โฟโตเคมีในวัฏภาคไอของสารกลุ่มเมทิลพิริดีน

นางสาว ธารินี วงศ์นคร

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VAPOR PHASE PHOTOCHEMISTRY OF METHYLPYRIDINES

Miss Tharinee Vongnakorn

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By	Miss Tharinee Vongnakorn
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Thesis Advisor	Associate Professor Supawan Tantayanon, Ph.D.
Thesis Co-advisor	Professor James W. Pavlik, Ph.D.

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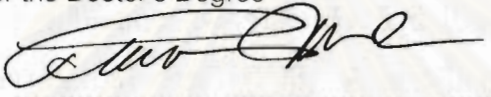

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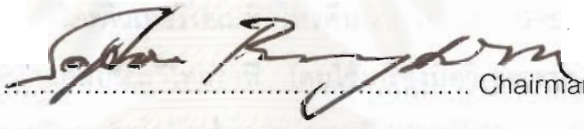

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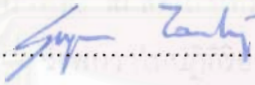

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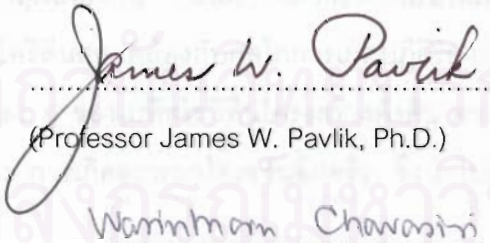

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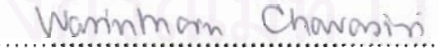

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ธารินี วงศ์นคร : โฟโตเคมีในวัฏภาคไอของสารกลุ่มเมทิลพิริดีน (VAPOR PHASE PHOTOCHEMISTRY OF METHYLPYRIDINES) อ.ที่ปรึกษา : รศ.ดร.ศุภวรรณ ตันตยานนท์, อ.ที่ปรึกษาร่วม : Prof. James W. Pavlik, Ph.D.; 205 หน้า. ISBN-917-17-6914-8.

สารในกลุ่มของเมทิลไพริดีนแต่ละชนิดสามารถเกิดปฏิกิริยาเคมีแสงในสภาวะไอได้สารผลิตภัณฑ์ที่อยู่ในกลุ่มของเมทิลไพริดีนที่มีโครงสร้างเป็นไอโซเมอร์กับสารตั้งต้น ปฏิกิริยาเคมีแสงของเมทิลไพริดีนนี้สามารถอธิบายได้ด้วย กลไกการเกิดปฏิกิริยาที่เกี่ยวเนื่องกับการเกิดพันธะระหว่างตำแหน่ง 2 และ 6 ของเมทิลไพริดีนโครงสร้างตั้งต้น ตามด้วยการเกิดการเคลื่อนย้ายของไนโตรเจนอะตอม และ การเกิดอะโรมาไทเซชันอีกครั้ง ซึ่งนำไปสู่การเกิดโครงสร้างของเมทิลไพริดีนผลิตภัณฑ์ดังกล่าวข้างต้น กลไกการเกิดปฏิกิริยาดังกล่าวนี้สามารถพิสูจน์ได้โดยอาศัยผลการทดลองจากปฏิกิริยาเคมีแสง ของเมทิลไพริดีนที่ถูกสังเคราะห์ขึ้นโดยไฮโดรเจนอะตอมถูกแทนที่ด้วยดิวเทอเรียมอะตอมดังต่อไปนี้ 2-ไตรดิวเทอริโอเมทิลไพริดีน-4,6-d_2 (2-4,6-d2), 3-เมทิลไพริดีน-2,6-d_2 (3-2,6-d2), และ4-ไตรดิวเทอริโอเมทิลไพริดีน-2,6-d_2 (4-2,6-d2) ปฏิกิริยาเคมีแสงเหล่านี้ ติดตามได้ด้วยเทคนิคแก๊สโครมาโทกราฟี โดยใช้เครื่องมือวิเคราะห์ประเภท เฟลมไอออไนเซชัน และ แมสสเปกโทรมิเทอร์ โครงสร้างของสารผลิตภัณฑ์ได้รับการยืนยันโดยการเปรียบเทียบข้อมูลทางโครมาโทกราฟฟี, แมสสเปกโทรเมทรี และ ตำแหน่งเคมิคอล์ชิป กับข้อมูลดังกล่าวของสารมาตรฐาน ซึ่งพบว่าในปฏิกิริยาเคมีแสงของกลุ่มเมทิลไพริดีนนี้สามารถเกิดผลิตภัณฑ์เป็นสารจำพวกกลุ่มเดียวกัน ผลการวิเคราะห์ยืนยันให้เห็นว่าการเกิดโฟโตทรานสโพสิชันของสารในกลุ่มเมทิลไพริดีนสอดคล้องกับกลไกการเกิดปฏิกิริยาที่ เกี่ยวเนื่องกับการเกิดพันธะระหว่างตำแหน่ง 2 และ 6 ของเมทิลไพริดีนโครงสร้างตั้งต้น ตามด้วยการเกิดการเคลื่อนย้ายของไนโตรเจนอะตอม และ การเกิดอะโรมาไทเซชันอีกครั้ง ซึ่งนำไปสู่การเกิดโครงสร้างของเมทิลไพริดีนผลิตภัณฑ์

ภาควิชา.....เคมี.....ลายมือชื่อนิสิต.....

สาขาวิชา.....เคมี.....ลายมือชื่ออาจารย์ที่ปรึกษา.....

ปีการศึกษา.....2547.....ลายมือชื่ออาจารย์ที่ปรึกษาร่วม.....

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KEY WORD: VAPOR PHASE PHOTOCHEMISTRY OF METHYLPYRIDINES

THARINEE VONGNAKORN : VAPOR PHASE PHOTOCHEMISTRY OF METHYLPYRIDINES THESIS ADVISOR : ASSOC.PROF. SUPAWAN TANTAYANON,Ph.D.; THESIS COADVISOR : PROF. JAMES W. PAVLIK, Ph.D.; 205 pp. ISBN-974-6914-8.

Irradiation of any one of the methylpyridine isomers **2**, **3**, or **4** in the vapor phase at 254 nm results in the formation of the other two. These interconversions are consistent with a mechanism involving 2,6-bonding, nitrogen migration, and re-aromatization. In order to gain further mechanistic information, 2-trideuteriomethylpyridine-4,6-d_2 (**2-4,6-d2**), 3-methylpyridine-2,6-d_2(**3-2,6-d2**), and 4-trideuteriomethyl-pyridine-2,6-d_2 (**4-2,6-d2**) were synthesized and their photochemistry studied in the vapor phase. The photoreactions were carried out with appropriate light sources and analyzed by ^{1}H-NMR, GLC and GC-MS. The product identification was performed by the comparison of their chromatographic and mass spectroscopic data with the chemical shift of authentic methylpyridines.

Department…….....Chemistry……...Student's signature…….....
Field of study.…….Chemistry……...…Advisor's signature…….....
Academic year 2004……Co-advisor's signature…….

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Finally, I would like to express my appreciation to my parents, brothers, sisters and friends for their support, devotion, and encouragement during the course of this work.

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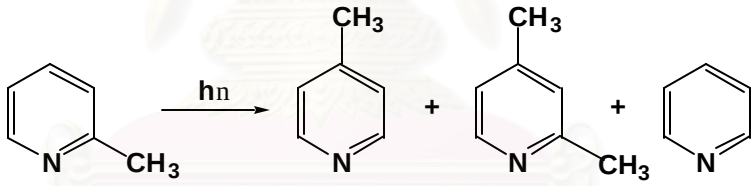
CHAPTER 1

INTRODUCTION

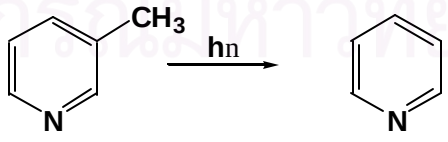
1.1 Vapor Phase Photochemistry of Methyl Substituted Pyridines

1.1.1 Methylpyridines

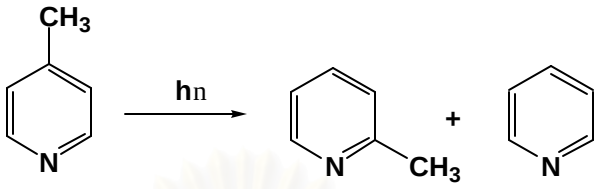
The first report of the vapor phase photochemistry of methyl substituted pyridines was published by Caplain and Lablache-Combier(1). Irradiations were performed with a Rayonnet R.S. reactor at 2537 Å in a quartz vessel for 1 hour, at a pressure of 10 mm Hg of starting material vapor. They reported that irradiation of 2-methylpyridine resulted in the formation of 4-methylpyridine, a transposition product, 2,4-lutidine, a methylation product, and pyridine, a demethylation product.



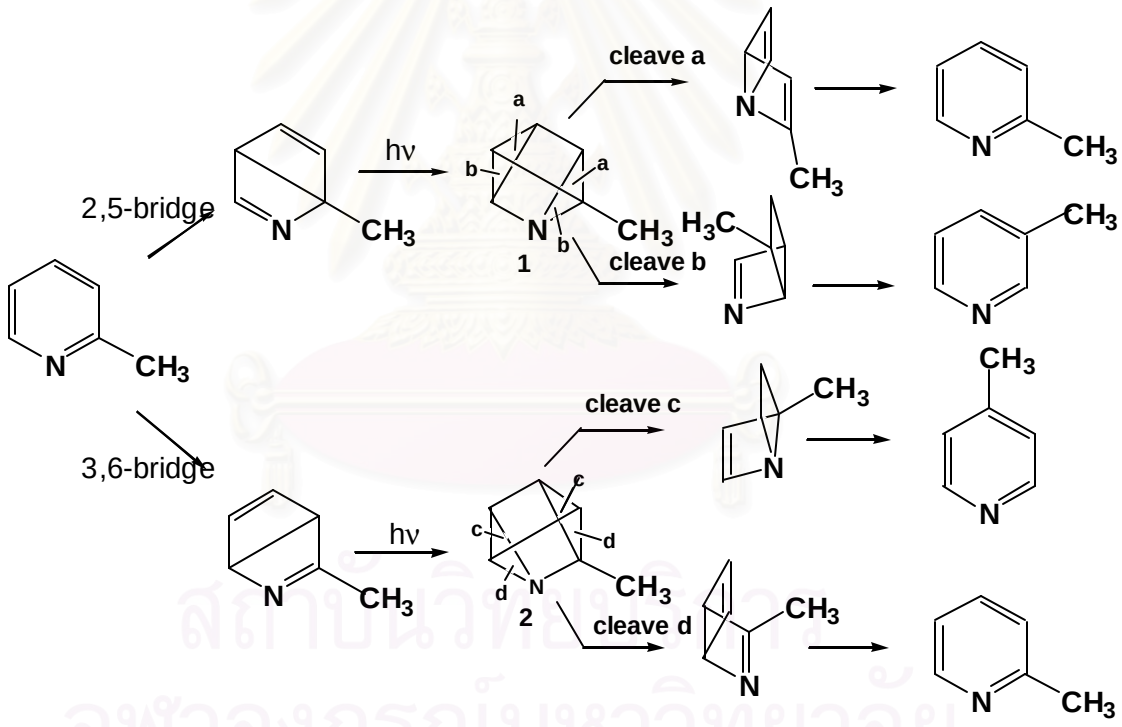
In the case of 3-methylpyridine the only product reported was the demethylation product, pyridine.



4-Methylpyridine, however, was reported to undergo phototransposition to 2-methylpyridine and demethylation to yield pyridine.



Lablache-Combier(1) proposed that the transposition occurs via a mechanism involving Dewar-pyridine and azaprismane intermediates. The phototransposition of 2-methylpyridine by this mechanistic pathway is shown in Scheme 1.

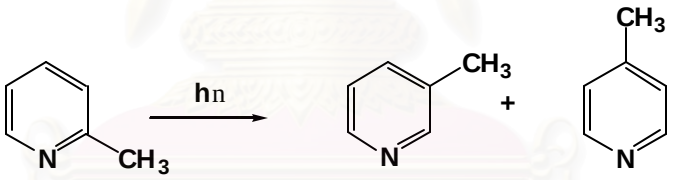


Scheme 1: Azarprismane mechanism in the photochemistry of 2-methylpyridine: 2,5-bridging and 3,6-bridging.

Thus, according to this mechanism, Dewar-pyridine fromation can occur by either 2,5- or 3,6-bridging. 2,5-Bridging leads to azarprismane **1** which can cleave by either

breaking the bonds labeled **a** and **b** to yield eventually 2-methylpyridine, the reactant, and 3-methylpyridine, a product not reported in this reaction. 3,6-Bridging leads to azarprismane **2.** Cleavage by either breaking the bonds labeled **c** and **d** leads eventually to 2-methylpyridine, the reactant, and 4-methylpyridine, the observed product. Thus, if this mechanism is correct, it requires that 3,6-bridging occurs but not 2,5-bridging. It is not obvious why the original bridging should be so selective to give 4-methylpyridine but not 3-methylpyridine. Furthermore it is not obvious why 3-methylpyridine does not phototranspose since Dewar formation from 3-methylpyridine should also be possible.

Roebke(2) also studied the gas-phase photochemistry of 2-methylpyridine. According to his report, irradiation in the π-π^* (238-266 nm) region yielded 3-and 4-methylpyridines which were formed in a 10:1 ratio. Lablache-Combier(1) reported that irradiation of 2-methylpyridine led to the formation of 4-methylpyridine as the only transposition product. It is difficult to understand why Lablache-Combier[1] and his colleagues observed only the minor transposition product formed but not the major transposition product. These results differ from the observation of Lablache-Combier(1).

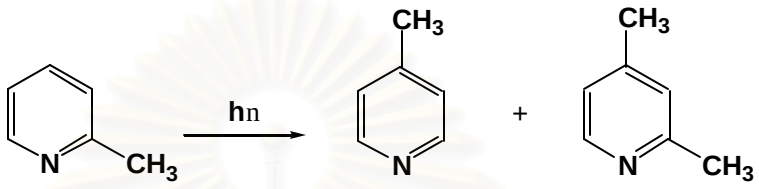


However, when 2-methylpyridine was irradiated in the n-π^* (0,0) transition region (~288nm), Roebke(2) observed that no photoproducts were formed. It thus appears that the phototransposition originates from the $S_2(\pi,\pi^*)_{vib}$ state of 2-methylpyridine.

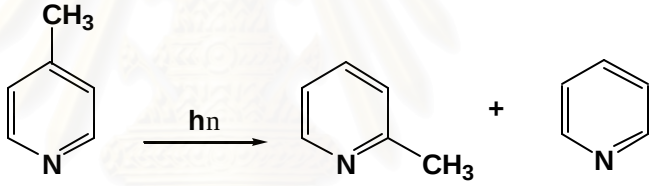
In the solution phase, irradiation of 2-methylpyridine was studied using light with energy either in the n-π^* (265 nm) or π-π^* (248 nm) regions(2). Under these conditions no photoproducts was detected. In the solution phase it is expected that vibrationally excited $S_2(\pi,\pi^*)_{vib}$ states would rapidly undergo vibrational relaxation to $S_2(\pi,\pi^*)_0$. It thus appears that the phototransposition occurs from a vibrationally excited $S_2(\pi,\pi^*)_{vib}$ state.

Roebke(2) proposed that the product formation occur via an azaprismane mechanism which required the formation of a Dewar pyridine.

O.S. Pascual(3) has carried out vapor phase photolysis of 2- and 4-methylpyridines with a Hg lamp for 72 hours periods. Irradiation of 2-methylpyridine yielded 4-methylpyridine, 2,4-dimethylpyridine and a large amount of polymer.



Irradiation of 4-methylpyridine gave 2-methylpyrine, pyridine, and a small amount of polymer but no dimethylpyridines were reported.

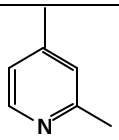
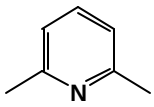
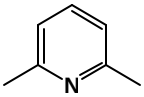
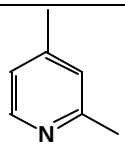
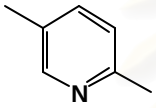
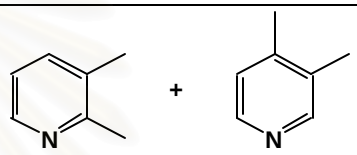
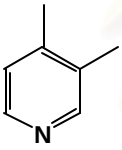
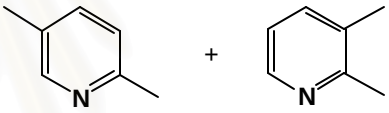
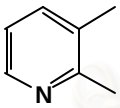
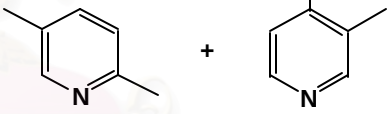
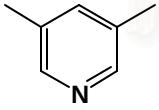


Pascual suggested that the reaction may occur through a radical type methylation-demethylation reaction.

1.1.2 Dimethylpyridine

Caplain and Lablache-Combier(1) also studied the gas phase photochemistry of the six isomeric dimethylpyridines. Their results are summarized in Table 1. It is interesting to note that although these workers reported that methylpyridines undergo photo-demethylation, no demethylpyridine product was reported for dimethylpyridines.

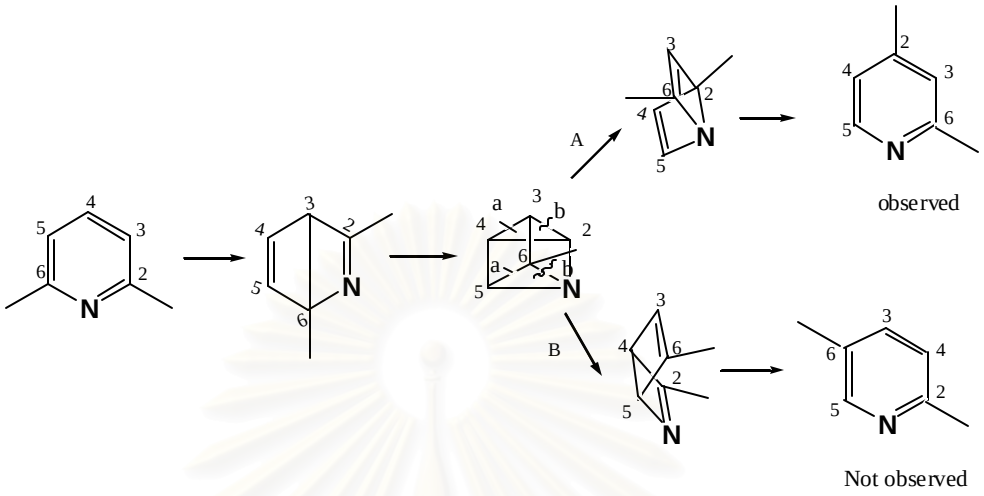
Table 1: The gas phase photochemistry of dimethylpyridines reported by Caplain and Lablache-Combier(1).

Reactants	Products
	
	
	
	
	
	No isomerization product

To account for these photoisomerizations, Caplain and Lablache-Combier again suggested a mechanism involving Dewar-pyridine and azarprismane intermediates. The difficulty with this mechanism is again the selectivity required to explain the products reported.

