

A Stepwise Strategy for the Synthesis of HMX from 3,7-Dipropionyl-1,3,5,7-Tetraazabicyclo[3.3.1]Nonane

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Abstract: 1,3,5,7-Tetranitro-1,3,5,7-tetraazacyclooctane (HMX) is one of the most powerful and widely used explosives. A new method for the synthesis of HMX from 3,7-dipropionyl-1,3,5,7-tetraazabicyclo[3.3.1]nonane (DPPT) was investigated. Two important intermediates, 1,5-dipropionyl-3-nitroso-7-nitro-1,3,5,7-tetraazacyclooctane (DPNNO) and 1,5-dipropionyl-3,7-dinitro-1,3,5,7-tetraazacyclooctane (DPDN), were isolated from the reaction mixture. The reaction mechanism, involving a nitrolysis-nitrosolysis-nitrolysis-nitrolysis process, was proposed and verified by the ¹H-

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NMR tracking. Based on the reaction mechanism, a stepwise method to prepare HMX from DPPT was developed. DPPT could be efficiently and smoothly converted to DPNNO in red fuming nitric acid with excellent yield up to 94.2 %. The influence factors on the yields of HMX such as reaction temperature, loading amounts of N₂O₅ were investigated. Under the optimized conditions, HMX was obtained with a satisfactory yield of 85.0 %. The overall yield of the stepwise procedure was as high as 80.0 %.

1 Introduction

1,3,5,7-Tetranitro-1,3,5,7-tetraazacyclooctane (HMX) is one of the most popular used explosives with excellent performance [1]. Until now, the Bachmann process is the predominant method in the industrial production of HMX [2]. However, this method has undesirable features including poor yield, excessive usage of acetic anhydride and acetic acid, difficult workup process and high cost [3]. Therefore, a number of preparation methods have been developed (Scheme 1). Among them, 3,7-diacetyl-1,3,5,7-tetraazabicyclo[3.3.1]nonane (DAPT) can be easily synthesized from hexamine (HA) in good yield [4]. Unfortunately, one-pot synthesis of HMX from DAPT by nitrolysis with traditional nitration systems was found to be inefficient and give low yield. However, with the assistance of ultrasonic irradiation, the reaction proceeded smoothly and afforded HMX in 67 % yield [5]. DAPT can be converted to 1,5-diacetyl-3,7-dinitro-1,3,5,7-tetraazacyclooctane (DADN), 1,5-diacetyl-3-nitroso-7-nitro-1,3,5,7-tetraazacyclooctane (DANNO) and 1,3,5,7-tetraacetyl-1,3,5,7-tetraazacyclooctane (TAT) [6]. Although the nitrolysis of DADN, DANNO or TAT can produce HMX with higher yield, the drastic reaction conditions such as stronger nitration system, higher reaction temperature and longer reaction time are required, because the strong electron-withdrawing property of acetyl group makes it difficult to be replaced by NO₂⁺ [7]. It's interesting that *N*-propionyldialkyamines could be efficiently and smoothly nitrolyzed to *N*-nitramines [8]. The nitrolysis of 1,3,5-triacetyl-1,3,5-triazacyclohexane (TRAT) and 1,3,5-tripropionyl-1,3,5-triazacyclohexane (TRAP) under classical nitrolysis conditions was investigated. The results showed that TRAP af-

firmed 1,3,5-trinitro-1,3,5-triazacyclohexane (RDX) in a higher yield than TRAT. The reason was attributed to the easier departure of propionyl group than acetyl group with the attacking of NO₂⁺ [9]. However, the nitrolysis of 3,7-dipropionyl-1,3,5,7-tetraazabicyclo[3.3.1]nonane (DPPT), prepared from urotropine by propionylation, is relatively unexploited compared to other methods for preparing HMX [4a]. DPPT has only been converted to 1,5-dipropionyl-3,7-dinitro-1,3,5,7-tetraazacyclooctane (DPDN) or 1,3,5,7-tetrapropionyl-1,3,5,7-tetraazacyclooctane (TPT) [10].

3,7-Dinitro-1,3,5,7-tetraazabicyclo[3.3.1]nonane (DPT) is also an important precursor for HMX preparation, unfortunately, nitrolysis in a series of nitration systems afforded HMX inevitably with a yield about 60 % [11]. Recently, a new stepwise protocol for the reaction of DPT in fuming HNO₃ has been established and a new reaction mechanism for the formation of HMX via 1-nitroso-3,5,7-trinitro-1,3,5,7-tetraazacyclooctane (MNX) was proposed [12]. And this stepwise procedure afforded HMX with a yield up to 78 %, much higher than traditional one-pot nitrolysis protocol [12b, c].

