (V) always was formed, although it was not isolable unless the drowned reaction mixture was boiled. The yields of V in Table I are based on unboiled reaction liquors and are comparable with those of Vroom and Winkler if they corrected only for the slight solubility of V in water. Presumably they did not boil their reaction liquors since otherwise they would have reported slight yields of V in all preparations.

TABLE I

NITROLYSIS OF 0.01 MOLE HEXAMINE DINITRATE IN 0.47 MOLE OF NITRIC ACID

Reaction time, sec.	Concentration aqueous nitric acid	Temperature, °C.		Yield	
		Initial	Final	VI %	V %
45	99	−38	−20		10
45	99	−35	−18		13
45	98	−50	−50		0
45	100	−40	−35		23
130	97	−40	−20	57	7
60	99	−40	−25		31
60	99	−40	−10		62
130	97	−40	−30	57	0
120	97	−40	−31	62	0
60	98	−40	−22		43*
60	88	−50	0	53	Trace
45	97	−40	−35	40	None
45	97	−40	−30	36	None
45	97	−40	−30	48	None
60	97	−45	−40	51	None
60	97	−45	−40	54	None
60	97	−42	−32	33	None*
60	97	−40	−35	52	None

* *Prior to dilution 50 ml. of absolute ether was added and then decanted from the precipitate.*

The conditions of temperature, concentration, and excess of acid must be controlled carefully. Thus with 47 equivalents of 97% nitric acid a temperature rise 5-10 degrees higher than those specified in Table I will produce 5-8% of Cyclonite isolable from the unboiled liquors. Likewise reaction with 92 moles of 97% nitric at −40° to −30°C. causes formation of 4-7% of Cyclonite. The effect of these factors is exemplified by the experiments shown in Table I wherein nitric acid at concentrations of 98-100 were used and the reaction, once started, could not be held within the specified temperature limits.

The recommended preparative method of Vroom and Winkler using 88% nitric acid was repeated and found to yield 10% more of VI than they reported. The remainder of the experiments reported in Table I were carried out in 97% nitric acid. Yields of 33-62% of the theoretical quantity of VI were obtained free from contaminant Cyclonite (V) when the reaction period was varied from 45 to 130 sec.

It was noted that when the 97% acid reaction mixture was diluted with ice the solution was at first clear, but it became increasingly turbid over a period of about one minute. It seemed possible from this behavior that the formation of 3,5-dinitro-3,5-diazapiperidinium nitrate (VI) occurred in the aqueous diluate rather than in the original reaction mixture. Under these circumstances the intermediate indicated by the difference found by Vroom and Winkler between hexamine consumption and Cyclonite producibility should be either I or II. Demethylolation of such substances in cold dilute acid might then produce VI.

A test of this hypothesis that VI was not present as an intermediate of appreciable life in the nitrolytic medium but, instead, was formed after aqueous dilution might be afforded by determining the stability of VI in 97% nitric acid. While direct comparison with nitrolysis of hexamine was complicated by the low solubility of VI in the cold strong acid, it was evident by the 5° rise in temperature that a reaction had occurred. The results obtained after subsequent dilution and destruction of recovered VI in hot 70% nitric acid are shown in Table II. In every case the formation of Cyclonite demonstrated that 3,5-dinitro-3,5-diazapiperidinium nitrate was not stable under the controlled nitrolytic conditions presumably employed by Vroom and Winkler.

Despite the fact that the stability of VI in 97% nitric acid was not altered by inclusion of 5% hexamine dinitrate (Expt. 1, Table II) it might be argued by some that VI could survive the actual reaction system comprising degradation fragments dissolved in the acid. We partially simulated such conditions by treating hexamine dinitrate with 97% nitric acid under the controlled conditions previously outlined, and subsequently added 3,5-dinitro-3,5-diazapiperidinium nitrate using the same controlled conditions over the same length of time. The results, shown in Table III, confirm that VI is unstable under the controlled reaction conditions, although (as might be expected) less Cyclonite is formed than in the absence of hexamine dinitrate.