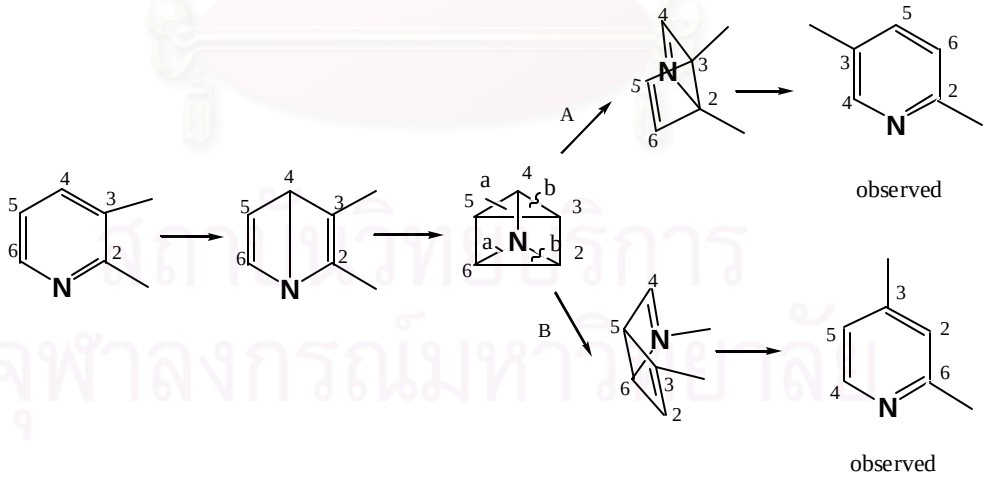
As shown in Scheme **2**, for example, the reported conversion of 2,6-dimethylpyridine to 2,4-dimethylpyridine required that the reactant first undergoes 2,5-(or 3,6) bonding (but not N_1-C_4 bonding) and regiospecific opening of the subsequently formed azaprismane via cleavage of the C_3-C_4 and N_1-C_6 bonds (path A),

but not of the C_2-C_3 and N_1-C_6 bonds (Path B) which would have led to the formation of 2,5-dimethylpyridine.



Scheme 2: Azaprismane mechanism in the photoisomerization of 2,6-dimethylpyridine: 3,6-bridging

Alternatively, the reported conversion of 2,3-dimethylpyridine to a mixture of 3,4-dimethylpyridine and 2,5–dimethylpyridine requires initial N_1-C_4 bonding as shown in Scheme 3 (but not 2,5-or 3,6-bonding), followed by cleavage of the azaprismane via both possible pathways.

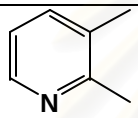
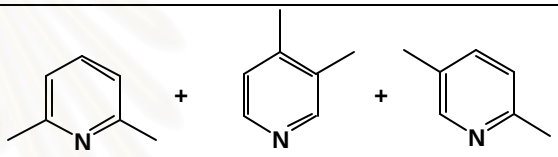
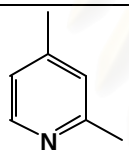
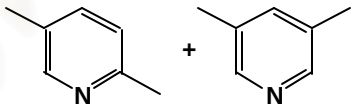
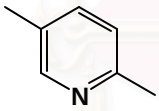
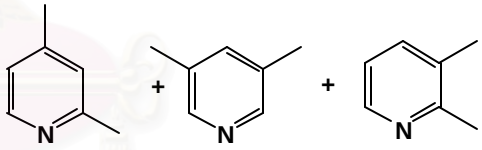
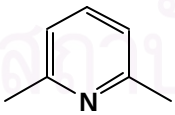
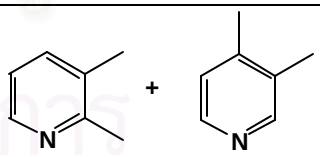
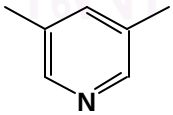
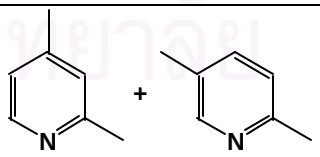
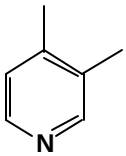
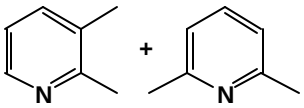


Scheme 3: Azaprismane mechanism in the photoisomerization of 2,3-dimethylpyridine: 1,4-bridging

These examples illustrate the arbitrary selectivity that must be imposed upon the possible modes of formation of the initially formed Dewar-pyridine as well as the rearomatization of the subsequently formed azaprismanes.

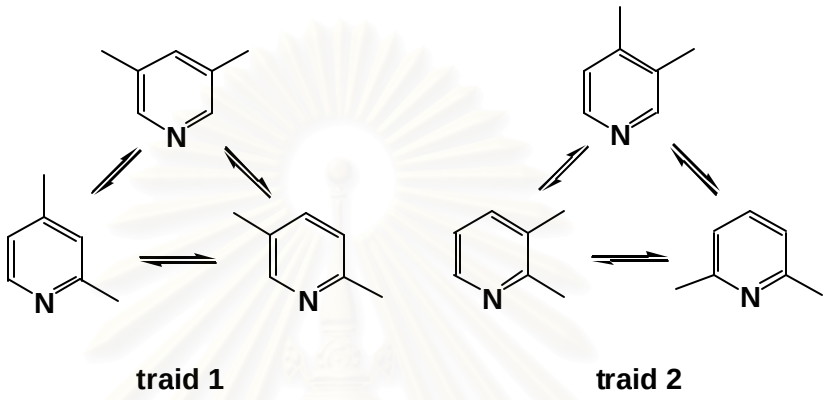
Later work by Kebede and Pavlik(4) reported that photochemistry of dimethylpyridines undergo phototransposition upon irradiation in the vapor phase (1-4 Torr) at 254 nm to give totally different products from those reported by Caplain and Lablache-Cambier. These products are shown in Table 2.

Table 2: The gas phase photochemistry of dimethylpyridines reported by Kebede and Pavlik(4)

Reactant(s)	Product(s)
	
	
	
	
	
	

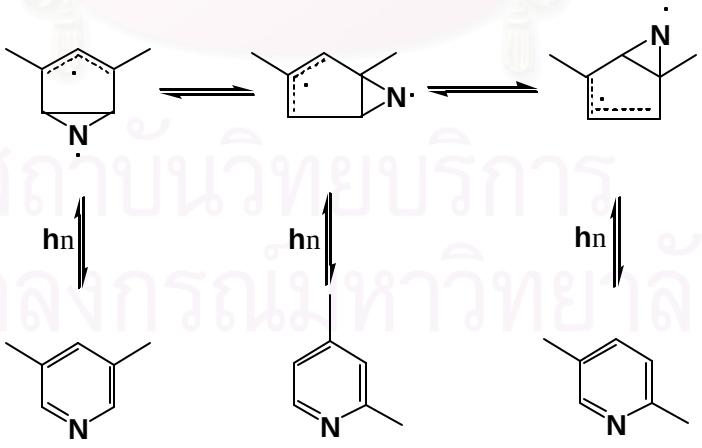
They found that the six isomeric dimethylpyridines could be divided into two triads each containing three interconverting compounds shown in Scheme 4.

Photo-interconversions of dimethylpyridines

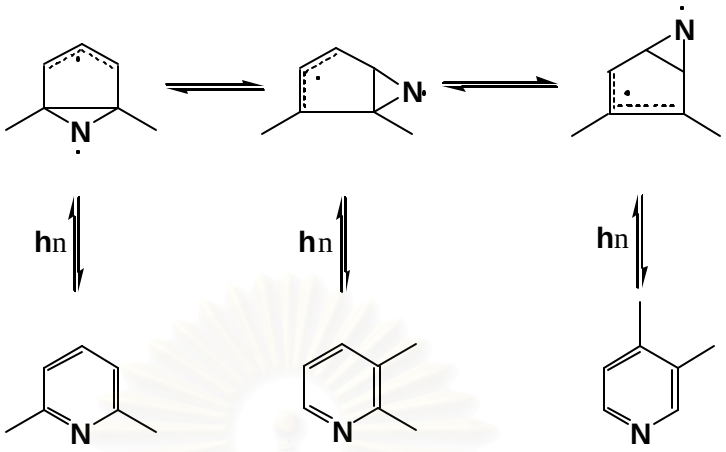


Scheme 4: Photo-interconversion of dimethylpyridines

The interconversions within each triad were suggested to occur via a mechanism involving 2,6-bonding followed by nitrogen migration and rearomatization shown in Schemes 5 and 6.



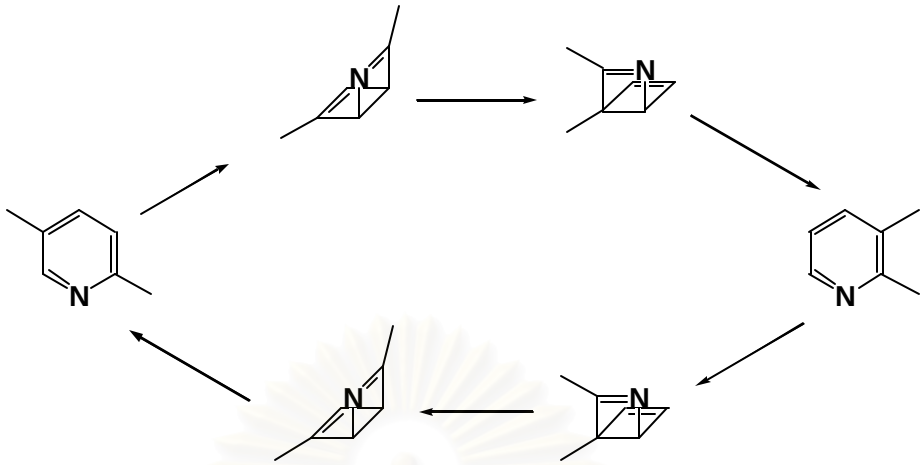
Scheme 5: Mechanism for interconversions within triad 1 of dimethypyridines



Scheme 6: Mechanism for interconversions within triad 2 of dimethypyridines

The 2,6-bonding-nitrogen migration mechanisms shown in Schemes 5 and 6 account for interconversions of the three members of each triad but does not allow for interconversions between members of triad 1 with members of triad 2. These intra-triad reactions were observed to occur upon irradiation of the dimethylpyridines at 254 nm in the gas phase. These reactions were quenched by the addition of nitrogen gas (15-20 Torr) to the reaction mixture and did not take place when the dimethylpyridines were irradiated with light of greater than 290 nm.

Although the mechanism in Schemes 5 and 6 do not account for inter-triad interconversions, Kebede and Pavlik(4) showed that 2,5-dimethylpyridine, a member of triad 1, interconverts with 2,3-dimethylpyridine, a member of triad 2. Unlike the intra-triad interconversions, these inter-triad conversions were enhanced by dilution with nitrogen gas and were the only photo-transpositions observed upon irradiation with light of greater than 290 nm. These inter-triad isomerizations were suggested to occur via the interconverting Dewar-pyridine mechanism shown in Scheme 7.



Scheme 7: Inter-triad iomeriazation via Dewar-pyridine mechanism

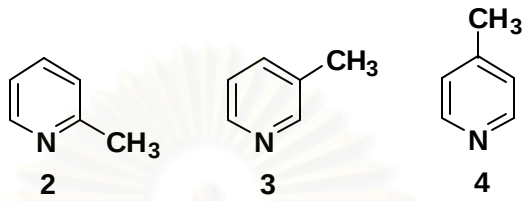
Cao and co-workers(5) have carried out a theoretical study of the photochemistry of 2,3-and 3,5-dimethylpyridine. Interestingly, although these calculations indicate that for 3,5-dimethylpyridine S_1 and S_2 are n,π∗ and π,π∗ respectively, these states are inverted in 2,3-dimethylpyridine. Thus, in 2,3-dimethylpyridine S_1 is π,π∗ and S_2 is n,π*.

Based on these calculation these workers have concluded that S_0—— $S_1(\pi,\pi*)$ excitation of 2,3-dimethylation leads to dimethyl-Dewar-pyridine which can be formed either via the intermediacy of a Mobious-pyridine or directly from the excited singlet state of 2,3-dimethylpyridine. Calculation also suggest that S_0——$S_2(\pi,\pi*)$ excitation of 3,5-dimethylpyridine can result in the formation of an azabenvalene intermediate which can lead to the interconversion of 3,5-dimethylpyridine, 2,4-dimethylpyridine, and 2,5-dimethylpyridine as reported by Kebede and Pavlik.

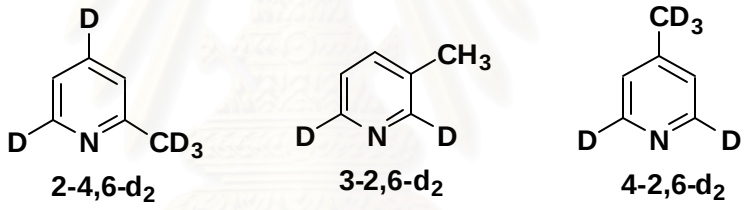
According to these calculations, phototransposition can also occur on the triplet surface. In this case, the photoisomerizations are predicted to occur via interconverting triplet azaprefulvene intermediates as previously suggested by Kebede and Pavlik(4).

1.2 Objectives

In this thesis, it is proposed to study the vapor phase photochemistry of three isomeric picolines by irradiation of each isomer at 254 nm.



In order to gain addition mechanistic information of the photochemistry of these compounds, it is also proposed to synthesize and to study the vapor phase photochemistry



of 4,6-dideuterrio-2-methylpyridine **2-4,6-d_2**, 2,6-dideuterio-3-methylpyridine **3-2,6-d_2**, and 2,6-dideuterrio-4-methylpyridine **4-2,6d_2**. Determination of the position of the deuterium atoms in the phototransposition products will help to define the mechanism of these reactions.

CHAPTER 2

EXPERIMENTAL

2.1 Synthesis of deuterated compounds

The photochemistry of deuterium labeled of methylpyridines have also been studied in order to clarify the phototransposition mechanism of methylpyridines. 2-Trideuteriomethylpyridine-4,6-d_2, 3-methylpyridine-2,6-d_2, and 4-trideuterio-methylpyridine-2,6-d_2 were synthesized for these photochemical studies.

2.1.1 Synthesis of 2-methylpyridine-4,6-d_2

2.1.1.1 Synthesis of 2-trideuteriomethylpyridine N-oxide-6d

2-Methylpyridine-N-oxide (3.4 g, 36.5 mmole) was dissolved in a solution of sodium carbonate (2.0 g) in deuterium oxide d_2 (20 mL). The mixture was heated at 110°C in an oil bath for twelve hours. The resulting solution was cooled and then extracted with dichloromethane (5×30 mL). The combined dichloromethane extracts were dried over anhydrous sodium sulfate. Dichloromethane was removed to give a yellow liquid of partially deuterated 2-trideuteriomethylpyridine N-oxide-6d (3.2 g, 32.3 mmole, 87.4 %). ^{1}H-NMR analysis indicated that this deuterated 2-methylpyridine N-oxide still contained approximately 10% of hydrogen at position 6. Thus, the material was subjected to a second deuteration as above to give 2-trideuteriomethylpyridine N-oxide-6d (2.98 g, 27.3 mmole, 84.5%); **^{1}H-NMR** ($CDCl_3$) δ 2.6 (s, residual ^{1}H of CH_3), δ 7.06-7.22 (m, 3H), δ 8.2 (d, residual $^1H_6$); **^{13}C-NMR** ($CDCl_3$) δ 17.5 (m,-CD_3), 123.9, 126.3, 126.9, 139.2 (t, C_6 J = 28.4 Hz), 149.4; **MS** *m/z* (%) 113 ($M^{+\bullet}$; 89), 112 (37), 95 (100), 94 (32), 68 (63), 67 (66).

2.1.1.2 Synthesis of 4-nitro-2-trideuteriomethylpyridine *N*-oxide-6d

Concentrated sulphuric acid (5 ml) and concentrated nitric acid (5 mL) was slowly added to a 50 ml round bottom flask while cooling in an ice bath. 2-Trideuteriomethylpyridine *N*-oxide-6d (2.5 g; 22.1 mmol) was added dropwise via a pipette to the acidic solution while keeping the temperature under 50 °C. The resulting clear solution was allowed to stir at room temperature for 10 min and heated at 110 °C for 5 hour. The resulting solution was allowed to cool to room temperature and neutralized with saturated aqueous sodium bicarbonate. The neutralized solution was extracted with dichloromethane (3×50 mL). The combined dichloromethane extracts were dried over anhydrous sodium sulfate. The solvent was removed to give yellow solid (1.7 g; 10.75 mmole; 48 % mp 130-140°C). TLC analysis (9:1 EtOAc:MeOH) of this solid showed two spots with R_f of 0.17 and 0.5. The component with the R_f of 0.5 corresponded to the 4-nitro-2-trideuteriomethylpyridine-6d. The yellow solid was recrystallized from acetone to give 4-nitro-2-trideuteriomethylpyridine-6d as yellow crystals; **mp** 153-155°C (lit. mp[ref] 153-154 °C); **^{1}H-NMR** ($CDCl_3$) δ 2.3 (s, residual H of CD_3), 7.9 (s, 1H), 8.1 (s, 1H), 8.2 (d, residual $^1H_6$); **^{13}C-NMR** ($CDCl_3$) δ 17.1 (m,-CD_3), 117.5, 120.2, 139.3 (t, C_6 J = 28.4Hz), 141.2, 150.1.

2.1.1.3 Synthesis of 4-chloro-2-trideuteriomethylpyridine *N*-oxide-6d

4-Nitro-2-trideuteriomethylpyridine *N*-oxide-6d (1.5 g, 9.5 mmol) was dissolved in concentrated hydrochloric acid (20 mL) in a 50 mL round bottom flask. The reaction mixture was heated at 135°C in an oil bath for 18 hours. TLC analysis of the reaction solution showed 2 spots with R_f of 0.5 (starting material) and 0.15 (desired product). The reaction was stopped and cooled to room temperature. The crude reaction solution was extracted with chloroform (5×20 mL). The combined chloroform extracts were dried over anhydrous sodium sulfate. The solvent was removed to give a yellow solid (1.0 g). The crude yellow solid was purified by column chromatography (100% EtOAc). Two fractions were collected. The first eluted component was starting material. The second component was eluted with 100% MeOH to give the desired product. The solvent was removed to give 4-chloro-2-trideuteriomethylpyridine *N*-oxide-6d as a yellow viscous liquid (0.6 g, 4.1 mmol, 43 %); **^{1}H-NMR** ($CDCl_3$); δ 2.3 (s, residual of CH_3), δ 7.0 (s, 1H), δ 7.2 (s, 1H), δ 8.1 (d, residual $^1H_6$); **^{13}C-NMR** ($CDCl_3$) δ 17.7 (m,-CD_3), 124.2, 126.8, 131.7, 140.1 (t, C_6 J = 29.1 Hz), 150.5; **MS** *m/z* (%) 149 (P+2; 22), 147 ($M^{+\bullet}$; 70), 146 (45), 129 (100), 128(45), 92 (40).

2.1.1.4 Synthesis of 4-chloro-2-trideuteriomethylpyridine-6d

The solution of 4-chloro-2-trideuteriomethylpyridine *N*-oxide-6d (0.8 g, 5.4 mmole) in dichloromethane (40 mL) was added dropwise to a 100 mL round bottom flask ,cooled in an ice bath, containing PCl_3 (3 mL). The mixture was refluxed for one hour. The reaction mixture was allowed to cool to room temperature and then poured onto ice. The mixture was basified by saturated aqueous sodium hydroxide until pH 11. The aqueous solution was extracted by dichloromethane (5×30mL). The dichloromethane extract was dried over anhydrous sodium sulphate. The solvent was removed to give 4-chloro-2-trideuteriomethylpyridine-6d as a brown viscous liquid (0.5 g, 3.7 mmol, 69%); **^{1}H-NMR** ($CDCl_3$) δ 2.3 (s, residual of CH_3), δ 6.9 (s, 1H), δ 7.0 (s, 1H), δ 8.3 (d, residual $^1H_6$); **^{13}C-NMR** ($CDCl_3$) δ 23.9 (m, -CD_3), 121.1, 123.5, 144.1, 149.7 (t, C_6 J = 27.6Hz),159.9; **MS** *m/z* (%) 133 (P+2; 30.2), 131 ($M^{+\bullet}$; 100), 131 (62), 95 (33), 94 (13).