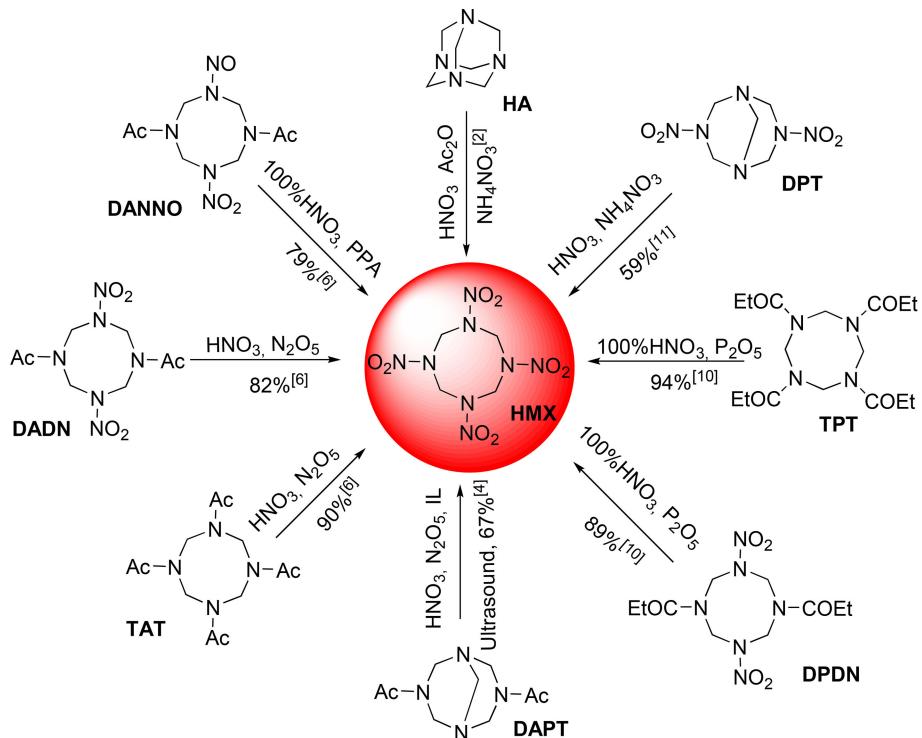
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Scheme 1. Synthetic paradigms for HMX of previous work.

Similar to DPT, DPPT has the *N,N'*-methylene motif. In this work, two intermediate 1,5-dipropionyl-3-nitroso-5-nitro-1,3,5,7-tetraazacyclooctane (DPNNO) and 1,5-dipropionyl-3,7-dinitro-1,3,5,7-tetraazacyclooctane (DPDN), were isolated from the reaction mixture of DPPT in fuming $\text{HNO}_3/\text{N}_2\text{O}_5$. And a possible mechanism for the conversion of DPPT to HMX was proposed. The reaction proceeds through four successive steps including nitrolysis, nitrosolysis and another two nitrolyses. Some evidences for the reaction mechanism were obtained by $^1\text{H-NMR}$ tracking. According to the mechanism, we designed and accomplished a synthetic route to prepare HMX from DPPT.

2 Experimental Section

2.1 General Information

DPPT, N_2O_5 , N_2O_4 and 100% HNO_3 were prepared by reported procedure [11f]. Other chemicals (AR grade) were obtained from commercial sources and used without further purification. $^1\text{H-NMR}$ and $^{13}\text{C-NMR}$ spectra were recorded on a Bruker Avance-III DRX spectrometer operating at 500 MHz and 125 MHz respectively, using CDCl_3 or DMSO-d_6 as solvent. Electrospray ionization (ESI) mass spectra were recorded on a Finnigan TSQ Quantum ultra-AM mass spectrometer (Thermo Fisher Scientific, Waltham, MA USA). IR spectra were recorded with a Nicolet FTIR IS10

Spectrometer. The melting points were determined with a WRS-1B melting point apparatus. Elemental analysis of all new compounds was performed by using a Vario EL III CHN elemental analyzer. X-ray intensity data were collected on a Bruker D8 CMOS detector employing graphite-monochromated Mo-K α radiation ($\lambda=0.71073 \text{ \AA}$). The purity of HMX was tested by high performance liquid chromatography (HPLC) with a reverse phase micro C18 column (waters Alliance HPLC system) and the eluent was a mixture of methanol and water (70:30) with a flow rate of 1 mL/min.

2.2 General Procedure for the Synthesis of DPPT

To the solution of hexamine (7 g, 50 mmol) and anhydrous sodium acetate (19.5 g, 150 mmol) in 50 mL water was added dropwise propionic anhydride (13.1 g, 150 mmol) with stirring at 5 °C. After stirring 1 hour, the solution was evaporated to dryness in *vacuo*. The wet, acid solid was dissolved in 25 mL water and the solution made weakly alkaline with sodium carbonate. Evaporation to dryness gave a white solid, and the solid was extracted with acetone (30 × 3 mL). The combined extracts were evaporated to gain crude product, and the pure DPPT was obtained through the recrystallization with acetone. $^1\text{H-NMR}(\text{CDCl}_3, 500 \text{ MHz})$: 5.74 (d, 2H, $J=15 \text{ Hz}$), 5.00 (d, 2H, $J=10 \text{ Hz}$), 4.71 (d, 2H, $J=10 \text{ Hz}$), 4.23 (s, 2H), 4.22(d, 2H, $J=15 \text{ Hz}$), 2.48–2.41 (m, 2H),

2.19–2.11 (m, 2H), 1.09–1.06 (m, 6H) ppm. ^{13}C -NMR (CDCl_3 , 125 MHz): 172.37, 70.61, 66.19, 62.47, 25.87, 8.83 ppm.

2.3 General Procedure for the Isolation of Stable Intermediates

To the solution of N_2O_5 (2.3 g, 21 mmol) in fuming HNO_3 (7.4 mL, 168 mmol) was added NH_4NO_3 (0.34 g, 4.2 mmol). Then DPPT (1 g, 4.2 mmol) was added under vigorous stir at -10°C and the temperature was strictly controlled below 0°C during the feeding course. After 5 minutes, the mixture was quickly poured into ice water (30 mL) to quench the reaction. The mixture was neutralized by sodium bicarbonate, while precipitate formed gradually. Two compounds, M_1 and M_2 , were obtained via column chromatography.