It is thus evident that 3,5-dinitro-3,5-diazapiperidinium nitrate (VI) is not yet formed during the 45-60 sec. reaction period with hexamine dinitrate

TABLE II

NITRATION OF 3, 5-DINITRO-3, 5-DIAZAPIPERIDINIUM NITRATE WITH 0.235 MOLE 97% NITRIC ACID

Moles amine nitrate	Reaction time, sec.	Temperature, °C.		Yield	
		Initial	Final	VI %	V %
.005*	60	−40	−28	42	16
.004	60	−55	−45	68	2
004	60	−40	−45	75	1
.004	60	−45	−40	72	2
.003	60	−40	−32	50	13
.003	60	−38	−35	48	9
.004	120	−40	−38	62	9
.004	45	−43	−38	50	2

* *Contained 5% of hexamine dinitrate.*

in 97% nitric acid at −40°. since otherwise the isolated product would have contained Cyclonite. The formation of (VI) during dilution attests the extreme instability of the methylolamines (I) and (II) in aqueous acid, and renders doubtful that either will ever be isolated from this medium.

However isolation of derivatives of (I) or (II) wherein hydroxyl groups were blocked should be possible, and this was attempted in two ways with acetic anhydride. In the first instance the nitrolysis system was chilled below −55°C. and acetic anhydride was added slowly so that the temperature did not exceed −25°. As might have been expected this produced Cyclonite since the water content of the nitric acid was reduced below 2%.* In addition to this 50% yield a 25% yield of 1-acetoxy-7-nitroxy-2,4,6-trinitro-2,4,6-triazaheptane (IV, R = CH_3CO, R′ = NO_2) was obtained. A variation of this procedure involved addition of the nitrolyzed system into the cold acetic anhydride. The Cyclonite yield was about the same but the second product was not the mixed ester, but instead, 1,7-diacetoxy-2,4,6-trinitro-2,4,6-triazaheptane (IV, R, R′ = CH_3CO) in 15% yield together with a persistent impurity which could not be isolated as a chemical individual.

TABLE III

NITRATION OF 3, 5-DINITRO-3, 5-DIAZAPIPERIDINIUM NITRATE WITH HEXAMINE DINITRATE TREATED IN 0.47 MOLE 97% NITRIC ACID AT −40° TO −30° OVER ONE MINUTE

Moles HADN	Moles VI	Time, VI → V sec.	Temperature, °C.		Yield, moles	
			Initial	Final	VI	V
0.01	0.01	60	−38	−30	0.0146	0.0002
0.01	0.01	60	−42	−31		0.0002
0.01	0.01	120	−55	−30	0.0142	0.0004
0.01	0.0025	60	−40	−28	0.0084	0.0001
0.005	0.005	60	−40	−29	0.0061	0.0008*
0.005	0.01	60	−38	−30	0.0105	0.0011*

* *Under these conditions the hexamine dinitrate alone would account for 0.0004 moles of Cyclonite.*

Neither of these products (containing four carbon atoms) could have been derived from VI (which contains three carbon atoms) unless resynthesis of hexamine fragments occurred (11, 1). The high purity of the Cyclonite which was obtained in the same reaction indicates that resynthesis did not occur. An intermediate must therefore be sought which contains four or more carbon atoms.

Evidence contributing toward specification of this intermediate has recently been presented by Dunning and Dunning (7). They nitrolyzed hexamine dini-

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* *The sharp transition in nitrolytic effect when the concentration of water is less than 2% has been attributed by some to the consequent stabilization of nitronium or nitracidium salts. While such stabilization has amply been demonstrated it does not necessarily follow that either of these salts per se is directly involved in nitrolysis. Instead in proper environment, an amine nitrate may become an amine–nitronium salt analogous with, but alternate to, the water–nitronium type known as nitracidium salt. Indeed, presence of the latter may be detrimental to formation of the former.*

trate in 97% nitric acid over nearly six minutes, drowned it in diethyl ether, and obtained a gum which yielded 1-ethoxymethyl-3,5-dinitro-1,3,5-triazacyclohexane in 17% yield when it was treated with ethanol. This is presumptive for a larger amount of the 1-nitroxy analogue in the gum. Although they isolated no 3,5-dinitro-3,5-diazapiperidinium nitrate (VI) they seemed not to be certain of its absence. This uncertainty probably was due to their isolation of 3-nitramino-2-nitro-2-azapropylammonium nitrate which might have been formed from VI by degradation. Certainly they demonstrated that a cyclic compound comprising more than three carbon atoms survived in the nitrolysis system at −28.5° for more than five minutes.