2.1.1.5 Synthesis of 2-trideuteriomethylpyridine-4,6-d_2

4-Chloro-2-trideuteriomethylpyridine-6d (0.5 g), potassium carbonate (1.5 g) and 10% palladium-charcoal (0.3 g) in ether (20 mL) were placed in a 50 mL side arm Buchner flask equipped with a balloon and sealed with a rubber septum. This flask was connected to and sealed side arm test tubing, containing sodium metal (1.2 g), by rubber tubing equipped with a needle. The system was purged with nitrogen gas for 2 min. D_2O (3 mL) was slowly added by syringe through the septum to the side arm test tube cooled in an ice bath. The reaction was allowed to stir at room temperature for four hours. The mixture was filtered and washed by dichloromethane. The filtrates were collected. The solvent (dichloromethane and ether) was removed by distillation at 40°C to give a brown liquid residue (0.3 g). The brown liquid residue was further purified by bulb to bulb distillation.

- Bulb to bulb distillation

A 25 mL round bottom flask containing the brown liquid residue (0.3 g) was equipped with two bulbs. The system was allowed to stand at 60 mm.Hg (RT; water aspirator) for 30 min. The system was brought back to atmospheric pressure and slowly heated and maintained at 40°C for 20 min and 70°C for 20 min. The oven was, then, heated to 130°C. 2-Trideuteriomethylpyridine-4,6-d_2 was collected in the bulb cooled in a dry ice bath as a clear liquid (0.13 g); **^{1}H-NMR** ($CDCl_3$) δ 2.4 (s, residual H of CD_3), δ 7.1 (s, H_3), 7.2 (s, H_5), 7.4 (t, residual $^1H_4$), 8.3 (d, residual $^1H_6$); **^{13}C-NMR** (acetone-d_6) δ 24.3 (m,-CD_3), 121.6, 124.1, 136.9 (t, C_4 J = 28.3 Hz), 150 (t, C_6 J_{CD} = 27.6 Hz), 159; **MS** *m/z* (%) 98 ($M^{+\bullet}$; 100), 70 (42), 69 (12).

2.1.1 Synthesis of 3-methylpyridine-2,6-d_2

2.1.2.1 Synthesis of 3-methylpyridine *N*-oxide-2,6-d_2

3-Methylpyridine *N*-oxide (1.0 g, 9.0 mmol) was dissolved in a solution of sodium carbonate (2.0 g) in deuterium oxide-d_2 (20 mL). The mixture was heated at 110°C in an oil bath for twelve hours. The resulting solution was cooled to room temperature and extracted with dichloromethane (5×30 mL). The combined dichloromethane extract was collected and dried over anhydrous sodium sulfate. The dichloromethane was removed to give a yellow liquid of partially deuterated 3-methylpyridine *N*-oxide-2,6-d_2 (0.87 g, 7.8 mmol, 76 %). ^{1}H-NMR analysis indicated that this deuterated 3-methylpyridine N-oxide still contained approximately 3% of ^{1}H at positions 2 and 6. This material was subjected to a second deuteration as described above to give 3-methylpyridine *N*-oxide-2,6-d_2 as a colorless viscous liquid (0.8g, 7.2 mmol, 80%); **^{1}H-NMR** ($CDCl_3$) δ 2.3 (s, CH_3), δ 7.26 (d, H_5 J = 8.08 Hz), δ 7.42 (d, H_4 7.83 Hz), δ 8.32 (d, residual $^1H_{2,6}$); **^{13}C-NMR** ($CDCL_3$) δ 18.4 (s, CH_3), 125.4, 127.8, 136.3 (t, C_2 J = 27.6Hz), 136.6, 139.3 (t, C_6 J = 26.8 Hz).

2.1.2.2 Synthesis of 3-methylpyridine-2,6-d_2

The 3-methylpyridine *N*-oxide-2,6-d_2 (0.8g, 7.2 mmol) was dissolved in dichloromethane (40 ml). This solution was added dropwise to a 100 ml round bottom flask containing phosphorus trichloride (2.4 ml) at 0°C. The reaction mixture was refluxed for one hour. This solution was then poured onto ice (15 g) and basified by addition of sodium hydroxide solution. The mixture was extracted with dichloromethane (5×30 mL). The dichloromethane layer was dried over anhydrous sodium sulfate. The solvent was removed to give 3-methylpyridine-2,6-d_2 as a colorless viscous liquid (0.5 g, 5.3 mmol, 73%); **^{1}H-NMR** ($CDCl_3$) δ 2.1(s, CH_3), δ 7.1 (d, H_5 J = 8.08 Hz), δ 7.4 (d, H_4 J = 7.83 Hz), δ 8.4 (d, residual $H_{2,6}$); **^{13}C-NMR** ($CDCL_3$) δ 18.5 (s, CH_3), 123.4, 133.3, 136.8, 146.9 (t, C_2 J = 27.6Hz), 150.2 (t, C_6 J = 26.8 Hz); **MS** *m/z* (%) 95 ($M^{+\bullet}$; 100), 68 (36), 67 (39).

3. Synthesis of 3-methylpyridine-2,4,6-d_3

2.1.3.1 Synthesis of 3-methylpyridine *N*-oxide-2,6-d_2

3-Methylpyridine-*N*-oxide (2.5 g, 22.9 mmol) was dissolved in a solution of sodium carbonate (2.0 g) in deuterium oxide d_2 (20 mL). The mixture was heated at 110-120°C in an oil bath for twelve hours. The resulting solution was cooled and then extracted with dichloromethane (5×30 mL). The combined dichloromethane extracts were dried over anhydrous sodium sulfate. Dichloromethane was removed to give a yellow liquid of partially deuterated 3-methylpyridine *N*-oxide-2,6-d_2 (2.2 g, 19.8 mmol, 86%). ^{1}H-NMR analysis indicated that this deuterated 3-methylpyridine *N*-oxide still contained approximately 10% of hydrogen at position 6. Thus, the material was subjected to a second deuteration as above to give 3-methylpyridine *N*-oxide-2,6-d_2 (1.9 g, 17.17mmole, 87%); ^{1}H-NMR analysis indicated that this deuterated 3-methylpyridine N-oxide still contained approximately 3% of ^{1}H at positions 2 and 6. This material was subjected to a second deuteration as described above to give 3-methylpyridine *N*-oxide-2,6-d_2 as a colorless viscous liquid (1.9.g, 17.17mmole, 87%); **^{1}H-NMR** ($CDCl_3$) δ 2.3 (s, CH_3), δ 7.26 (s, H_5, J = 8.08 Hz), δ 7.42 (d, H_4, J = 7.83 Hz), δ 8.32 (d, residual $^1H_{2,6}$); **^{13}C-NMR** ($CDCL_3$) δ 18.4 (s, CH_3), 125.4, 127.8, 136.3 (t, C_2 J = 27.6Hz), 136.6, 139.3 (t, C_6 J = 26.8 Hz).

2.1.3.2 Synthesis of 4-nitro-3-methylpyridine *N*-oxide-2,6d

Concentrated sulfuric acid (5 mL) and concentrated nitric acid (5 mL) was slowly added to a 50 ml round bottom flask while cooling in an ice bath. 3-Methylpyridine *N*-oxide-2,6-d_2 (1.9 g; 17.17mmol) was added dropwise via a pipette to the acidic solution while keeping the temperature under 50 °C. The resulting clear solution was allowed to stir at room temperature for 10 min and heated at 110 °C for 5 hours. The resulting solution was allowed to cool to room temperature and neutralized with saturated aqueous sodium hydroxide. The neutralized solution was extracted with dichloromethane (3×50 mL). The combined dichloromethane extracts were dried over anhydrous sodium sulphate. The solvent was removed to give yellow solid (1.3 g; 8.3 mmol; 48% mp 154-157°C); **^{1}H-NMR** ($CDCl_3$) δ 2.6 (s, CH_3), 8.0 (s, 1H); **^{13}C-NMR** ($CDCl_3$) δ 18.5 (m,-CD_3), 122.5, 133.2, 137.9 (t, C_6 J = 28.4 Hz), 141.8 (t, C_2 J = 26.8Hz), 143.4. **MS** *m/z* (%) 156 ($M^{+\bullet}$; 100), 140 (7), 139 (13), 84 (30).

2.1.3.3 Synthesis of 4-chloro-3-methylpyridine *N*-oxide-2,6-d_2

4-Nitro-3-methylpyridine *N*-oxide-2,6-d_2 (1.3 g, 8.3 mmol) was dissolved in concentrated hydrochloric acid (20 mL) in a 50 mL round bottom flask. The reaction mixture was heated at 135°C in an oil bath for 12 hours. TLC analysis of the reaction solution showed 2 spots with R_f of 0.5 (starting material) and 0.15 (desired product). The reaction was stopped and cooled to room temperature. The crude reaction solution was extracted with chloroform (5×20 mL). The combined chloroform extracts were dried over anhydrous sodium sulphate. The solvent was removed to give a yellow solid (0.9 g). The crude yellow solid was purified by column chromatography (100% EtOAc). Two fractions were collected. The first eluted component was starting material. The second component was eluted with 100% MeOH to give the desired product. The solvent was removed to give 4-chloro-3-methylpyridine *N*-oxide-2,6-d_2 as a yellow viscous liquid (0.5 g, 3.5 mmol, 42%); **^{1}H-NMR** ($CDCl_3$); δ 2.2 (s, CH_3), δ 7.2 (s, 1H), δ 7.9 (d, residual $^1H_6$), δ 8.1 (s, residual $^1H_2$); **^{13}C-NMR** ($CDCl_3$) δ 16.8 (s,CH_3), 124.3, 132.3, 144.4, 148.2 (t, C_6 J = 28.4 Hz), 151.5 (t, C_2 J = 28.4 Hz). **MS** *m/z* (%) 145 ($M^{+\bullet}$; 100), 129 (63), 94 (42), 54 (47).

2.1.3.4 Synthesis of 4-chloro-3-methylpyridine-2,6-d_2

The solution of 4-chloro-3-methylpyridine *N*-oxide-2,6-d_2 (0.5 g, 3.5 mmol) in dichloromethane (25 mL) was added dropwise to a 100 mL round bottom flask ,cooled in an ice bath, containing PCl_3 (3 mL). The mixture was refluxed for one hour. The reaction mixture was allowed to cool to room temperature and then poured onto ice. The mixture was basified by saturated aqueous sodium hydroxide until pH 11. The aqueous solution was extracted by dichloromethane (5×30mL). The dichloromethane extract was dried over anhydrous sodium sulfate. The solvent was removed to give 4-chloro-3-methylpyridine-2,6-d_2 as a brown viscous liquid (0.3 g, 2.3 mmol, 66%); **^{1}H-NMR** ($CDCl_3$) δ 2.3 (s, CH_3), δ 6.9 (s, 1H), δ 7.2 (s, 1H), δ 8.3 (d, residual $^1H_6$), δ 8.4 (s, residual $^1H_2$); **^{13}C-NMR** ($CDCl_3$) δ 16.8 (m, -CH_3), 124.2, 132.5, 148.2 (t, C_6 J = 28.4Hz), 151.6 (t, C_2 J = 28.4Hz); **MS** *m/z* (%) 131 (P+2; 35), 129 ($M^{+\bullet}$; 100), 94 (87), 66 (74).

2.1.3.5 Synthesis of 3-methylpyridine-2,4,6-d_3

4-Chloro-3-methylpyridine-2,6-d_2 (0.25 g), potassium carbonate (1.0 g) and 10% palladium-charcoal (0.3 g) in methanol (10 mL) were placed in a 50 mL side arm Buchner flask equipped with a balloon and sealed with a rubber septum. This flask was connected to and sealed side arm test tubing, containing sodium metal (0.8 g), by rubber tubing equipped with a needle. The system was purged with nitrogen gas for 20 min. D_2O (3 mL) was slowly added by syringe through the septum to the side arm test tube cooled in an ice bath. The reaction was allowed to stir at room temperature for four hours. The mixture was filtered and washed by dichloromethane. The filtrates were collected. The solvent (dichloromethane and ether) was removed by distillation at 40°C to give a brown liquid residue (0.25 g). The brown liquid residue was further purified by bulb to bulb distillation.

- Bulb to bulb distillation

A 25 mL round bottom flask containing the brown liquid residue (0.20 g) was equipped with two bulbs. The system was allowed to stand at 60 mm.Hg (RT; water aspirator) for 30 min. The system was brought back to atmospheric pressure and slowly heated and maintained at 40°C for 20 min and 70°C for 20 min. The oven was, then, heated to 130°C. 3-methylpyridine-2,4,6-d_3 was collected in the bulb cooled in a dry ice bath as a clear liquid (0.1 g); **^{1}H-NMR** ($CDCl_3$) δ 2.2 (s, -CH_3), δ 7.1 (s, H_5), 7.4 (t, residual $^1H_4$), 8.37 (d, residual $^1H_6$), 8.39 (s, residual $^1H_2$); **^{13}C-NMR** ($CDCl_3$) δ 18.7 (s,-CH_3), 123.2, 133.2, 136.7 (t, C_4 J = 24.5 Hz), 147 (t, C_6 J_{CD} = 26.8 Hz), 150.3(t, C_2 J_{CD} = 26.8 Hz); **MS** *m/z* (%) 96 ($M^{+\bullet}$; 100), 67 (31), 68 (46), 69 (37).

2.1.4 Synthesis of 4-trideuteriomethylpyridine -2,6-d_2

2.1.4.1 Synthesis of 4-trideuteriomethylpyridine *N*-oxide-2,6d_2

4-Methylpyridine *N*-oxide (1.0 g, 9.0 mmol) was dissolved in a solution of sodium carbonate (2.0 g) in deuterium oxide-d_2 (20 mL). The solution was heated at 110°C in an oil bath for twelve hours. The resulting solution was cooled to room temperature and extracted with dichloromethane (5×30 mL). The combined dichloromethane extract was dried over anhydrous sodium sulfate. The dichloromethane extract was removed to give a white solid of 4-trideuteriomethylpyridine *N*-oxide-2,6-d_2 (0.87g, 7.6 mmol, 84 %). ^{1}H-NMR analysis indicated that this deuterated 4-methylpyridine-*N*-oxide still contained approximately 10% of ^{1}H at positions 2 and 6. Thus, this material was subjected to a second deuterated as described above to give 4-trideuteriomethylpyridine *N*-oxide-2,6-d_2 as a colorless viscous liquid (0.7 g, 6.0 mmol, 79%); **^{1}H-NMR** (D_2O) δ 2.1 (s, residual ^{1}H of CD_3), δ 7.28 (s, 2H), δ 8.0 (s, residual $^1H_{2,6}$); **^{13}C-NMR** ($CDCl_3$) δ 19.8 (m, CD_3), 128.4, 138.5 (t, $C_{2,6}$ J = 29.1 Hz), 146.2.

2.1.4.2 Synthesis of 4-trideuteriomethylpyridine-2,6-d_2

4-Trideuteriomethylpyridine *N*-oxide-2,6-d_2 (0.7 g, 6.0 mmol) was dissolved in dichloromethane (40 mL). This solution was added dropwise to a 100 mL round bottom flask containing phosphorus trichloride (2.4 mL) at 0°C. The reaction mixture was refluxed for one hour. This solution was then poured onto ice (15 g) and basified by addition of sodium hydroxide solution. The mixture was extracted with dichloromethane (5×3 mL). The dichloromethane extract was dried over anhydrous sodium sulfate. The solvent was removed to give 4-trideuteriomethylpyridine-2,6-d_2 as a colorless viscous liquid (0.45 g, 4.5 mmol, 75%); **^{1}H-NMR** ($CDCl_3$) δ 2.2 (s, ^{1}H residual CD_3), δ 7.06 (s, 1H), δ 8.4 (s, residual $H_{2,6}$); **^{13}C-NMR** ($CDCL_3$) δ 20.5 (m, $-CD_3$), 124.9, 147.2, 149.5 (t, $C_{2,6}$ J = 26.8 Hz); **MS** *m/z* (%) 98 ($M^{+\bullet}$; 100), 80 (5), 70 (43).

2.2 Irradiation and analytical procedures

Photochemical reactions were carried out by irradiating the vapor of each methylpyridine using a Rayonet reactor equipped with 15 low-pressure mercury arc lamps. Prior to introduction of the material into the reaction flask, any dissolved gas in the materials to be irradiated was removed by three freeze-thaw cycles using an acetone–dry ice bath.

Irradiation at 254 nm

2-Methylpyridine (2)

The vapor of 2-methylpyridine (6.2 Torr) was obtained by vaporizing the sample into the 3L quartz flask at 25 °C. This was then irradiated in the Rayonet reactor at 254 nm using 15 low pressure mercury arc lamps for 24, 48, 72 and 96 hours. After irradiation the material was recovered by pumping it out through a trap cooled in acetone-dry ice. This was then dissolved in dichloromethane. Analysis of the solution by GLC showed the consumption of **2** and formation of 3-methylpyridine **3** and 4-methylpyridine **4,** the phototransposition products, 2,6-dimethylpyridine a methylation product, and pyridine, a demethylation product, with retention times relative to **2** of 1.7, 1.8, 1.28 and 0.8 min, respectively. Table 3 shows photolysis conditions and quantitative results.

Table 3: Irradiation of 2-methylpyridine at 254 nm.

Exp NO.	Sample (g)	Recover (g)	Irradiation (hrs)	Consumption 2-MP (%)	Formation 3-MP (%)	Formation 4-MP (%)	3MP:4MP
1	0.202	0.091	24	6	61	10	6.1
2	0.196	0.067	48	3	-	-	-
3	0.198	0.060	72	28.7	11	2	5.5
4	0.197	0.062	96	9	41	10	2.2

A brown film was observed coating the reactor wall after irradiation with 254 nm lamps. The brown film was extracted by acetone (100 mL). The acetone solution was concentrated (0.010 g) and analyzed by GLC. The GC trace showed 2-methylpyridine and some 3-and 4-methylpyridine. No 2,6-dimethylpyridine or pyridine were observed.

3-Methylpyridine (3)

The vapor of 3-methylpyridine was obtained by vaporizing the sample into the 3L quartz flask at 25 ℃. This was then irradiated in the Rayonet reactor at 254 nm using 15 low pressure mercury arc lamps for 24, 48, 72 and 96 hours. After irradiation the material was recovered by pumping it out through a trap cooled in acetone-dry ice. This was then dissolved in dichloromethane. Analysis of the solution by GLC showed the consumption of **3** and formation of 2-methylpyridine **2** and 4-methylpyridine **4,** the phototransposition products, and pyridine, a demethylation product, with retention times relative to **3** of 0.28, 1.08, and 0.42 min, respectively. Table 4 shows photolysis conditions and quantitative results.

Table 4: Irradiation of 3-methylpyridine at 254 nm

Exp NO.	Sample (g)	Recover (g)	Irradiation (hrs)	consumption 3-MP (%)	Formation 2-MP (%)	%Formation 4-MP (%)	2MP:4MP
1	0.140	0.043	24	31	73	27	2.7
2	0.160	0.050	48	35	73	25	2.9
3	0.140	0.035	72	47	61	18	3.4
4	0.160	0.028	96	44	62	23	2.7

A brown film was observed coating the reactor wall after irradiation with 254 nm lamps. The brown film was extracted by acetone (100 mL). The acetone solution was concentrated (0.012g) and analyzed by GLC. The GC trace showed mainly 3-methylpyridine and some 2-and 4-methylpyridine but no pyridine was observed.