2.4 General Procedure for the NMR Tracking

To the solution of N_2O_5 (31 g, 292 mmol) in fuming HNO_3 (100 mL, 2.3 mol) was added NH_4NO_3 (4.7 g, 58.3 mmol). Then DPPT (14 g, 58.3 mmol) was added under vigorous stir at -10°C and the temperature was strictly controlled below 0°C during the feeding course. The reaction mixture (0.5 mL) was sampled every 15 minutes and poured into ice water. After 1 hour, the reaction was warmed to 30°C , then the reaction mixture (0.5 mL) was sampled every 15 minutes and poured into ice water. The samples were neutralized by sodium bicarbonate, while precipitate formed gradually. Then, the precipitate was separated centrifugally, washed with water and dried, the solid samples were dissolved in CDCl_3 or DMSO-d_6 and detected by ^1H -NMR.

2.5 General Procedure for the Synthesis of DPNNO from DPPT

To fuming HNO_3 (7.4 mL 168 mmol), N_2O_4 and NH_4NO_3 were added in succession. Then DPPT (1 g, 4.2 mmol) was added slowly under vigorous stir at a certain temperature and let reacting for 10 minutes. The reaction was quenched by ice water (30 mL) and neutralized by sodium bicarbonate. The precipitated product was filtered, washed with water and dried, DPNNO was achieved as white powder.

2.6 General Procedure for the Synthesis of HMX from DPNNO

DPNNO (1 g, 3.3 mmol) was added into 100% HNO_3 (6.9 mL, 165 mmol)/ N_2O_5 under vigorous stir at 0°C , the reaction mixture was then warmed to a certain temperature. After a certain time, water (0.3 mL) was added. The reaction mixture was stirred for 15 minutes between 60°C and 65°C , then cooled to 40°C , additional water (10 mL) was added.

After the same workup described above, HMX was gotten with an awesome purity $\geq 99\%$. ^1H -NMR (DMSO-d_6 , 500 MHz): 6.03 (s, 8H) ppm. ^{13}C -NMR (DMSO-d_6 , 125 MHz): 63.92 ppm; IR (ν/cm^{-1}): 3037, 1526, 1261, 1139, 942, 759.

3 Results and Discussion

3.1 Characterization of M_1 and M_2

3.1.1 Characterization of M_1

M_1 is a white powder with a melting point at 172°C . The characteristic data listed below suggested that it was 1,5-dipropionyl-3,7-dinitro-1,3,5,7-tetraazacyclooctane (DPDN). IR (ν/cm^{-1}): 2983, 2943, 1669, 1531, 1271, 762 cm^{-1} . ^1H -NMR (DMSO-d_6): 5.52 (s, 8H), 2.63 (q, $J=7.2\text{ Hz}$, 4H), 1.01 (t, $J=5.0\text{ Hz}$) ppm. ^{13}C -NMR (DMSO-d_6): 173.05, 62.50, 59.69, 25.15, 8.95 ppm. ESI-MS: m/z [$(\text{M}+\text{H})^+$]: 319.23. $C_{10}\text{H}_{18}\text{N}_6\text{O}_6$ calcd. C 37.74; N 26.40; H 5.70; found: C 37.78; N 26.34; H 5.73.

3.1.2 Characterization of M_2

M_2 is a white powder with a melting point at 135°C . The characteristic data listed below suggested that it was 1,5-dipropionyl-3-nitroso-7-nitro-1,3,5,7-tetraazacyclooctane (DPNNO). IR (ν/cm^{-1}): 2995, 2944, 1683, 1525, 1435, 1261, 1049, 810, 605 cm^{-1} . ^1H -NMR (CDCl_3): 5.93–5.09 (m, 8H), 2.61–2.46 (m, 4H), 1.21–1.16 (m, 6H) ppm. ^{13}C -NMR (DMSO-d_6): 174.11, 173.47, 63.84, 63.37, 62.72, 61.73, 61.11, 60.33, 58.95, 58.38, 57.07, 56.58, 54.79, 54.59, 26.01, 25.46, 8.70, 8.57. ESI-MS: m/z [$(\text{M}+\text{H})^+$]: 303.12. $C_{10}\text{H}_{18}\text{N}_6\text{O}_5$ calcd. C 39.73; N 27.80; H 6.00; found: C 39.75; N 27.76; H 6.02.

Single crystal analysis further supported the structure of M_2 (Figure 1). Crystallographic data of DPNNO were listed following: $C_{10}\text{H}_{18}\text{N}_6\text{O}_5$, orthorhombic, $Pbca$, $a=14.1386(9)\text{ \AA}$, $b=6.1281(4)\text{ \AA}$, $c=15.4692(10)\text{ \AA}$, $V=1340.29(15)\text{ \AA}^3$, $Z=4$, calculated density = $1.498\text{ g}\cdot\text{cm}^{-3}$, absorption coefficient = 0.121 mm^{-1} , $F(000)=640$, crystal size = $0.280\times 0.090\times 0.050\text{ mm}^3$, $R_1=0.0483$, $R_2=0.0530$. And the CCDC number is 1858017. Further information about the crystal-structure determination is given in Supporting Information.