Both of the linear compounds (IV) which we obtained by treatment of the nitrolysis system at −40° with acetic anhydride were undoubtedly derived either from 1-hydroxymethyl-3,5-dinitro-1,3,5-triazacyclohexane (II) or 1-dimethylolaminomethyl-3,5-dinitro-1,3,5-triazacyclohexane (I). This is evident in the fact that the type of ester linkage obtained was dependent on the mode of addition of acetic anhydride. Since reaction in a side chain is more facile than in the ring (otherwise Cyclonite would not be the principal product under normal conditions of reaction) the first step in the formation of IV will be either esterification of II, or nitrolysis of I at linkage "A". In either case the product will be VII, wherein OR will be nitroxy or acetoxy depending on the relative concentrations of nitrogen pentoxide and acetic anhydride.* The second step, evidently slower than the first, involves nitrolysis of the ring at linkage "B". In consequence OR′ will preponderantly be acetoxy because of the excess of acetic anhydride when this slower reaction occurs. No other explanation can account for the isolation of IV ($R = NO_2$, $R' = CH_3CO$) largely uncontaminated with the two alternative symmetrical esters.

The evidence thus far presented by Dunning, Dunning, and ourselves cannot differentiate between I and II as the stable reaction intermediate from which dinitrodiazapiperidinium nitrate (VI) was derived by hydrolysis with water. A choice ought to be possible, however, if dimethylolnitramide (VIII) could be found in the hydrolyzate. If the intermediate were II then VIII ought to be found as well, whereas only formaldehyde and ammonia would be obtained if 1-dimethylolaminomethyl-3,5-dinitro-1,3,5-triazacyclohexane were the progenitor in the hydrolyzate which produced dinitropiperidinium nitrate (VI). A simple method for detection of VIII involves neutralization of the hydrolyzate with ammonia in presence of formalin, whereby 1, 5-endomethylene-3, 7-dinitro-1,3,5,7-tetracycloöctane (IX) is precipitated if dimethylolnitramide (VIII) is present (4).

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* *It is assumed that the equilibrium* $Ac_2O + 2HNO_3 \rightleftharpoons N_2O_5 + 2HOAc$ *prevails in the nitric acid–acetic anhydride system and that acetyl nitrate is practically absent. The presence of nitrogen pentoxide has been suggested by Jones and Thorn (8) and the absence of acetyl nitrate by the demonstration (9) that this substance will not cause nitrolysis of hexamine. It was surprising to observe that Dunning and Dunning (7) continually mention acetyl nitrate as a nitrolytic agent. If these authors actually used the nitric acid–acetic anhydride mixture then a correction ought to be issued by them in consideration of the danger in manipulation of true acetyl nitrate.*

Unfortunately, in the interest of exact correlation, the presence of VIII cannot be demonstrated in a reaction mixture containing more than 20 moles of nitric acid per mole of hexamine (4). For this reason the conditions which Vroom and Winkler probably used could not be simulated for this test. However when we used 20 moles of 97% nitric acid per mole of hexamine at −40° to −20° we were able to isolate IX in quantity representing 8% of the dimethylolnitramide which would have been formed by nitrolysis of 1-dimethylolaminomethyl-3,5-dinitro-1,3,5-triazacyclohexane (I) to give 1-methylol-3, 5-dinitro-1,3,5-triazacyclohexane, II. The other product of the reaction was dinitrodiazapiperidinium nitrate contaminated with hexamine dinitrate but not with Cyclonite. It is therefore evident that at least some of II has an appreciable lifetime under these reaction conditions. The low yield does not, of course, preclude the simultaneous presence of I.