4-Methylpyridine (4)

The vapor of 4-methylpyridine (5.4 Torr) was obtained by vaporizing the sample into the 3L quartz flask at 25 ℃. This was then irradiated in the Rayonet reactor at 254 nm using 15 low pressure mercury arc lamps for 24, 48, 72 and 96 hours. After irradiation the material was recovered by pumping it out through a trap cooled in acetone-dry ice. This was then dissolved in dichloromethane. Analysis of the solution by GLC showed the consumption of **4** and formation of 2-methylpyridine **2** and 3-methylpyridine **3,** the phototransposition products, 2,6-lutidine, a methylation product, and pyridine, a demethylation product, with retention times relative to **4** of 0.5, 0.9, 0.69 and 0.39 min, respectively. Table 5 shows photolysis conditions and quantitative results.

Table 5: Irradiation of 4-methylpyridine at 254 nm

Exp NO.	Sample (g)	Recover (g)	Irradiation (hrs)	Consumption 4-MP (%)	Formation 2-MP (%)	%Formation 3-MP (%)	2MP: 3MP
1	0.150	0.043	24	72	5	6	0.83
2	0.146	0.044	48	53	16	19	0.84
3	0.168	0.032	72	65	9	10	0.9
4	0.160	0.047	96	58	14	16	0.87

A brown film was observed coating the reactor wall after irradiation with 254 nm lamps. The brown film was extracted by acetone (100 mL). The acetone solution was concentrated (0.010g) and analyzed by GLC. The GC trace showed mainly 4-methylpyridine and formation of 2-and 3-methylpyridine but no pyridine or 2,6-lutidine were observed.

Deuterium labeling studied

2-Methylpyridine-4,6-d_2

The vapor of 2-methylpyridine-2,6-d_2 (3.0 Torr) was obtained by vaporizing the sample into the 3L quartz flask at 25 ℃. This was then irradiated in the Rayonet reactor at 254 nm using 15 low pressure mercury arc lamps for 24 and 48 hours as shown in Table 6. After irradiation the material was recovered by pumping it out through a trap cooled in acetone-dry ice. This was then dissolved in chloroform-d and acetone-d_6. Analysis of the solution by ^{1}H-NMR ($CDCl_3$) showed 2-methylpyridine-3,5-d_2 at δ 7.5 (s, H_4) and δ 8.44 (s, H_6); 3-methylpyridine-4,6-d_2 at δ 7.5 (s, H_2) and δ 8.4 (s, H_6); 3-methylpyridine2,5-d_2 at δ 7.4 (s, H_4) and δ 8.36 (s, H_6); and 4-methylpyridine-2,5-d_2 at δ 7.05 (s, H_3) and δ 8.39 (s, H_6).

Table 6: Irradiation of 2-methylpyridine-4,6-d_2 at 254 nm

Exp NO.	Sample (g)	Recover (g)	Irradiation (h)	Solvent
1	0.050	0.015	24	Acetone-d_6
2	0.060	0.010	48	Acetone-d_6
3	0.040	0.010	24	$CDCl_3$

The brown film was observed coating on the reactor wall after irradiation with 254 nm lamps. The brown film was extracted by acetone (100 mL). The acetone solution was concentrated (0.007 g) and analyzed by ^{1}H-NMR. The ^{1}H-NMR spectrum in $CDCl_3$ showed 2-methylpyridine-3,5-d_2 at δ 7.5 (s, H_4) and δ 8.4 (s, H_6); 3-methylpyridine-4,6-d_2 at δ 7.5 (s, H_2) and δ 8.4 (s, H_6); 3-methylpyridine2,5-d_2 at δ 7.4 (s, H_4) and δ 8.36 (s, H_6); and 4-methylpyridine-2,5-d_2 at δ 7.05 (s, H_3) and δ 8.39 (s, H_6).

3-Methylpyridine-2,6-d_2

The vapor of 3-methylpyridine-2,6-d_2 (4.0 Torr) was obtained by vaporizing the sample into the 3L quartz flask at 25 °C. This was then irradiated in the Rayonet reactor at 254 nm using 15 low pressure mercury arc lamps for 24 and 48 hours as shown in Table 7. After irradiation the material was recovered by pumping it out through a trap cooled in an acetone-dry ice. This was then dissolved in chloroform-d and acetone-d_6. Analysis of the solution by ^{1}H-NMR ($CDCl_3$) showed 2-methylpyridine-5,6-d_2 at δ 7.13 (s, H_3) and δ 7.54 (s, H_4), 2-methylpyridine-3,4-d_2 at δ 7.05 (s, H_5) and δ 8.47 (s, H_6), 3-methylpyridine-4,5-d_2 at δ 8.48 (s, H_6) and δ 8.43 (s, H_2), and 4-methylpyridine-5,6-d_2 at δ 7.05 (s, H_3) and δ 8.4 (s, H_2) as the phototransposition products.

Table 7: Irradiation of 3-methylpyridine-2,6d_2 at 254 nm

Exp NO.	Sample (g)	Recover (g)	Irradiation (h)	Solvent
1	0.146	0.059	24	Acetone-d_6
2	0.070	0.025	48	$CDCl_3$

A brown film was observed coating the reactor wall after irradiation with 254 nm lamps. The brown film was extracted by acetone (100 mL). The acetone solution was concentrated (0.011 g) and analyzed by ^{1}H-NMR. The ^{1}H-NMR ($CDCl_3$) spectrum showed the signals of 2-methylpyridine-5,6-d_2 at δ 7.13 (s, H_3) and δ 7.54 (s, H_4), 2-methylpyridine-3,4-d_2 at δ 7.05 (s, H_5) and δ 8.47 (s, H_6), 3-methylpyridine-4,5-d_2 at δ 8.48 (s, H_6) and δ 8.43 (s, H_2), and 4-methylpyridine-5,6-d_2 at δ 7.05 (s, H_3) and δ 8.4 (s, H_2) as the phototransposition products.

3-Methylpyridine-2,4,6-d_3

The vapor of 3-methylpyridine-2,4,6-d_3 (4.0 Torr) was obtained by vaporizing the sample into the 3L quartz flask at 25 °C. This was then irradiated in the Rayonet reactor at 254 nm using 15 low pressure mercury arc lamps for 24 hours as shown in Table 8. After irradiation the material was recovered by pumping it out through a trap cooled in an acetone-dry ice. This was then dissolved in chloroform-d. Analysis of The ^{1}H-NMR spectrum showed 2-methylpyridine-3,5,6-d_2 at δ 7.58 (s, H_4); 2-methylpyridine-3,4,6-d_3 at δ 7.1 (s, H_5); 3-methylpyridine-2,4,5-d_3 at δ 8.43 (s, H_6); and 4-methylpyridine-3,5,6-d_3 at δ 8.46 (s, H_2) due to as the phototransposition products.

Table 8: Irradiation of 3-methylpyridine-2,4,6-d_3 at 254 nm

Exp NO.	Sample (g)	Recover (g)	Irradiation (h)	Solvent
1	0.040	0.013	24	$CDCl_3$

A brown film was observed coating the reactor wall after irradiation with 254 nm lamps. The brown film was extracted by acetone (100 mL). The acetone solution was concentrated (0.011 g) and analyzed by ^{1}H-NMR. The ^{1}H-NMR spectrum showed 2-methylpyridine-3,5,6-d_2 at δ 7.58 (s, H_4) ; 2-methylpyridine-3,4,6-d_3 at δ 7.1 (s, H_5); 3-methylpyridine-2,4,5-d_3 at δ 8.43 (s, H_6); and 4-methylpyridine-3,5,6-d_3 at δ 8.46 (s, H_2) due to as the phototransposition products.

4-Methylpyridine-2,6-d_2

The vapor of 4-methylpyridine-2,6-d_2 (4.0 Torr) was obtained by vaporizing the sample into the 3L quartz flask at 25 °C. This was then irradiated in the Rayonet reactor at 254 nm using 15 low pressure mercury arc lamps for 24 and 48hours as shown in Table 9. After irradiation the material was recovered by pumping it out through a trap cooled in an acetone-dry ice. This was then dissolved in chloroform-d or acetone-d_6. Analysis of the solution by ^{1}H-NMR ($CDCl_3$) showed 3-methylpyridine-5,6-d_2 at δ 7.5 (s, H_4) and δ 8.4 (s, H_6); and 2-methylpyridine-4,5-d_2 at δ 7.16 (s, H_3) and δ 8.49 (s, H_6) as the phototransposition products.

Table 9: Irradiation of 4-methylpyridine-2,6-d_2 at 254 nm

Exp NO.	Sample (g)	Recover (g)	Irradiation (h)	Solvent
1	0.050	0.015	24	Acetone-d_6
2	0.050	0.015	24	$CDCl_3$
3	0.050	0.012	48	$CDCl_3$

A brown film was observed coating on the reactor wall. The brown film was extracted by acetone (100 mL). The acetone solution was concentrated (0.013 g) and analyzed by ^{1}H-NMR. The ^{1}H-NMR ($CDCl_3$) showed the signals of 3-methylpyridine-5,6-d_2 at δ 7.5 (s, H_4) and δ 8.4 (s, H_6); and 2-methylpyridine-4,5-d_2 at δ 7.16 (s, H_3) and δ 8.49 (s, H_6).

CHAPTER 3

RESULTS AND DISCUSSION

3.1 Analysis of Reaction Products

3.1.1 GLC analysis

After irradiation of **2**, **3**, or **4** in the vapor phase, the condensed reaction mixtures will be analyzed by gas chromatography (GC) and by ^{1}H-NMR spectroscopy.

GLC analyses were performed on a PE-9000 FID instrument equipped with 30 m × 0.53 m supelcowax-10 phase capillary column. The formation of photoproduct was monitored by removing aliquots for GLC analysis [50°C (2 min), 10 °C/min. to 60°C (3 min), 0.1°C/min. to 63°C (3 min) 10°C/min. to 70°C (5 min); range 1; attn 8]. Figures 1-3 show the GC traces of the three isomeric methylpyridines **2**, **3**, and **4** and Figure 4 shows the GC trace a mixture of three isomers. This shows that each isomer can be distinguished in a mixture of three.

Quantitative GC analysis was accomplished by determining the detector response for each isomer. This was accomplished by plotting the observed peak area response vs the concentrations for four different concentrations of each isomer. These plots are shown in Figures 5-7.