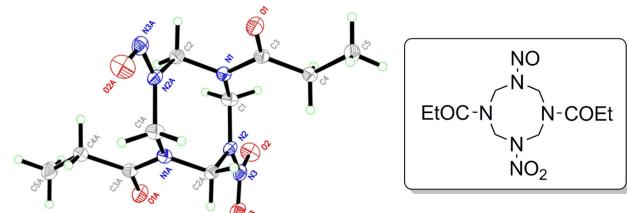


Figure 1. Molecular structure of DPNNO.

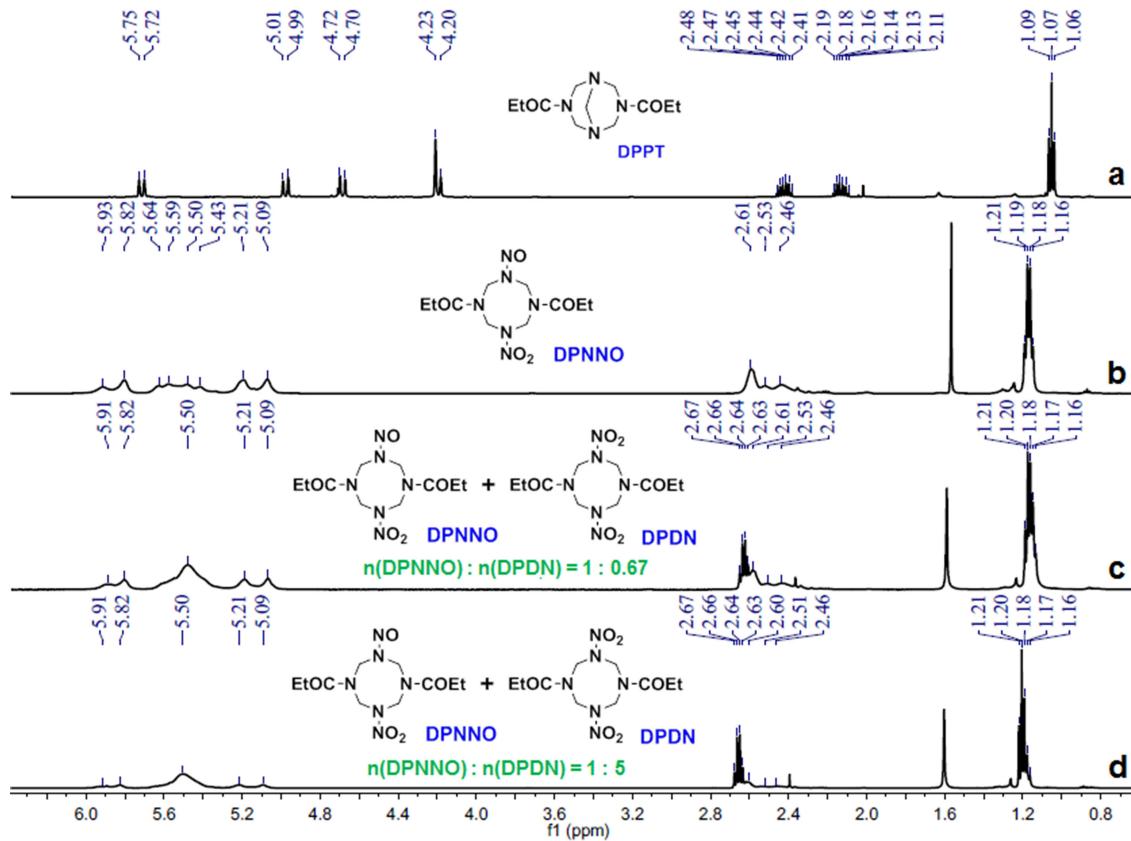


Figure 2. (a) ^1H -NMR spectrum of DPPT; ^1H -NMR spectrum of samples taken from the reaction mixture under -10°C at: (b) the end of the feeding course; (c) 0.5 hour; (d) 1 hour.

3.2 Mechanism Study on the Synthesis of HMX from DPPT in Fuming $\text{HNO}_3/\text{N}_2\text{O}_5$

To investigate the nitrolysis mechanism of DPPT, the process was monitored with ^1H -NMR test every 15 minutes. As shown in Figure 2a, the chemical shifts of DPPT are present at 5.75, 5.72, 5.01, 4.99, 4.72, 4.70, 4.23, 4.20, 2.48~2.41, 2.19~2.11 and 1.09~1.06 ppm [4a]. The ^1H -NMR spectrum of the sample taken at the end of the feeding course exhibits chemical shifts of DPNNO at 5.93~5.08, 2.60~2.45 and 1.20~1.16 ppm (Figure 2b). That is, DPPT disappeared immediately after the addition course. Then the amount of nitroso intermediate DPNNO increased quickly. The chemical shifts at 5.50, 2.67~2.63 and 1.22~1.19 ppm belong to DPDN. Comparing Figure 2c with Figure 2d, it was found that the proportion of DPDN increased along with the gradual disappearance of DPNNO. After 1 hour, the reaction was warmed to 30°C . According to Figure 3, HMX, exhibits chemical shift at 6.03 ppm, gradually formed along with the disappearance of DPDN.