In summary it should be observed that, while the isolation of 3, 5-dinitro-3, 5-diazapiperidinium nitrate does not establish it as a stable intermediate in the nitrolysis of hexamine to Cyclonite, it cannot be excluded as an individual in the reaction sequence which is involved in the complete nitrolysis. Its ease of nitration, characteristic of a weak secondary amine (6) precludes the necessity for nitramine formation by nitrolysis, which has been observed with a less easily nitrated amine (2). No evidence yet at hand excludes the possibility that II may simply demethylolate to give VI which is easily nitrated to V.

Experimental*

3, 5-Dinitro-3, 5-diazapiperidinium Nitrate (VI) and Cyclonite, V

The requisite concentration of nitric acid was prepared from colorless 100% and 70% acids. A 125 ml. flask equipped with thermometer was immersed in a dry-ice bath until it began to freeze, was then transferred to a bath at −40°C., and the amine nitrate added at once. The flask was swirled for the requisite time and then chilled in the dry-ice bath while sufficient ice was added at once to bring the volume to 50 ml. The temperature rose to about −18° during this dilution. When the mixture had warmed to 0° it was filtered and the solid washed with cold 95% ethanol and ethyl ether. The vacuum-dried product melted variously from 98° to 103°C. regardless of the content of Cyclonite.

The amount of Cyclonite was determined by treating 1/10th gm. samples of product with 1.5 ml. of 70% nitric acid. After the mixture was heated to boiling it was let stand without additional heat until strenuous decomposition occurred after several minutes. After dilution with 2.5 ml. of water the Cyclonite was filtered and washed with ethanol and ether. The vacuum-dried product melted variously from 196°-202°C. Recrystallization from 70% nitric acid raised this melting point to 204°-205°.

The yields of Cyclonite obtained in this manner do not include those amounts dissolved in the reaction liquors. If such reaction liquors are boiled until gas evolution is complete and then are cooled and half neutralized with alkali,

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* *All melting points have been corrected against reliable standards.*

additional Cyclonite is precipitated which augments the original yield by 0.5-2.5%. The yields reported in Tables I, II, and III represent Cyclonite isolated from unboiled reaction liquors.

3, 7-Endomethylene-1, 5-dinitro-1, 3, 5, 7-tetrazacycloöctane (IX)

The procedure was identical with that described above except that 2.66 gm. (0.01 mole) of hexamine dinitrate was treated with 8 ml. (0.20 mole) of 97% nitric acid at −45° to −25° over two minutes and then poured into fine ice. After five minutes the diluted reaction mixture was filtered rapidly at −15°. The filtrate was received into 150 gm. of ice containing 2 ml. of formalin. This cold filtrate was rapidly but cautiously and repeatedly neutralized with about 18 ml. of concentrated ammonia to pH 5.6. After three hours at +5° the endomethylenedinitrotetrazacycloöctane was filtered off, wt. 0.83 gm. This 4% yield was identified by mixed melting point. Decomposition with hot 70% nitric acid did not yield any Cyclonite.

1-Acetoxy-7-nitroxy-2, 4, 6-trinitro-2, 4, 6-triazaheptane (IV, R = NO_2; R′ = CH_3CO)

After 20 ml. (0.47) mole) of 97% nitric acid had been chilled to −45°C. and had partially crystallized it was treated at once with 2.66 gm. (0.01 mole) of hexamine dinitrate. The mixture was stirred for one minute while the temperature rose to −35°C. and then was chilled to −55° during one minute. To this stirred mixture was added over seven minutes 48.5 ml. (0.5 mole) of acetic anhydride with cooling so that the temperature was maintained between −35° and −25°.

A precipitate (Cyclonite, V) began to form after about half the anhydride was added. When the addition was complete the suspension was warmed to −20°C. and filtered. The Cyclonite (1.25 gm. or 56% of theoretical) melted at 204.5°-205°. It was evidently free from 1,3,5,7-tetranitro-1,3,5,7-tetrazacycloöctane (3) since 70% could be recovered (m.p. 205°-206°) by destruction of unstable impurities with boiling nitric acid.