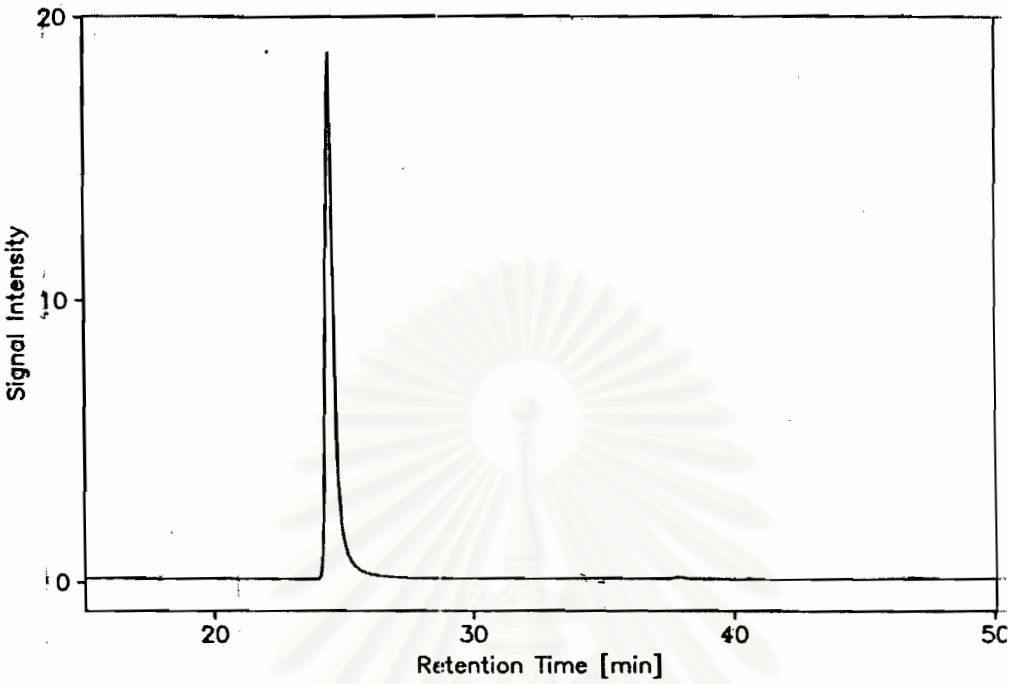


Figure 1: GC chromatogram of authentic 2-methylpyridine

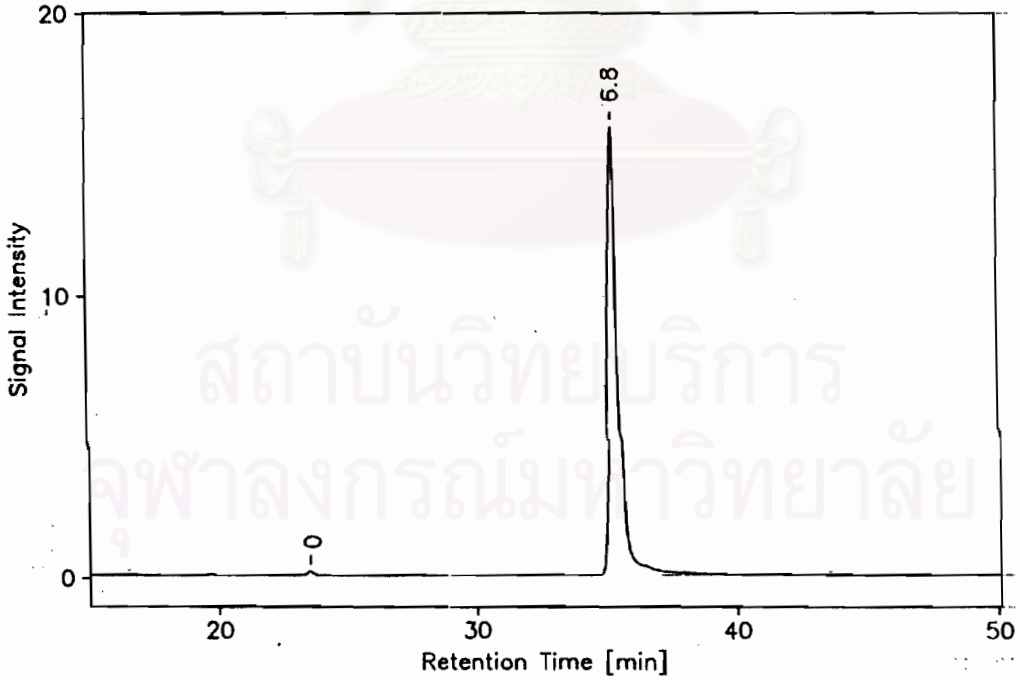


Figure 2: GC chromatogram of authentic 3-methylpyridine

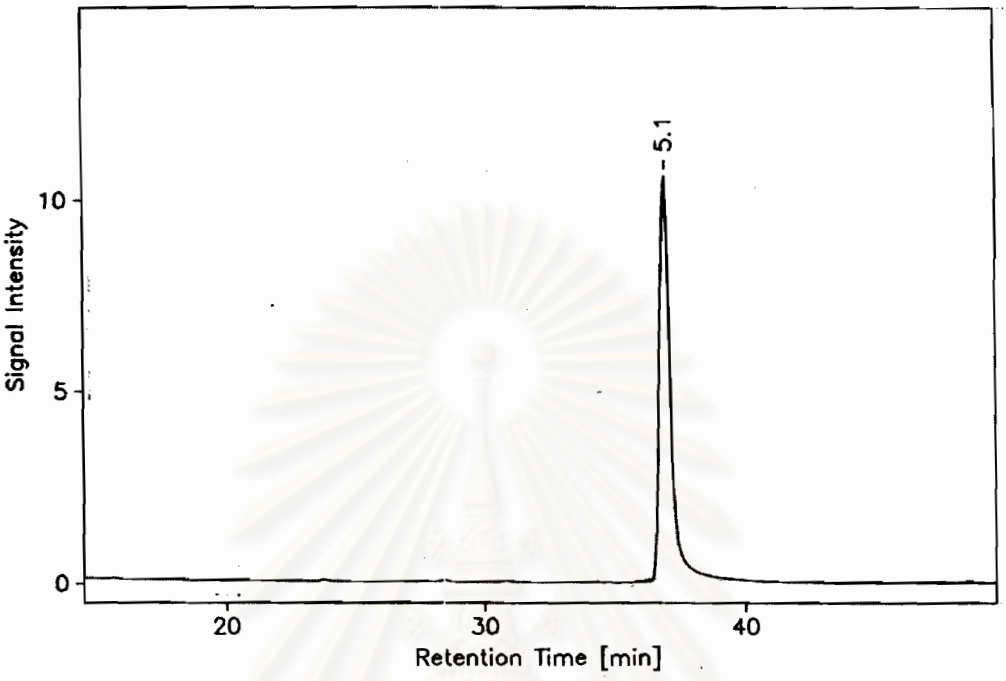


Figure 3: GC chromatogram of authentic 4-methylpyridine

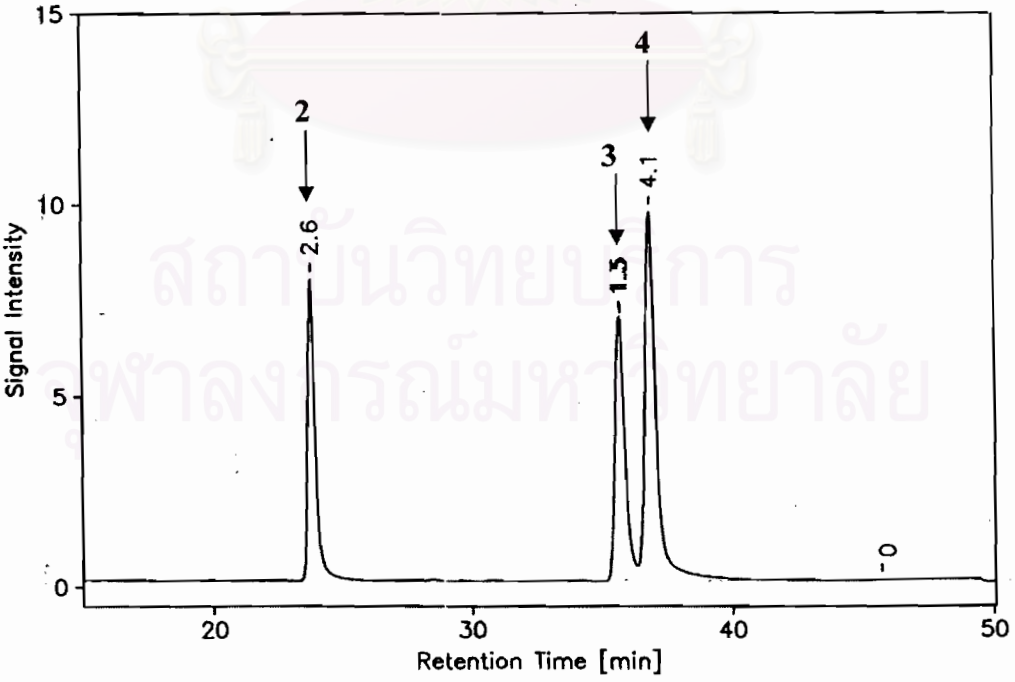


Figure 4: GC chromatogram of 2-, 3- and 4-methylpyridine mixture

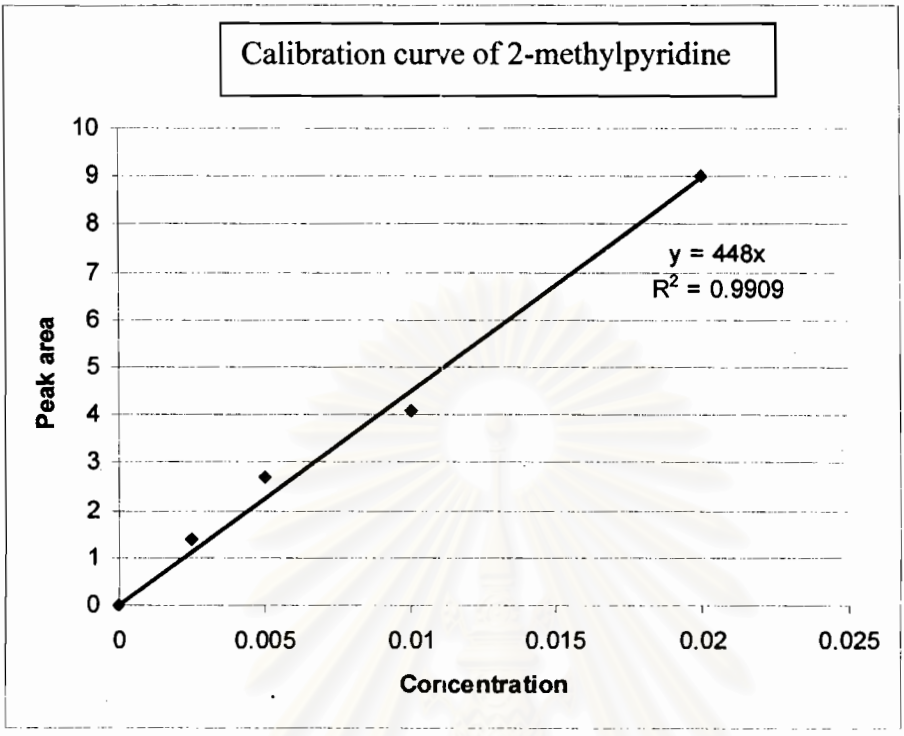


Figure 5: Calibration curve of 2-methylpyridine

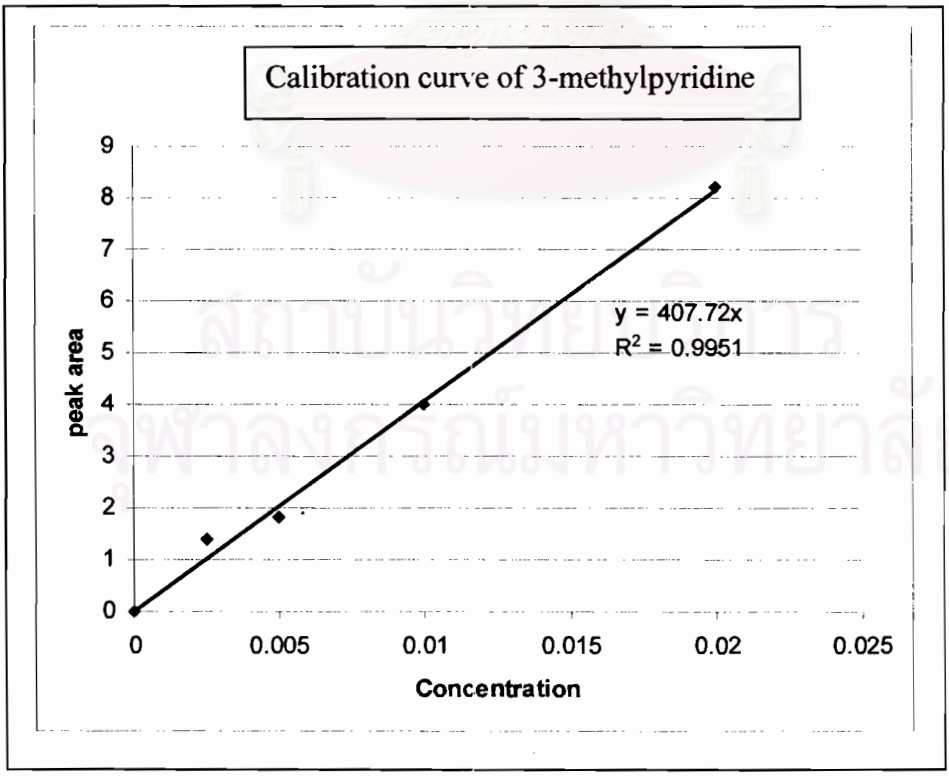


Figure 6: Calibration curve of 3-methylpyridine

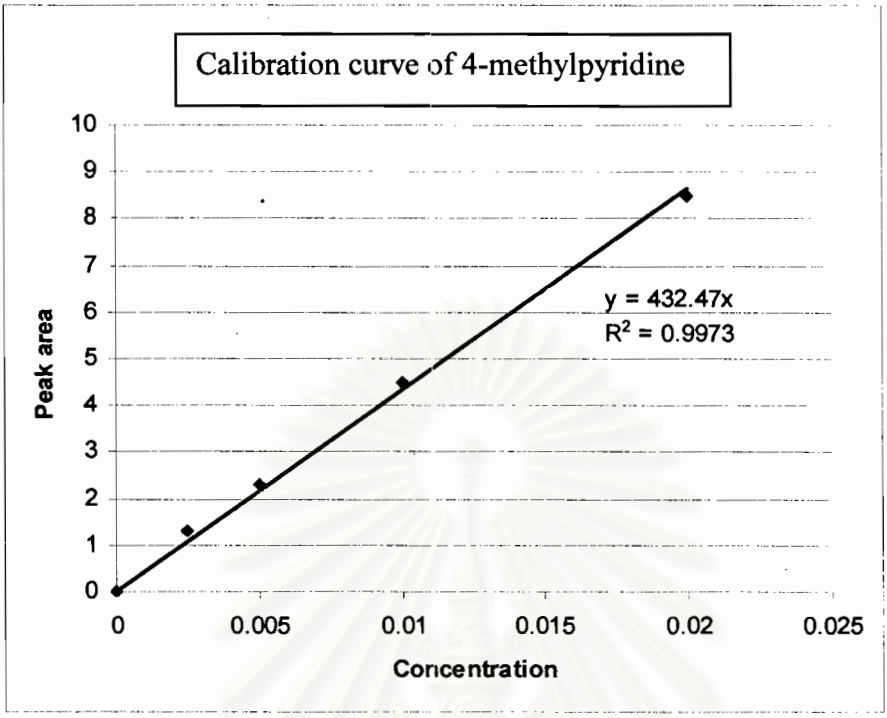


Figure 7: Calibration curve of 4-methylpyridine

3.1.2 ^{1}H-NMR Spectra of Ring Protons in 2-, 3-, and 4-methylpyridine

Introduction

The ring protons of the three isomeric methylpyridines absorb in the ^{1}H-NMR in three different regions of the spectrum. The protons in ring position 2 and 6 absorb furthest downfield at approximately δ 8.5 due to the deshielding of the adjacent nitrogen atom. The protons at ring position 3 and 5 are found to absorb furthest up field and are found in the region from δ 7.2 – 7.4. The proton at ring position 4 is found in between these two regions and is typically observed to absorb in the region δ 7.4-7.6.

In order to determine if ^{1}H-NMR could be used to analyze mixtures of the three methylpyridine isomers, the ^{1}H-NMR spectra of the pure isomers and of mixtures of the isomers were studied in acetone-d_6 and $CDCl_3$ solvents.

3.1.2.1 ^{1}H-NMR analysis of 2-, 3-, and 4-methylpyridine in acetone-d_6

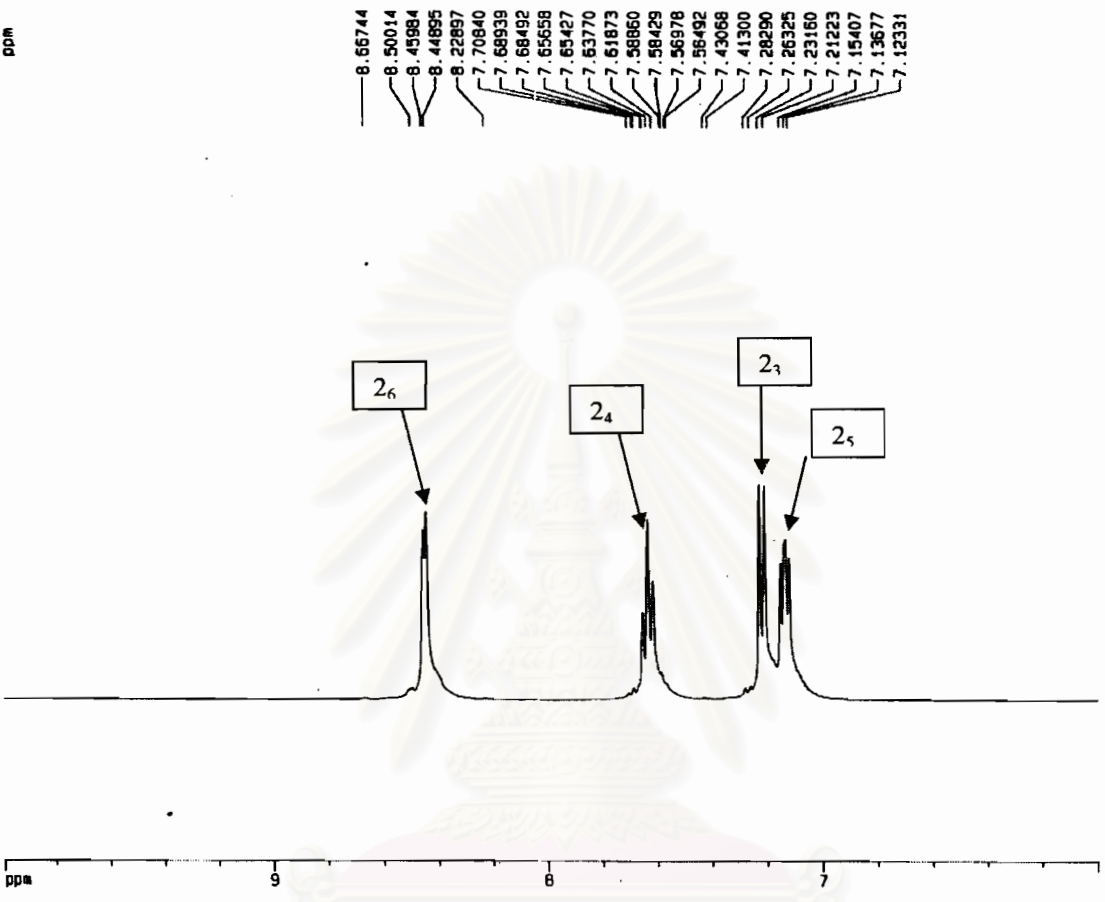


Figure 8: ^{1}H-NMR spectrum of 2-methylpyridine in acetone-d_6

The ^{1}H-NMR spectrum of the ring protons of authentic 2-methylpyridine shown in Figure 8 shows a doublet at δ 8.45 (J = 4.3 Hz) due to the proton at ring position 6 that is coupled to the proton at ring position 5. The signal due to the proton at ring position 4 appears as a triplet at δ 7.63 (J = 7.58 Hz) due to the spin-spin spitting with the protons at ring position 3 and 5. Two signals appear in the δ 7.0-7.4 region where the C-3 and C-5 protons are expected to appear. The doublet at δ 7.22 (J = 7.75 Hz) was assigned to the proton at position 3 since this proton is adjacent to only one ring carbon bearing a hydrogen atom (i.e, C-4). Finally, the distorted triplet at δ 7.14 (J = 5.6 and 6.8 Hz) was assigned to the proton at ring position 5 since this proton would be expected to be coupled to the protons at both ring position 4 and 6.

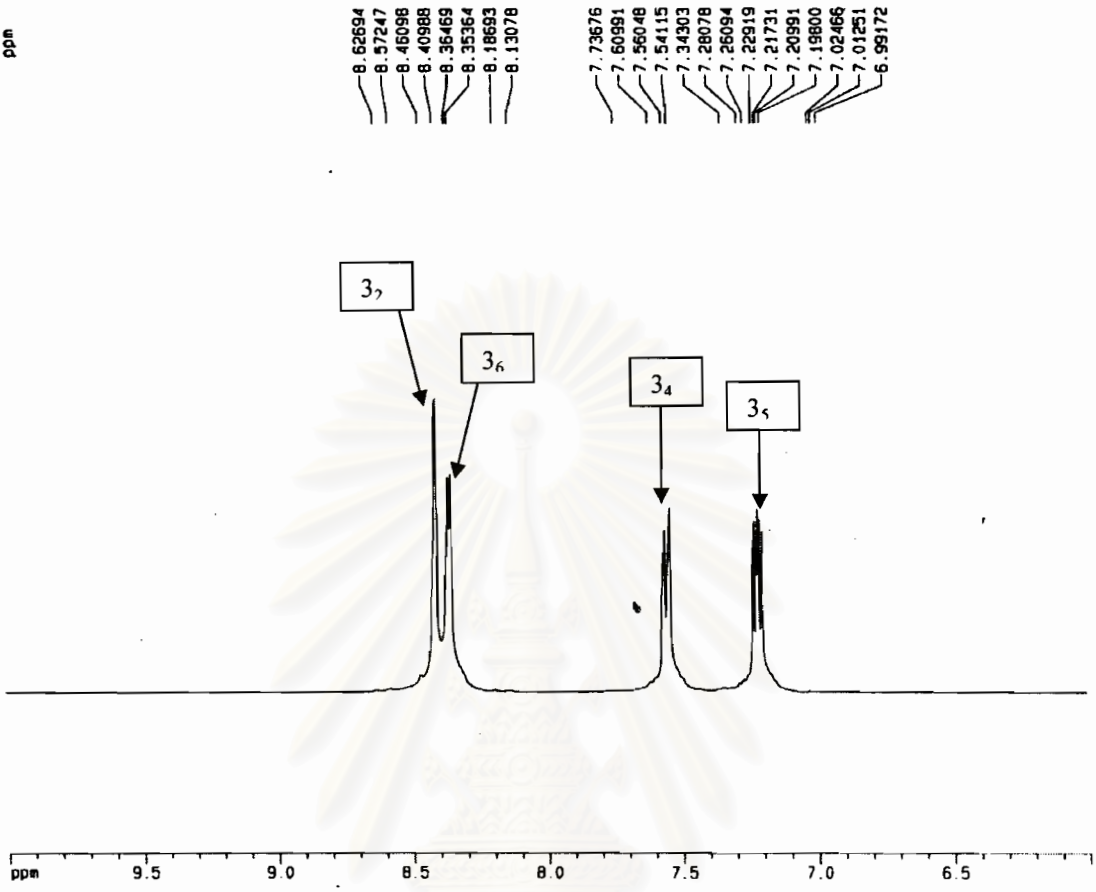


Figure 9: ^{1}H-NMR spectrum of 3-methylpyridine in acetone-d_6

The ^{1}H-NMR spectrum of the ring protons in authentic 3-methylpyridine shown in Figure 9 exhibits two signals between δ 8.3- 8.6 where protons in the 2 and 6 ring positions are known to absorb. The signal that appears as a singlet at δ 8.40 was assigned to the proton at ring position 2 since in 3-methylpyridine there are no protons on ring positions adjacent to C-2. The signal that appears as a doublet at δ 8.35 (J = 4.29 Hz) was therefore assigned to the proton at ring position 6 since in 3-methylpyridine this proton is coupled to the proton at ring position 5. The signal that appears as a doublet at δ 7.55 (J = 8 Hz), in the region where the C-4 proton is expected to absorb, was assigned to the C-4 proton. The signal due to this proton is expected to appear as a doublet since in 3-methylpyridine it is coupled only to the one proton at ring position 5. The signal from δ 7.19-7.22 was assigned to the proton at ring position 5. Scale expansion of this signal shown in Figure 10 reveals that the C-5 proton absorbs at δ 7.21 but appears as two doublets due to its coupling with the

proton absorbs at δ 7.21 but appears as two doublets due to its coupling with the proton at ring position 6, $J_{5,6}$ = 4.76Hz , and with the proton at ring position 4, $J_{4,5}$ = 7.72 Hz.