Recently, *N*-hydroxymethylmorpholine was proved to be an intermediate in the nitrolysis of dimorpholinomethane with fuming HNO_3 [13a]. And it's generally accepted that 1-hydroxymethyl-3,5,7-trinitro-1,3,5,7-tetraazacyclooctane and

1,5-diacetyl-3-hydroxymethyl-7-nitro-1,3,5,7-tetraazacyclooctane are key intermediates in the nitrolysis of DPT and DAPT, respectively [14]. Moreover, it was found that *N*-hydroxymethyl dialkylamines or 1-hydroxymethyl-3,5,7-trinitro-1,3,5,7-tetraazacyclooctane reacted with NO^+ to afford the *N*-nitrosoamines or 1-nitroso-3,5,7-trinitro-1,3,5,7-tetraazacyclooctane (MNX) and release formaldehyde, which would reduce nitric acid to nitrous acid [12c, 13]. Furthermore, DFT calculations reveal an essential feature that ammonia, merged from the decomposition of ammonium salts, acts as a Lewis base catalyst. The nitrosolysis was promoted by a hydrogen-bonding interaction between hydroxymethyl group of active intermediate, NH_3 and H_2O molecules [13a]. Based on these results, we proposed a plausible mechanism for the synthesis of HMX from DPPT, Scheme 2. First, HNO_3 attacks DPPT to form active intermediate 1,5-dipropoinyl-3-hydroxymethyl-7-nitro-1,3,5,7-tetraazacyclooctane. HNO_2 in fuming HNO_3 is converted to NO^+ , and some free NH_3 emerges through the equilibrium with NH_4NO_3 . The active intermediate is conjoined to one ammonia molecule and three water molecules by hydrogen bonds. As a result, a prereactive complex is formed *in situ* [13a]. Then NO^+ attacks the bicyclic intermediate to form DPNNO and release formaldehyde. Formaldehyde is oxidized by HNO_3 to yield

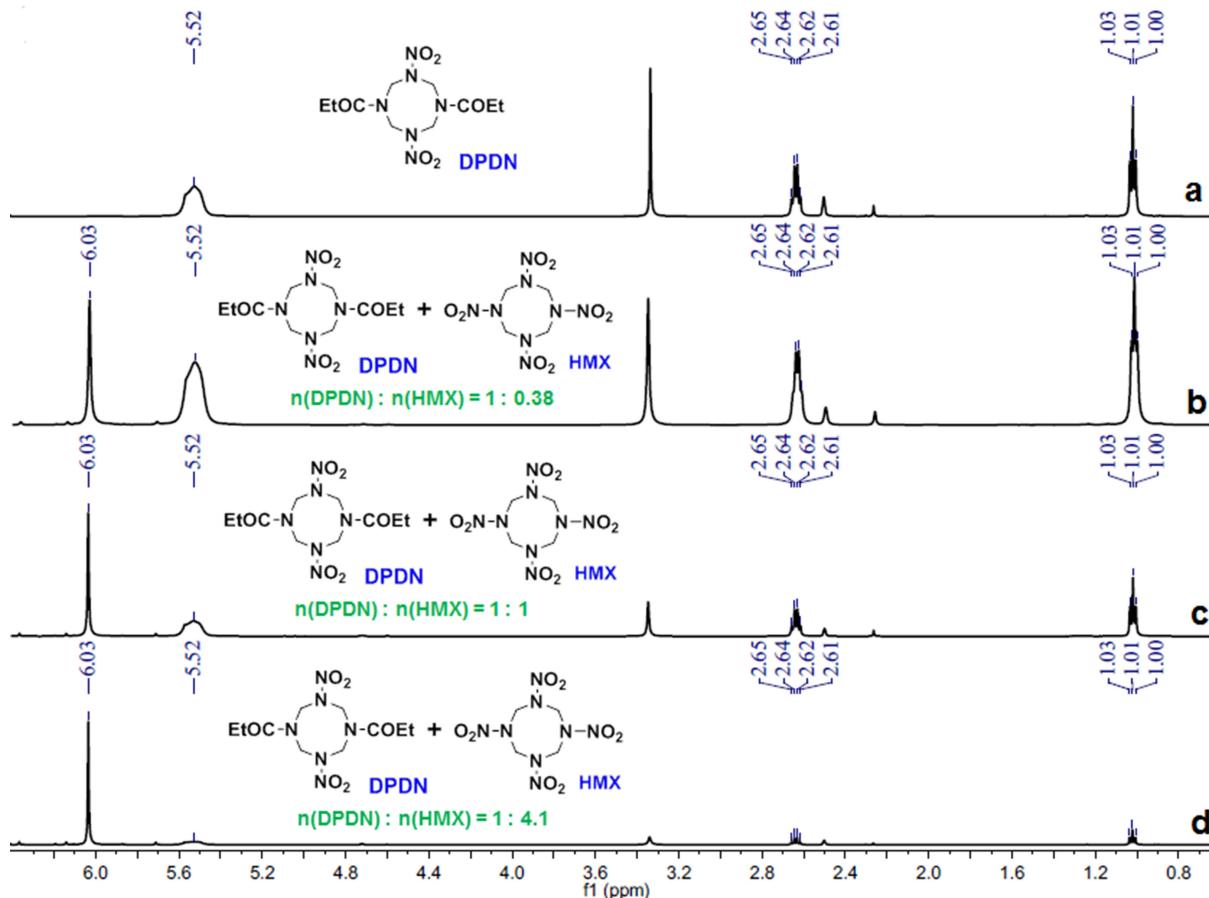


Figure 3. ^1H -NMR spectrum of samples taken from the reaction mixture under 30°C at: (a) 1.5 hours; (b) 2 hours; (c) 2.5 hours; (d) 3 hours.