The filtrate from which the Cyclonite was removed was diluted into 200 gm. of finely ground ice, and 120 ml. of 40% aqueous potassium hydroxide was added. The vacuum-dry compound which precipitated weighed 1.60 gm. (m.p. 126°-160°C.) after washing with cold ethanol and ether. This product was extracted with 12 ml. of dry acetone at 25°C. to leave 0.6 gm. of potassium nitrate. The extract was diluted with 30 ml. of petroleum ether (b.p. 40°-60°). The precipitate (0.62 gm.) melted at 143°-143.5°. Repeated purification from acetone–petroleum ether increased this melting point to 146°-147°C. (decomp.). Calc. for $C_6H_{11}N_7O_{11}$: C, 20.2; H, 3.11; N, 27.4%. Found: C, 19.8; H, 2.96; N, 27.9%. When this compound was crystallized by three minute reflux in ethanol it was converted to 1-acetoxy-7-ethoxy-2,4,6-trinitro-2,4,6-triazaheptane, m.p. 107°-108° (IV, R = Et, R′ = CH_3CO) (5). Calc. for $C_8H_{16}N_6O_9$: C, 28.5; N, 24.7%. Found: C, 28.2; N, 24.8%. Further proof was obtained by treatment of IV (R = NO_2, R′ = CH_3CO) with sodium acetate in acetic acid. It was thus converted to IV (R, R′ = CH_3CO) and identified by melting point, mixed melting point, and comparison of the X-ray diffraction patterns.

The principal lines of the X-ray diffraction patterns are recorded for these substances in Table IV together with that of 1-ethoxymethyl-3,5-dinitro-1,3,5-triazacyclohexane (VII, R = Et) in order to show nonidentity of the latter (7) with the compound specified as IV (R = Et, R′ = CH_3CO).

TABLE IV

X-RAY DIFFRACTION; CU, Kα RADIATION; d, kX

Substance	Intensity, I/I_0									
	1	2	3	4	5	6	7	8	9	10
IV (R = NO_2, R′ = Ac)	4.57	3.31	4.76	2.80	12.2	3.03	6.15	4.11	3.73	5.11
	2.92	3.48								
IV (R = Et, R′ = Ac)	2.37	1.89	4.14	4.52	6.13	3.26	2.69	2.97	3.92	5.20
IV (R, R′ = Ac)	8.56	2.10	4.32	3.03	3.28	2.89	3.75	13.1	3.97	5.08
	6.33	4.77	1.97	3.38	2.95	2.77	2.72	3.61	4.06	4.56
VII (R = Et)	2.56	7.31	2.46	4.03	3.13	3.04	3.79	3.62	8.06	5.77
	2.24	2.83	2.33	2.67	2.89	6.69	6.13	3.40	4.56	5.20

1, 7-Diacetoxy-2, 4, 6-trinitro-2, 4, 6-triazaheptane

The nitrolysis was identical with that of the previous experiment. The reaction mixture at −55° was then added over 45 sec. to 0.5 mole of acetic anhydride at −70°C. The temperature of the cooled mixture rose to −35° and then receded to −50° where it was maintained for five minutes. A precipitate appeared after the second minute. The suspension was warmed to −35° during three minutes and then was filtered to remove 0.75 gm. of Cyclonite, m.p. 202°-204°.

The filtrate was diluted into 200 gm. of fine ice to which 130 ml. of 40% aqueous potassium hydroxide was added. The vacuum-dry precipitate weighed 1.40 gm. after filtration and cold ethanol- and ether-washing, m.p. 152°-180° (soft at 142°). Decomposition of an aliquot with hot 70% nitric acid showed that it contained 15% of Cyclonite, augmenting the yield of this substance to 44% of theoretical.

The crude product was extracted with hot chloroform and this evaporated extract crystallized from carbon tetrachloride and then from 1 : 4 water–ethanol to yield 0.52 gm. (15% of theoretical) of 1,7-diacetoxy-2,4,6-trinitro-2,4,6-triazaheptane, m.p. 157°. A mixed melting point with an authentic sample was not depressed, and the X-ray powder patterns for the two samples were identical.

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