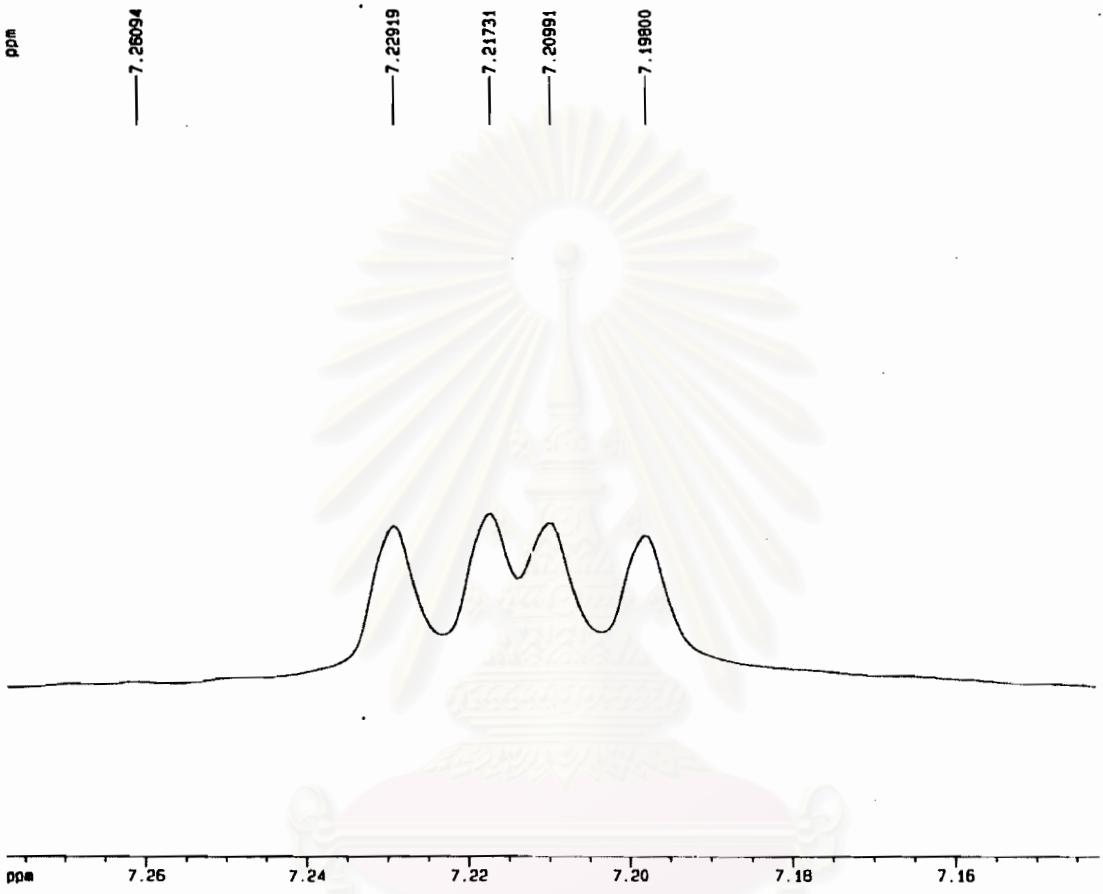


Figure 10: Scale expansion of C-5 proton of 3-methylpyridine

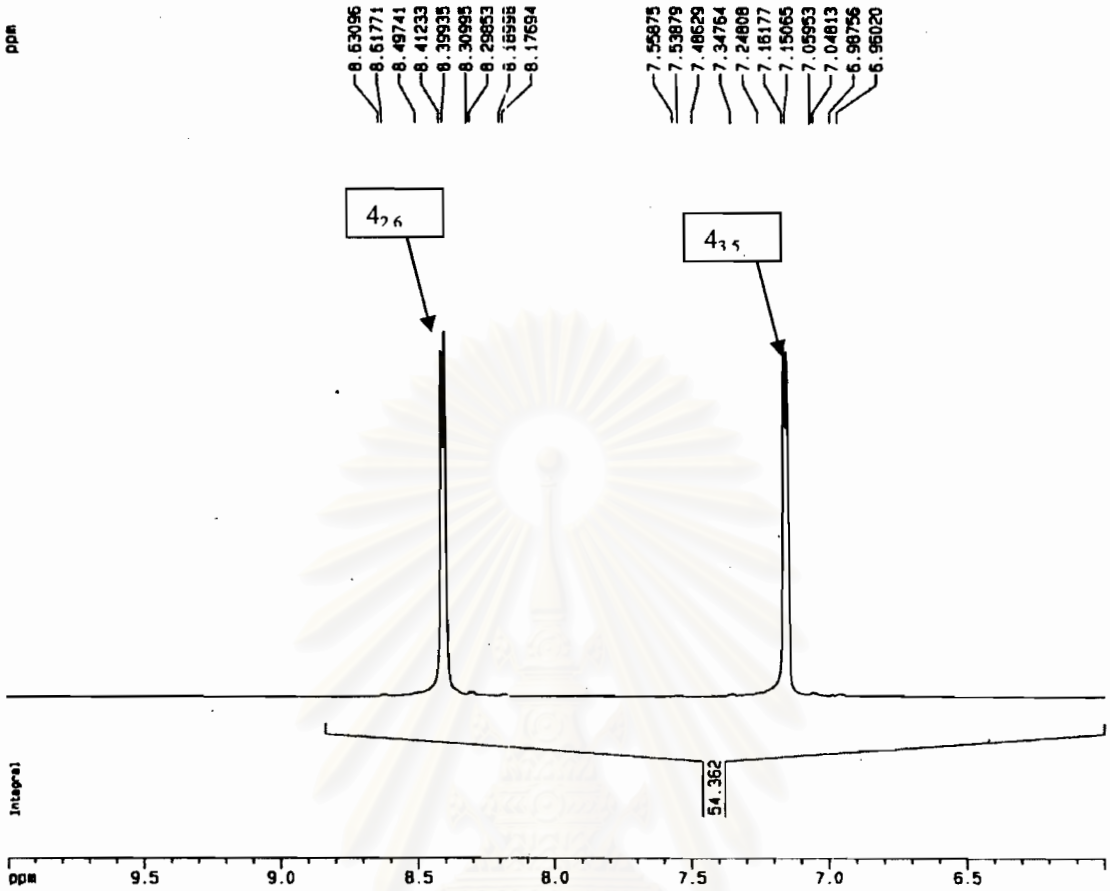


Figure 11: ^{1}H-NMR spectrum of 4-methylpyridine in acetone-d_6

The ^{1}H-NMR spectrum of the ring protons in an authentic sample of 4-methylpyridine is shown in Figure 11. Due to the symmetry of this molecule the spectrum consists of two doublets. The doublet at δ 8.4 (J = 5.31 Hz) was assigned to the two equivalent proton at ring position 2 and 6 which are coupled to the two equivalent proton at ring position 3 and 5 which appear as a doublet at δ 7.15 (J = 4.55Hz).

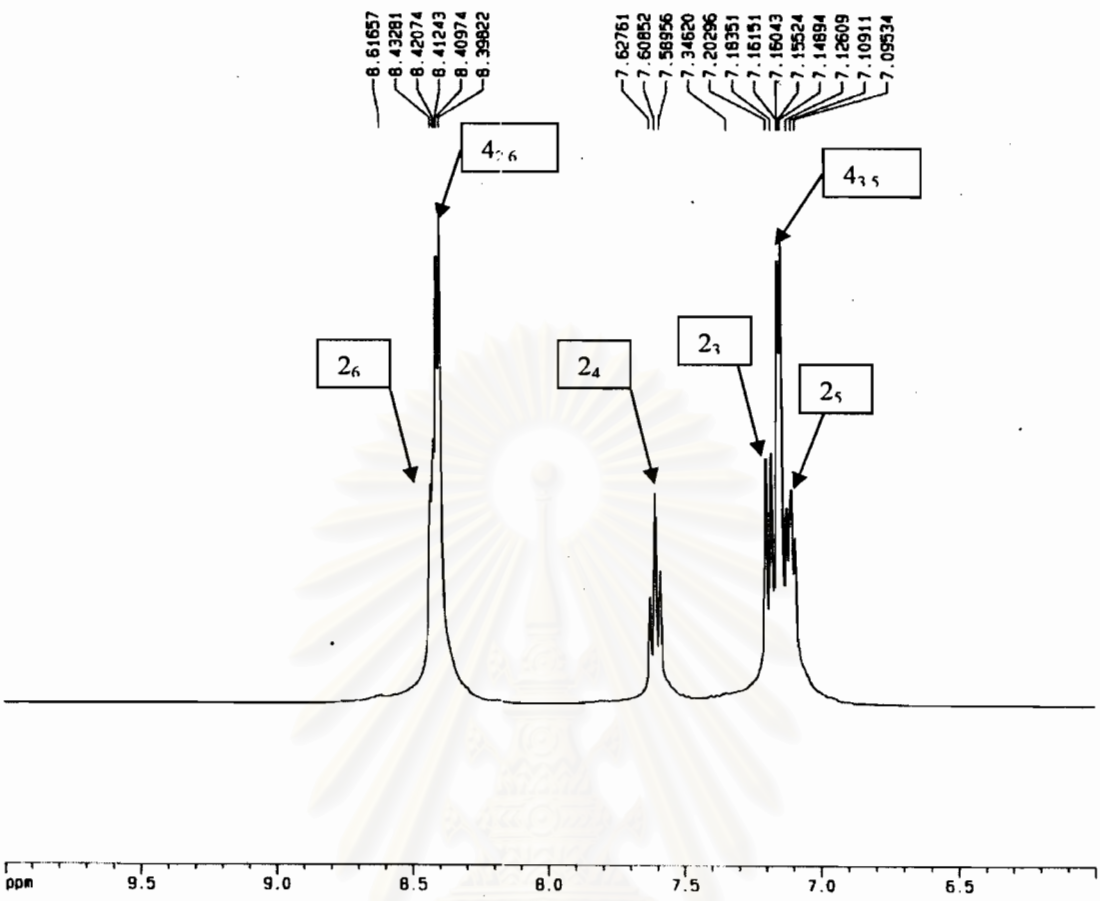


Figure 12: ^{1}H-NMR spectrum of 2- and 4-methylpyridines in acetone-d_6

Figure 12 shows the ^{1}H-NMR spectrum from δ 6.5- 9.5 of a mixture containing equal quantities of authentic samples of 2-and 4-methylpyridine in acetone–d_6 solvent. Examination of the region from δ 8.39-8.43 shows that the doublet due to the C-6 proton of 2-methylpyridine is barely visible on the downfield side of the doublet due to the equivalent C-2 and C-6 ring protons of 4-methylpyridine. Three distinct signals are observed in the C-3-5 region of the spectrum from δ 7.09-7.34. These include the doublet at δ 7.19 (J =7.78 Hz), the doublet at δ 7.16 (J =4.8 Hz), and the overlapping doublets absorbing at approximately δ 7.1-7.15. By comparison with the ^{1}H-NMR spectra of authentic 2- and 4-methylpyridine shown in Figures 8 and 11, these signals can be assigned to the C-3 proton of 2-methylpyridine, the C-3 and C-5 protons of 4-methylpyridine, and the C-5 proton of 2-methylpyridine respectively. The final signal which appears as a triplet at δ 7.60 (J = 7.58 Hz) can be assigned to the C-4 proton of

2-methylpyridine. From the spectrum shown in Figure 12, all signals of both 2- and 4-methylpyridine can be assigned

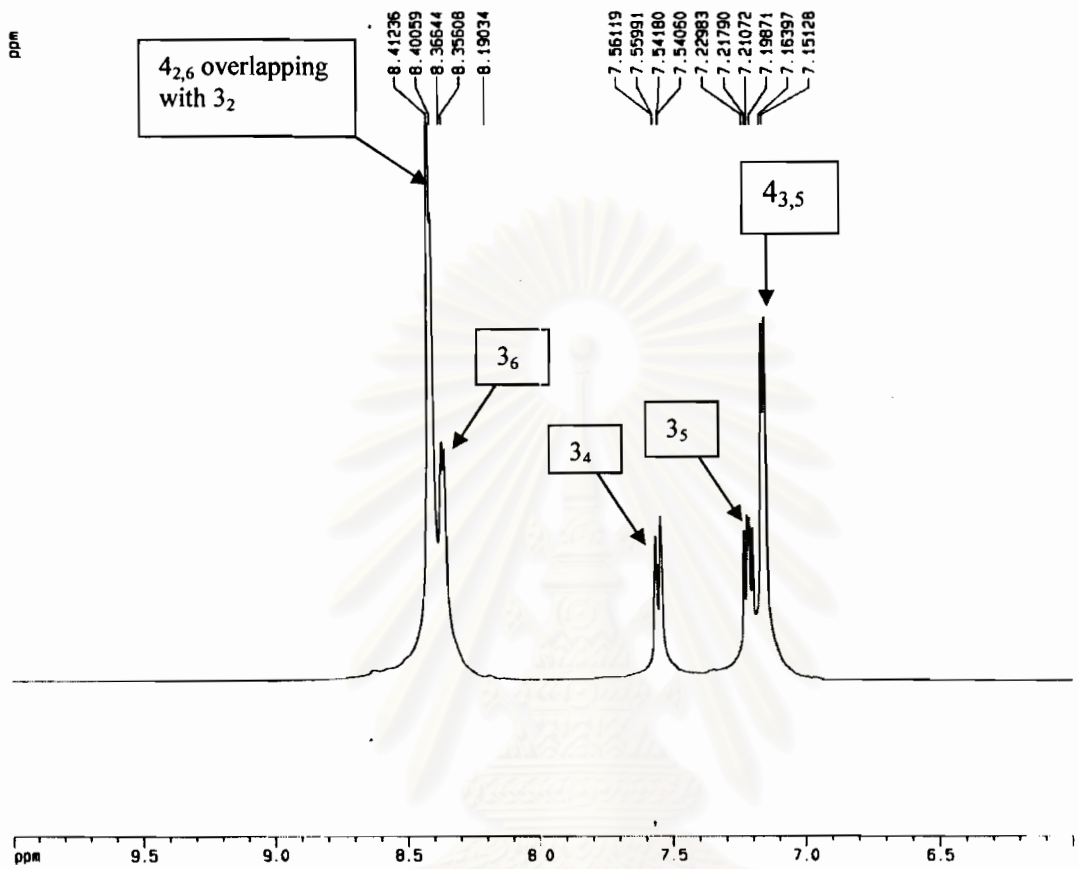


Figure 13: ^{1}H-NMR spectrum of 3- and 4-methylpyridine in acetone-d_6

Figure 13 shows the ^{1}H-NMR spectrum from δ 6.5- 9.5 of a mixture containing equal quantities of authentic 3- and 4-methylpyridine in acetone-d_6. The downfield portion of the spectrum from δ 8.3-8.5, where the C-2 and C-6 protons absorb, exhibits two signals. One of these signals that appears as a doublet at δ 8.36 (J = 4.29 Hz) can be assigned to the C-6 proton of 3-methylpyridine. Downfield from this, however, is a complex signal due to the overlap of the doublet due to H-2 and H-6 of 4-methylpyridine and the singlet due to the H-2 proton of 3-methylpyridine. Thus, signals due to these two sets of protons cannot be distinguished in this mixture. The upfield proton of the spectrum, where the C-4, C-3, and C-5 protons are known to absorb, consists of a doublet at δ 7.54 (J = 7.83 Hz), a multiplet at approximately δ 7.2, and the doublet at δ 7.15 (J = 4.58 Hz). By comparison with the spectra of

authentic 3- and 4-methylpyridine shown in Figures 9 and 11, these signals can be assigned to the C-4 proton of 3-methylpyridine, the C-5 proton of 3-methylpyridine, and the C-3 and C-5 protons of 4-methylpyridine respectively. Accordingly, only the C-2 and C-6 protons of 4-methylpyridine and the C-2 proton of 3-methylpyridine cannot be distinguished in this mixture.

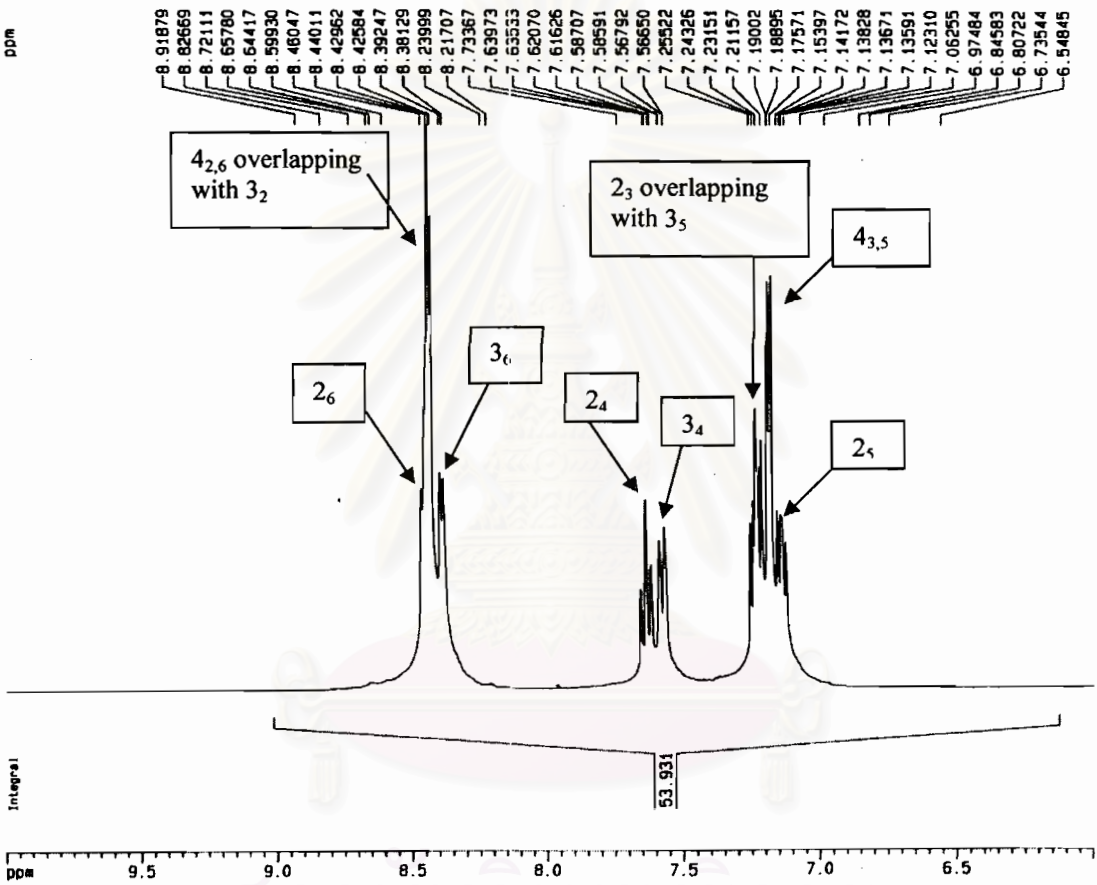


Figure 14: ^{1}H-NMR spectrum of 2-, 3- and 4-methylpyridine in acetone-d_6

Figure 14 shows the ^{1}H-NMR spectrum from δ 6.5-9.0 of a mixture of equal quantities of 2-, 3-, and 4-methylpyridine in acetone-d_6. The region from approximately δ 8.3-8.5, where C-2 and C-6 protons are known to absorb, consists of a distinct doublet at δ 8.39 (J = 4.7 Hz) due to the C-6 proton of 3-methylpyridine and a complex signal slightly downfield due to the overlapping signals due to the C-2 and C-6 protons of 4-methylpyridine and the C-2 proton of 3-methylpyridine. On the downfield edge of this signal, however, it is possible to distinguish a sharp singlet due

to the C-6 proton of 2-methylpyridine. The region of the spectrum between δ 7.6-7.7 consists of a triplet at δ 7.63 (J = 7.58 Hz) and a doublet at δ 7.5 (J = 7.83 Hz). By comparison with the spectra of pure samples shown in Figures 8 to 11, these signals can be assigned to the C-4 proton of 2-methylpyridine and the C-4 proton of 3-methylpyridine respectively. The region of the spectrum between δ 7.0-7.3 consists of overlapping signals due to the C-3 proton of 2-methylpyridine and the C-5 proton of 3-methylpyridine. Signals due to the individual protons cannot be distinguished. The doublet at δ 7.19 (J = 5.5 Hz) is, however, clearly visible and can be assigned to the equivalent C-3 and C-5 protons of 4-methylpyridine. In addition, the two closed spaced doublets between δ 7.1-7.2 the C-5 proton of 2-methylpyridine is also clearly visible.

This analysis shows that in a mixture of equal quantities of each isomer, the protons indicated in Figure 15 on each isomeric methylpyridine can be clearly distinguished. Those protons on each structure which are not shown cannot be distinguished because their signals overlap.