HNO_2 and HCOOH [12c, 13]. Subsequently, the nitroso functionality in DPNNO is converted to nitro group by classical nitrolysis, and DPDN undergoes another nitrolysis to afford the target product HMX.

3.3 New Route for the Synthesis of HMX from DPPT

We tentatively explored the one-pot process for the synthesis of HMX from DPPT under a series of nitration agents such as fuming $\text{HNO}_3/\text{NH}_4\text{NO}_3$, 100% $\text{HNO}_3/\text{NH}_4\text{NO}_3$, fuming $\text{HNO}_3/\text{NH}_4\text{NO}_3/\text{N}_2\text{O}_5$ and fuming $\text{HNO}_3/\text{NH}_4\text{NO}_3/\text{H}_2\text{SO}_4$. It's disappointed that the yields of HMX were inevitably less than 20%. Zhang and Yoshida found that adding N_2O_4 or NaNO_2 into the nitrolysis mixture of DPT or DAPT would increase the yield of MNX or DANNO dramatically [7f, g, 12b, c]. Therefore, we designed a new synthetic route to prepared HMX (Scheme 3). At first, red fuming HNO_3 (fuming $\text{HNO}_3/\text{N}_2\text{O}_4$) was used to prepare DPNNO with excellent yield. Then, DPNNO was efficiently nitrolyzed in 100% $\text{HNO}_3/\text{N}_2\text{O}_5$ to afford HMX. The results strongly supported the mechanism hypothesis illustrated in Scheme 2.

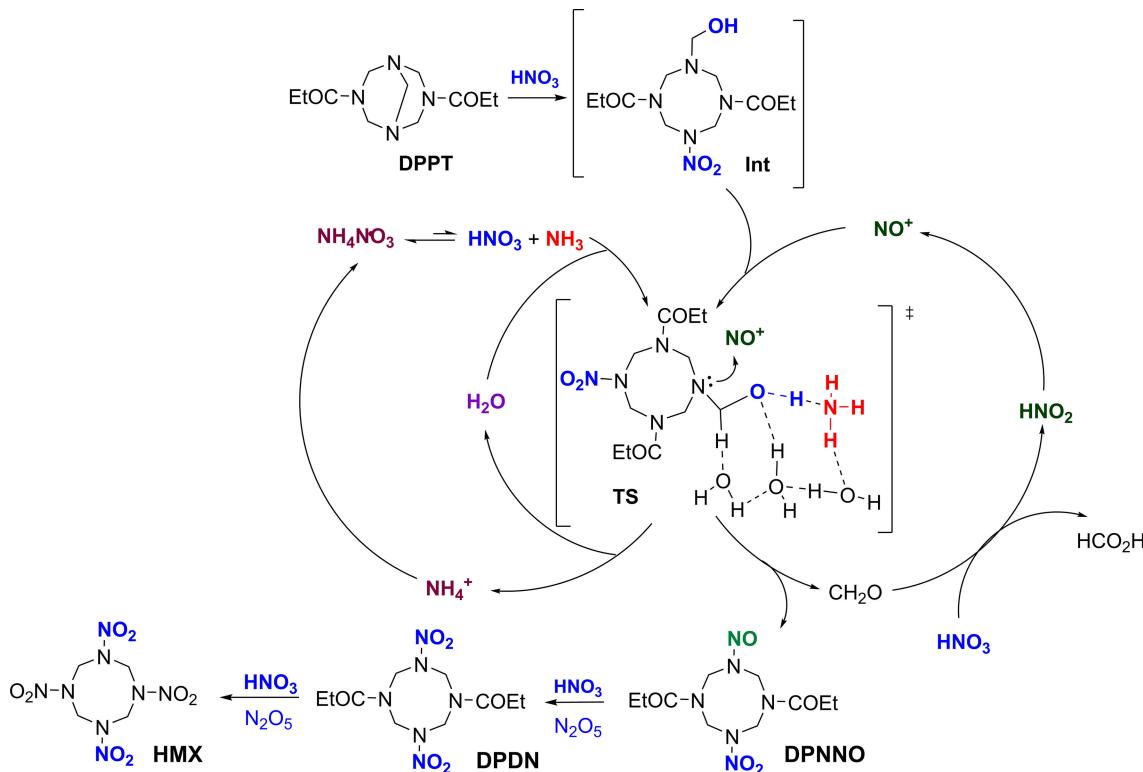
3.3.1 Preparation of DPNNO in Red Fuming $\text{HNO}_3/\text{NH}_4\text{NO}_3$ System

The reaction conditions for the preparation of DPNNO from DPPT were optimized first. As shown in Table 1, the yield ascended along with the increase of N_2O_4 (entries 2–4).