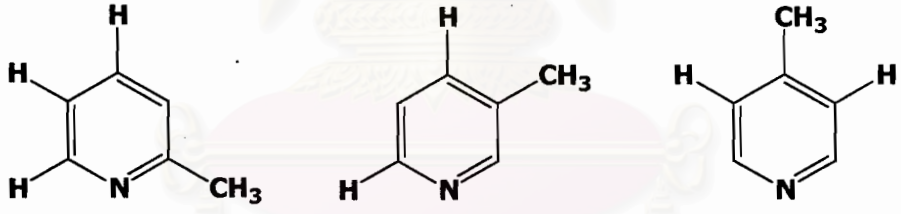


Figure 15: The protons on each isomeric methylpyridine

3.1.2.2 ^{1}H-NMR analysis of 2-, 3- and 4-methylpyridine in $CDCl_3$

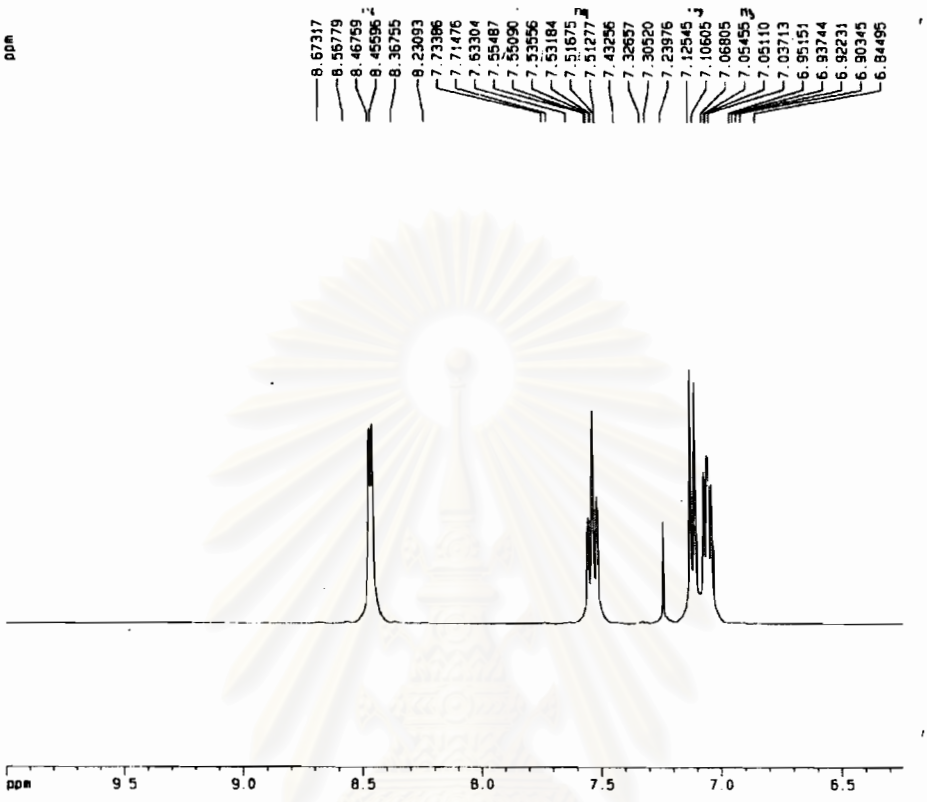


Figure 16: ^{1}H-NMR spectrum of 2-methylpyridine in $CDCl_3$

The ^{1}H-NMR spectrum of the ring protons of authentic 2-methylpyridine in chloroform-d solvent shown in Figure 16 exhibits a doublet at δ 8.45 (J = 4.65 Hz) due to the C-6 proton which is coupled to the proton at ring position 5. The proton at ring position 4 appears at δ 7.53 as a triple (J = 7.72Hz) due to the spin-spin spitting with the protons at ring position 3 and 5. Scale expansion of this signal is shown in Figure 17 and reveals addition coupling (J~1.56 Hz), possibly due to long-range coupling of the H_4 and H_6 protons. The protons at ring position 3 and 5 are expected to appear in the δ 7.0-7.1 region. Thus, the doublet at δ 7.1 (J = 7.76Hz) was assigned to the proton at position 3 since this proton is adjacent to only one ring carbon bearing a hydrogen atom (i.e, C-4). Finally, the signal at δ 7.05 was assigned the C-5 proton. Although this signal appears as a series of three lines, it does not show the typical 1:2:1 relative peak heights expected of a first-order triplet. Scale expansion of this signal shown in Figure 18 reveals considerable broadening of the

to appear in the δ 7.0-7.1 region. Thus, the doublet at δ 7.1 (J = 7.76Hz) was assigned to the proton at position 3 since this proton is adjacent to only one ring carbon bearing a hydrogen atom (i.e, C-4). Finally, the signal at δ 7.05 was assigned the C-5 proton. Although this signal appears as a series of three lines, it does not show the typical 1:2:1 relative peak heights expected of a first-order triplet. Scale expansion of this signal shown in Figure 18 reveals considerable broadening of the center peak relative to the outside signals. This suggests that the signal for H_5 appear as two doublets due to its coupling with H_4 and H_6 in which the two inside signals are overlapping and not resolved as shown below in Figure 19.

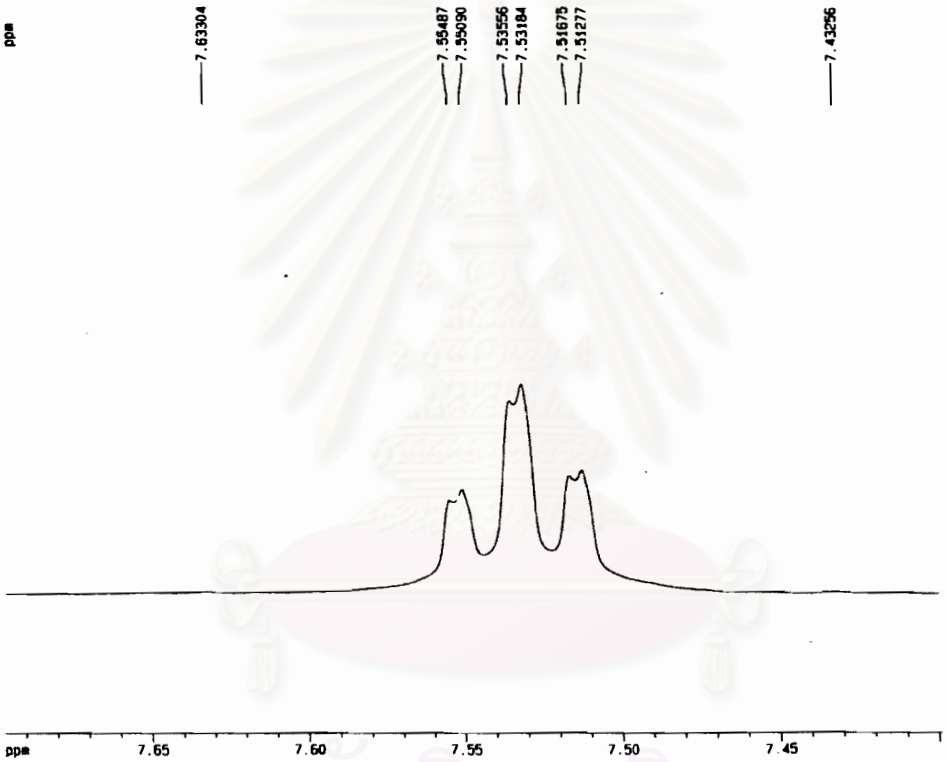


Figure 17: Scale expansion of C-4 proton of 2-methylpyridine

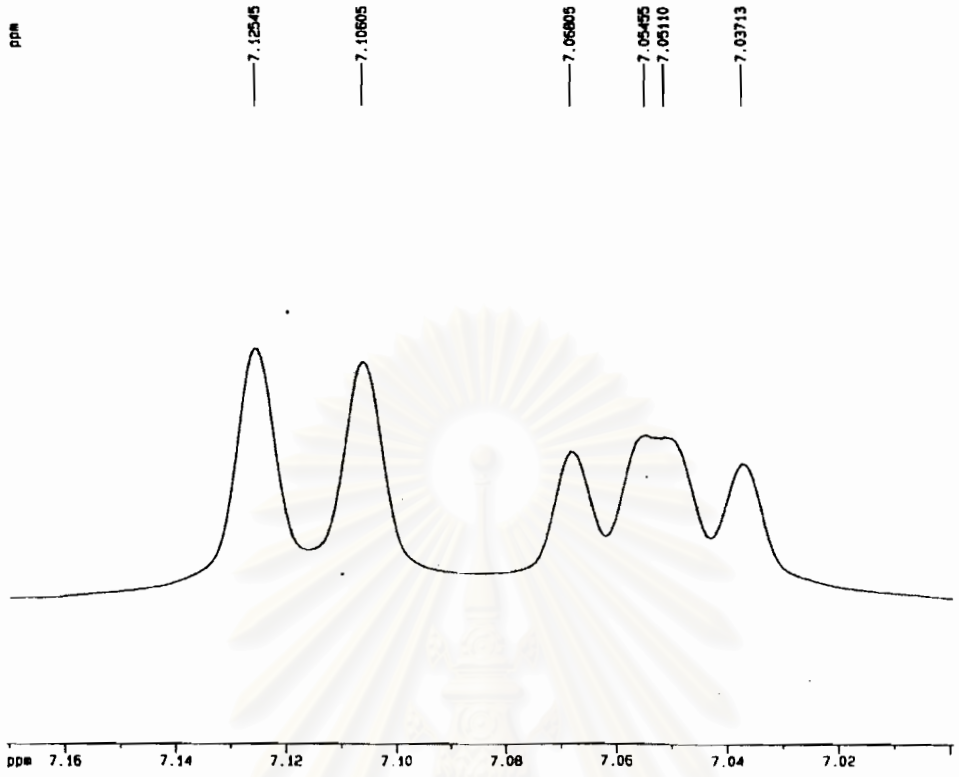


Figure 18: Scale expansion of C-5 proton of 2-methylpyridine

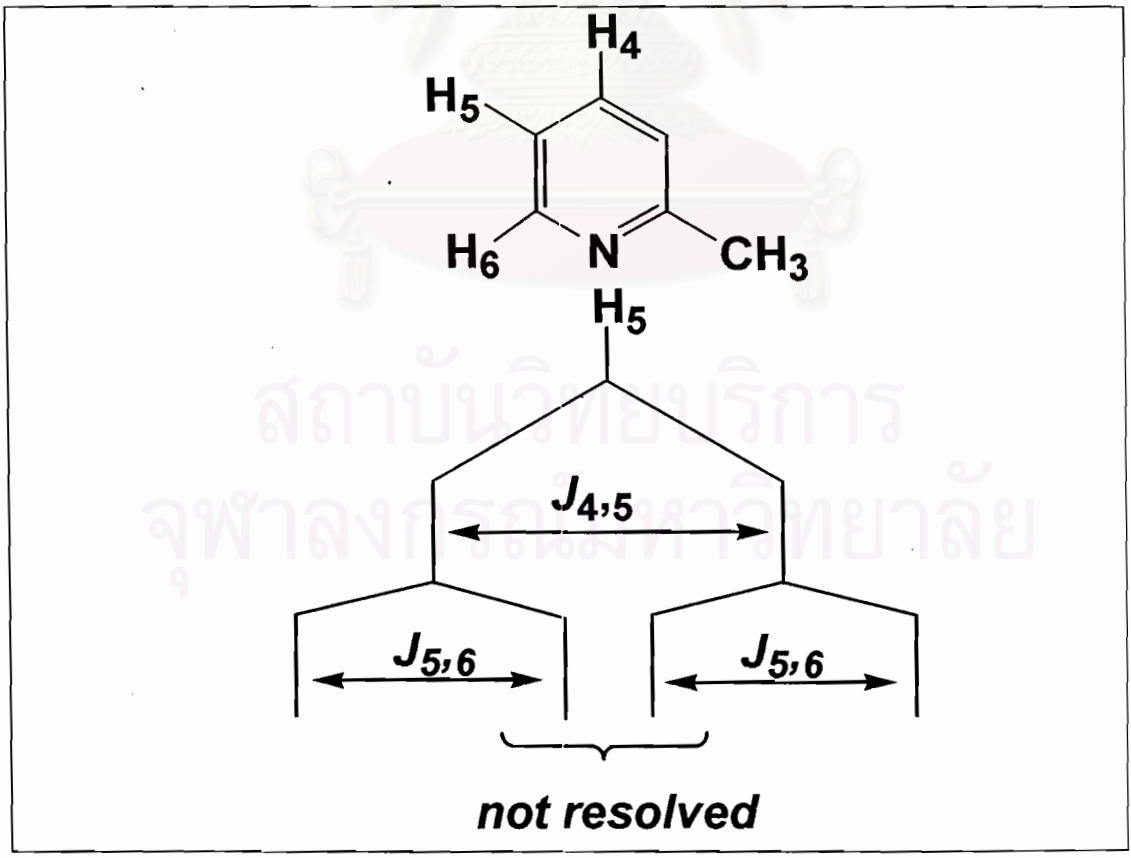


Figure 19: Illustrate a schematic coupling of H_5 with H_4 and H_6

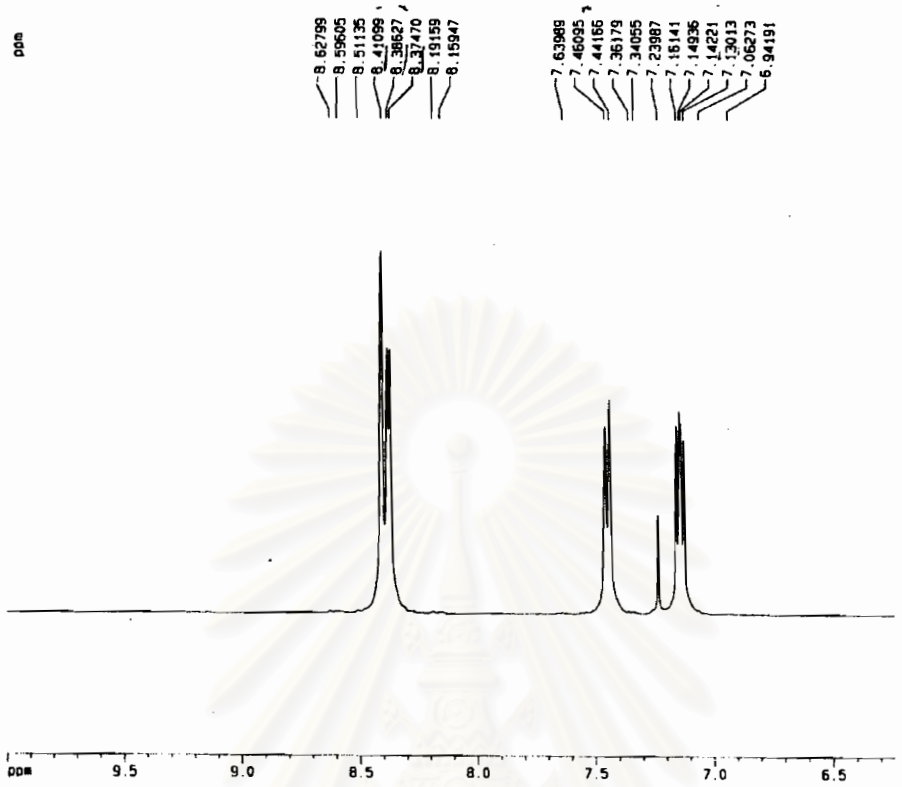


Figure 20: ^{1}H-NMR spectrum of 3-methylpyridine in $CDCl_3$

The ^{1}H-NMR spectrum of the ring protons in authentic 3-methylpyridine in chloroform-d solvent shown in Figure 20 exhibits two signals between δ 8.3- 8.4 where protons in the ring positions 2 and 6 are known to absorb. The signal that appears as a singlet at δ 8.41 was assigned to the proton at ring position 2. The signal that appears as a doublet at δ 8.38 (J = 4.29 Hz) was therefore assigned to the proton at ring position 6 which is coupled to the proton at ring position 5. The signal that appears as a doublet at δ 7.45 (J = 8 Hz), was assigned to the C-4 proton since this is where this proton is expected to absorb. As expected, this signal appears as a doublet since in 3-methylpyridine it is coupled only to the proton at ring position 5. The signal from δ 7.06-7.16 was assigned to the proton at ring position 5. Scale expansion of this signal is shown in Figure 21. In this case the two doublets due to the coupling of H_4 and H_5, $J_{4,5} = 7.69$, and H_5 and H_6, $J_{5,6} = 2.86$ Hz, are clearly shown.

at ring position 6 which is coupled to the proton at ring position 5. The signal that appears as a doublet at δ 7.45 (J = 8 Hz), was assigned to the C-4 proton since this is where this proton is expected to absorb. As expected, this signal appears as a doublet since in 3-methylpyridine it is coupled only to the proton at ring position 5. The signal from δ 7.06-7.16 was assigned to the proton at ring position 5. Scale expansion of this signal is shown in Figure 21. In this case the two doublets due to the coupling of H_4 and H_5, $J_{4,5}$ = 7.69, and H_5 and H_6, $J_{5,6}$ = 2.86 Hz, are clearly shown.

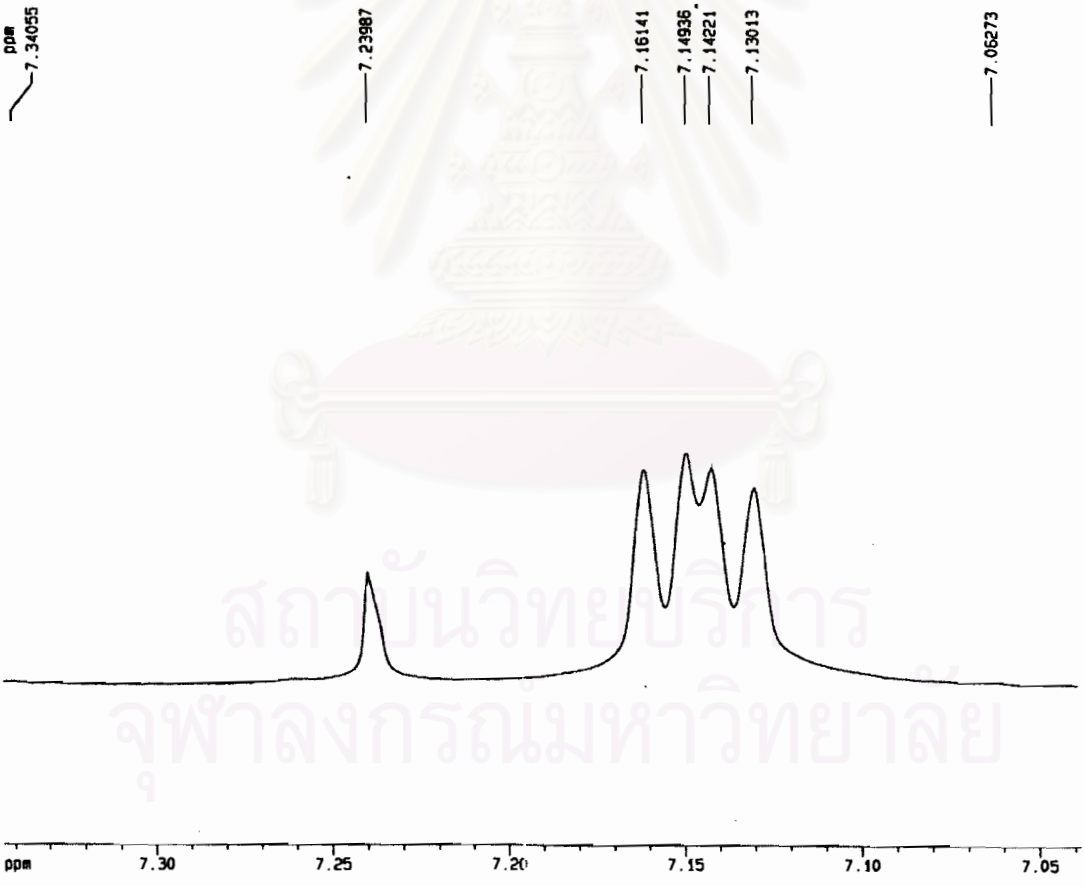


Figure 21: Scale expansion of C-5 proton of 3-methylpyridine

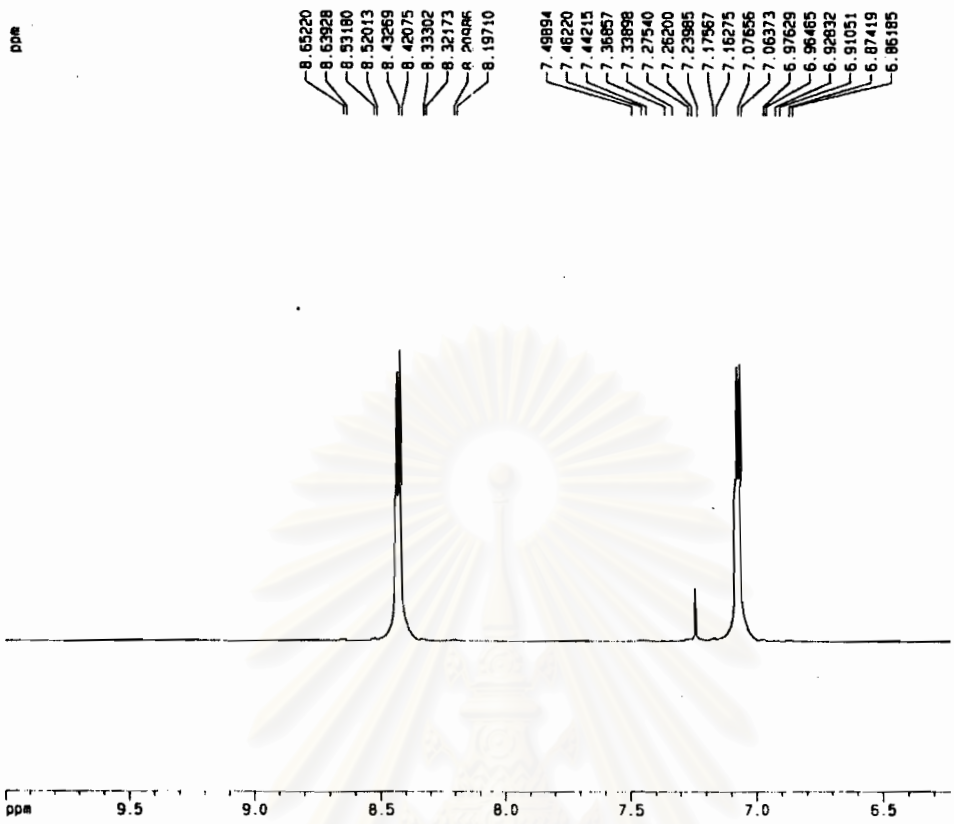


Figure 22: ^{1}H-NMR spectrum of 4-methylpyridine in $CDCl_3$

The ^{1}H-NMR spectrum of the ring protons in an authentic sample of 4-methylpyridine in chloroform-d solvent is shown in Figure 22. Due to the symmetry of this molecule the spectrum consists of two doublets. The doublet at δ 8.4 (J = 4.77 Hz) was assigned to the two equivalent proton at ring position 2 and 6 which are coupled to the two equivalent proton at ring position 3 and 5 these appear as a doublet at δ 7.0 (J = 5.13 Hz).