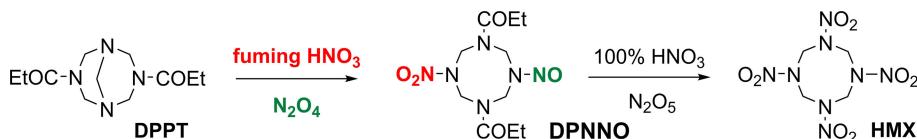
Table 1. Optimization of reaction conditions for the preparation of DPNNO^[a].

entry	n(N_2O_4):n(DPPT)	Temp/°C	yield of DPNNO/% ^[b]
1	0	-15	78.4
2	0.5:1	-15	85.6
3	0.75:1	-15	92.6
4	1:1	-15	94.2
5	1.25:1	-15	93.6
6	1.5:1	-15	93.3
7	1:1	5	88.0
8	1:1	-5	90.4
9	1:1	-25	94.8
10	1:1	-35	91.5

[a] DPPT (1 g, 4.2 mmol), fuming HNO_3 (7.4 mL, 168 mmol), NH_4NO_3 (1 equiv). [b] isolated yields.



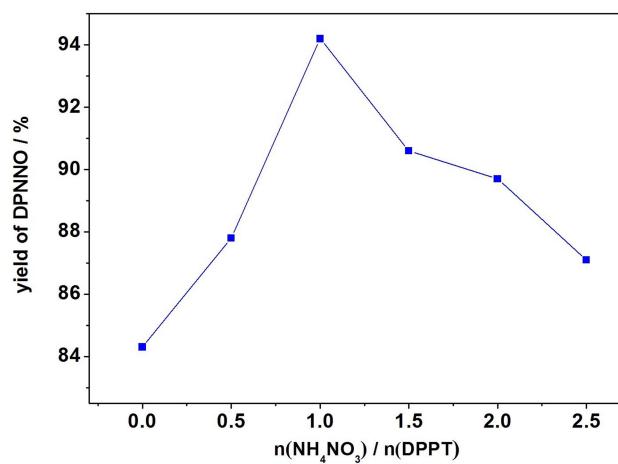
Scheme 2. Plausible mechanism for the synthesis of HMX from DPPT.



Scheme 3. Stepwise strategy for the synthesis of HMX from DPPT.

DPNNO was achieved in an excellent yield of 94.2% (entry 4) when 1 equivalent of N_2O_4 was used. However, the yield remained almost unchanged when the dosage of N_2O_4 exceeded 1 equivalent (entries 5, 6). After that, the reaction temperature was studied in the range of $5^\circ\text{C} \sim -35^\circ\text{C}$. As can be seen from Table 1, the yield increased along with the decline of reaction temperature (entries 4, 7–9). The highest yield of 94.8% was obtained when the reaction was carried out at -25°C , which might be attributed to the inhibition of the cleavage of cyclic structure at relative low temperature [11]. Lower temperature resulted in a little lower yield (entry 10), which was accounted for the higher viscosity and lower solubility of NH_4NO_3 and DPPT in the reaction system at -35°C . Less than 1% of yield improvement was achieved when the reaction temperature fell from -15°C to -25°C (entries 4, 9), so -15°C was applied for next study.

It's well known that the addition of NH_4NO_3 is necessary for the preparation of MNX from DPT [12]. Therefore, we further studied the effect of NH_4NO_3 dosage on the yield of DPNNO. As shown in Figure 4, the yield ascended initially

Figure 4. The effect of molar ratio of NH_4NO_3 to DPPT on the yield of DPNNO. Reaction conditions: DPPT (1 g, 4.2 mmol); fuming HNO_3 (7.4 mL 168 mmol); N_2O_4 (1 equiv); -15°C .

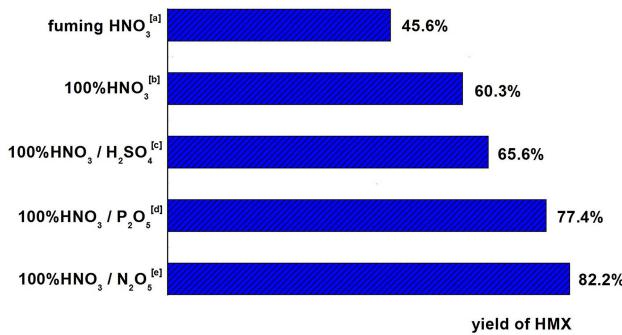


Figure 5. Synthesis of HMX from DPNNO with a series of nitrolyzing agents. Reaction conditions: DPPT (1 g, 3.3 mmol); 50 °C; 30 min. [a] fuming HNO_3 (50 equiv); [b] 100% HNO_3 (50 equiv); [c] H_2SO_4 (30 equiv); [d] P_2O_5 (5 equiv); [e] N_2O_5 (5 equiv).

and then descended with the increase of NH_4NO_3 . The highest yield of 94.2% was obtained when 1 equivalent of NH_4NO_3 was used. According to our previous work, NH_4NO_3 released some NH_3 during the reaction and NH_3 acted as a Lewis base to lower the activation energy of the nitrosolysis of DPPT via a bicyclic transition state constructing by hydrogen bonds [13a, 14a]. More NH_4NO_3 would reduce the yield because it would lower the solubility of DPPT and elevate the viscosity of the reaction mixture. In comparison, when its dinitro analogue DPT was used as the substrate to prepare MNX, the optimal dosage of NH_4NO_3 was 2.5 equivalents [12]. This reason must be that DPT has higher solubility in nitric acid than DPPT. In fact, similar phenomenon, precipitation of substrate, was observed when more than 1 equivalent and 2.5 equivalents of NH_4NO_3 were used in the nitrolysis of DPPT and DPT respectively.

3.3.2 Preparation of HMX from DPNNO

A series of nitrolyzing agents were applied in the synthesis of HMX from DPNNO and the results were depicted in Figure 5. Only a low yield of 45.6% was obtained when the reaction was performed in fuming HNO_3 . Anhydrous HNO_3 resulted in higher yield (60.3%). Further elevation of the nitrolyzing strength would promote the yield. When 100% $\text{HNO}_3/\text{H}_2\text{SO}_4$, 100% $\text{HNO}_3/\text{P}_2\text{O}_5$ and 100% $\text{HNO}_3/\text{N}_2\text{O}_5$ were used, the yield of HMX increased to 65.6%, 77.4% and 82.2%, respectively.

It can be seen from Figure 5 that 100% $\text{HNO}_3/\text{N}_2\text{O}_5$ was the best reaction media for the nitrolysis of DPNNO. Subsequently, the effect of N_2O_5 dosage on the yield of HMX was investigated, and the results were shown in Figure 6. It was observed that the yield was improved distinctively along with the increase of N_2O_5 dosage. The reason must be that N_2O_5 can produce more NO_2^+ , which facilitated the nucleophilic nitrolysis. However, the yield would decrease when the amount of N_2O_5 exceeded 4 equivalents. The rea-

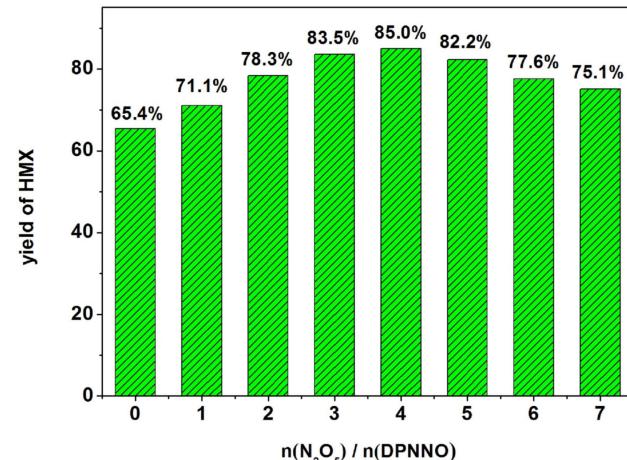


Figure 6. The effect of molar ratio of N_2O_5 to DPNNO on the yield of HMX. Reaction conditions: DPNNO (1 g, 3.3 mmol); 100% HNO_3 (50 equiv); N_2O_5 (5 equiv); 50 °C; 30 min.

son might be that too high nitrolyzing strength would reduce the reaction selectivity and result in some ring-opening side reaction to yield chain byproduct [11e–g].

The effect of reaction temperature in the range of 30 °C~80 °C on the yield of HMX was then examined and the results were listed in Table 2.

It was found that the yield of HMX went up along with the elevation of reaction temperature (entries 1–3), which could be attributed to the low reactivity of 100% $\text{HNO}_3/\text{N}_2\text{O}_5$ at relative low temperature. And further increase of the reaction temperature witnessed a sharp decrease of yield. When the reaction was performed at 80 °C, HMX was obtained with only 65.1% yield. Owing to its high volatility and instability, loss of N_2O_5 by decomposition at high temperature must be the main reason [11e–g]. Another possible reason is the destruction of the cyclic structure at high reaction temperature [11]. The effect of reaction time in the range 15~60 minutes on the yield of HMX was also studied (entries 3, 7–9). The results demonstrated that a yield as

Table 2. The effect of reaction temperature and reaction time on the nitrolysis of DPNNO.^[a]

entry	Temp/°C	time/min	yield of HMX/% ^[b]
1	30	30	67.2
2	40	30	76.5
3	50	30	85.0
4	60	30	78.6
5	70	30	76.3
6	80	30	65.1
7	50	15	74.4
8	50	45	83.7
9	50	60	80.2

[a] DPNNO(1 g, 3.3 mmol), 100% HNO_3 (6.9 mL, 165 mmol), N_2O_5 (4 equiv). [b] isolated yields.

high as 85.0% was achieved when the reaction was carried out for 30 minutes (entry 3). Shorter or longer time was unfavourable to the reaction. In comparison, when its diacetyl analogue DANNO was used as the substrate, more than 3 hours was required even the nitrolysis was performed in excess anhydrous HNO_3 and polyphosphoric acid under 60~65 °C, and the yield of HMX was comparable (79%) [6]. These results suggest that the substitution of propionyl by nitro through the attacking of NO_2^+ was easier than that of acetyl.

4 Conclusions

Two intermediates, 1,5-dipropionyl-3-nitroso-7-nitro-1,3,5,7-tetraazacyclooctane (DPNNO) and 1,5-dipropionyl-3,7-dinitro-1,3,5,7-tetraazacyclooctane (DPDN), were isolated from the nitrolysis of DPPT in fuming $\text{HNO}_3/\text{N}_2\text{O}_5$. Based on the $^1\text{H-NMR}$ monitor and our previous work, a reaction mechanism including nitrolysis, nitrosolysis and another two nitrolysis was proposed. Accordingly, a stepwise method to prepare HMX from DPPT was developed. DPPT could be efficiently and smoothly converted to DPNNO in red fuming HNO_3 with excellent yield up to 94.2%. The influence factors on the yields of HMX such as reaction temperature and reaction time, the loading amount of N_2O_5 were investigated. Under the optimized conditions, HMX could be obtained with satisfactory yield of 85.0%. The overall yield of the stepwise procedure was as high as 80.0%.

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