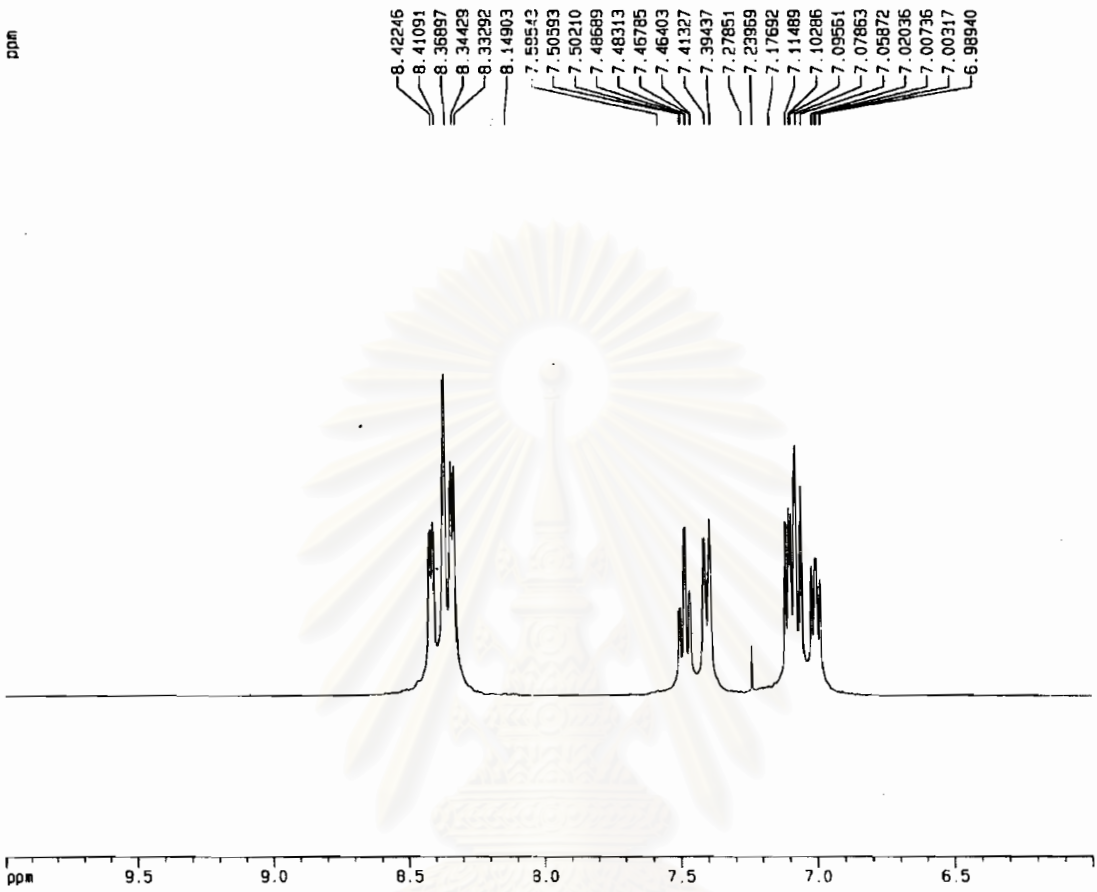


Figure 23: ^{1}H-NMR spectrum of 2- and 3-methylpyridine

The ^{1}H-NMR from δ 6.5-9.5 of a mixture of authentic 2- and 3-methylpyridine in $CDCl_3$ is shown in figure 23. The downfield protons of this spectrum from 8.3-8.5, where the C-2 and C-6 protons absorb, exhibit two signals. One of these signals that appear as a doublet at δ 8.41 (J = 4.62 Hz) can be assigned to the C-6 proton of 2-methylpyridine. The singlet at δ 8.36 is due to the H-2 proton of 3-methylpyridine and the doublet (J = 4.58 Hz) at δ 8.34 is due to the H-6 proton of 3-methylpyridine. The upfield portion of this spectrum from δ 7.35-7.55 shows a triplet (J = 7.62 Hz) which can be assigned to the H-4 of 2-methylpyridine and a doublet (J = 7.56 Hz) which is due to the C-4 proton of 3-methylpyridine. Upfield from this, the spectrum shows the overlapping triplet due to H-5 of 3-methylpyridine

and the doublet due to the H-3 proton of 2-methylpyridine. The triplet (J = 6.42 Hz) at δ 7.0 is due to H-5 of 2-methylpyridine.

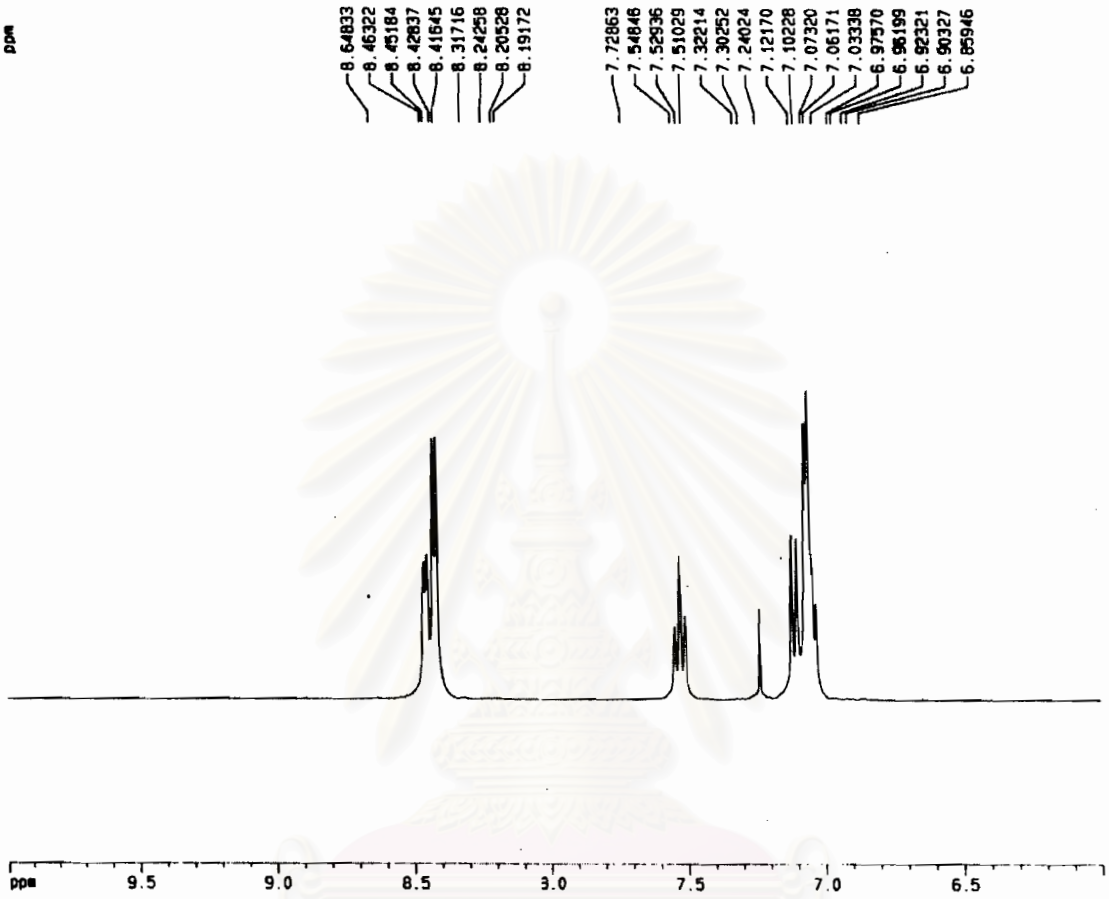


Figure 24: ^{1}H-NMR spectrum of 2-and 4-methylpyridine in $CDCl_3$

Figure 24 shows the ^{1}H-NMR spectrum of a mixture containing authentic samples of 2- and 4-methylpyridine in chloroform-d solvent. The signals in the region from δ 8.41-8.45 show that the first doublet at 8.45 (J = 4.55 Hz) is due to the ring proton at position 6 of 2-methylpyridine and the second doublet at δ 8.41 (J = 4.80 Hz) is due to the equivalent protons at C-2 and C-6 of 4-methylpyridine. The triplet at 7.52 (J = 7.6Hz) is due to the absorption of the C-4 proton 2-methylpyridine. The signals at δ 7.03-7.13 appear as three set of signals which can be assigned by comparison with the spectra of authentic samples in figures 16 and 22. The doublet at δ 7.11 (J = 8.41 Hz) can be assigned to the C-3 proton of 2-methylpyridine. The region of the spectrum between δ 7.03-7.07 consists of

overlapping signals due to the equivalent C-3 and C-5 protons of 4-methylpyridine. The signal due to the C-5 proton cannot be distinguished.

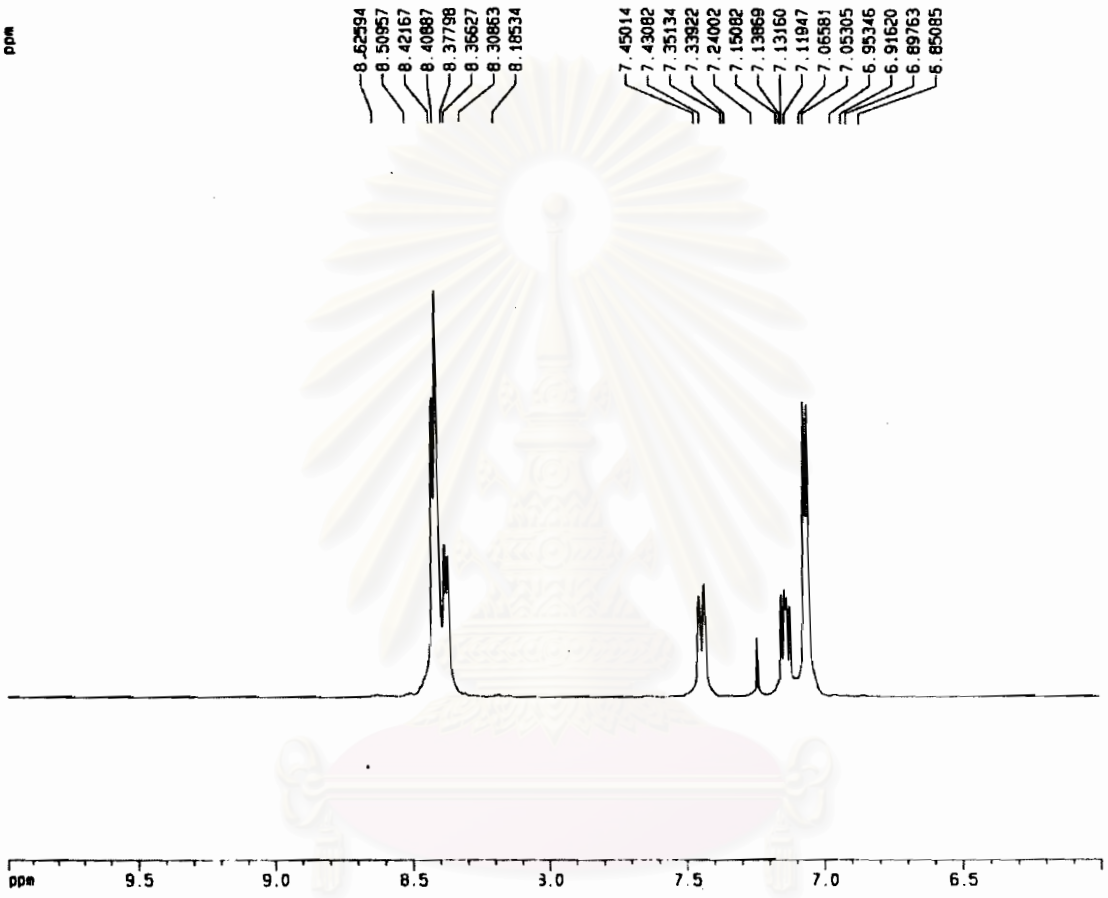


Figure 25: ^{1}H-NMR spectrum of 3-and 4-methylpyridine in $CDCl_3$

Figure 25 shows the ^{1}H-NMR spectrum from δ 6.5-9.0 of a mixture containing authentic 3- and 4-methylpyridine in $CDCl_3$ solvent. The downfield portion of the spectrum from δ 8.42-8.36, where the C-2 and C-6 protons absorb, exhibits three signals. One of these signals that appears as a doublet at δ 8.36 (J = 4.83 Hz) can be assigned to the C-6 proton of 3-methylpyridine. By comparison with the spectra of authentic 3-and 4-methylpyridine shown in Figures 19 and 21, the remaining portion of this signal consists of absorptions due to the C-2 and C-6 protons of 4-methylpyridine overlapping with the signal due to the C-2 proton of

3-methylpyridine. The doublet at δ 7.44 (J = 7.73 Hz) is due to the C-4 proton of 3-methylpyridine. The upfield region of the spectrum from δ 7.05-7.15 shows two signals as a doublet of doublets at δ 7.13 (J = 4.85 Hz) due to the C-5 proton of 3-methylpyridine, while the final signal appears at δ 7.03 and is due to the equivalent proton of C-3 and C-5 protons of 4-methylpyridine.

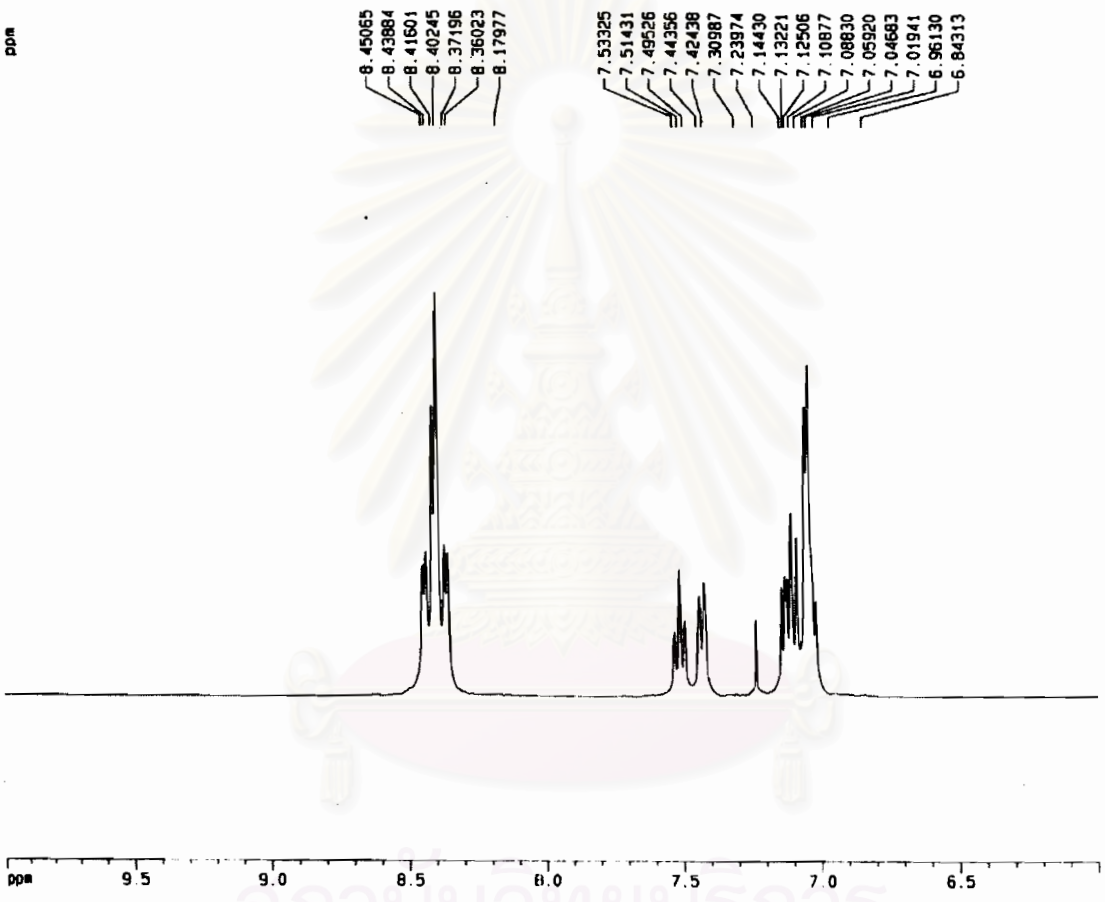


Figure 26: ^{1}H-NMR spectrum of 2-, 3- and 4-methylpyridine in $CDCl_3$

Figure 26 shows the ^{1}H-NMR spectrum from δ 6.5 -9.0 of a mixture of equal quantities of 2-, 3-, and 4-methylpyridine in chloroform-d solvent. The downfield portion of the spectrum from approximately δ 8.3-8.5, where the C-2 and C-6 protons are known to absorb, consists of a doublet at δ 8.44 (J = 4.7 Hz) and δ 8.36 (J = 4.3 Hz) due to the C-6 protons of 2- and 3-methylpyridine respectively. In between these absorptions at δ 8.40-8.41 the doublet for the C-2 and C-6 protons of 4-methylpyridine is overlapped with the singlet due to the C-2 proton of

3-methylpyridine. Thus, in a mixture of the three isomers it is possible to clearly detect the C-6 protons of 2- and 3-methylpyridine since they are not overlapping with any other signals.

The region of the spectrum δ 7.40-7.5 consists of a triplet at δ 7.5 (J = 7.72 Hz) due to C-4 of 2-methylpyridine and a doublet at δ 7.4 (J = 7.67 Hz) due to the C-4 of 3-methylpyridine. Thus, these two protons can also be distinguished in the mixture of the three isomers.

The up-field portion of the spectrum from δ 7.08-7.14 consists of the overlapping signals due to the C-5 proton of 3-methylpyridine overlapping with the C-3 proton of 2-methylpyridine. Because they are overlapping, these signals can not be distinguished in the spectrum of the mixture. The signals due to the C-3 and C-5 protons of 4-methylpyridine are also overlapping with the signal due to the C-5 proton of 2-methylpyridine in the δ 7.0-7.08 region of the spectrum. Therefore, these signals cannot be distinguished in a mixture of the compounds.

3.2 Photochemistry of methylpyridines

3.2.1 Vapor phase photochemistry of 2-methylpyridine

The UV absorption spectrum of 2-methylpyridine **(2)** in the vapor phase was recorded in a closed UV cell containing one drop of **2** which was allowed to stand at room temperature for 10 minutes in order to saturate the air in the cell. Figure 27 shows the UV absorption spectrum of **2** vapor with absorption maxima at 264, 258, and 253 nm.

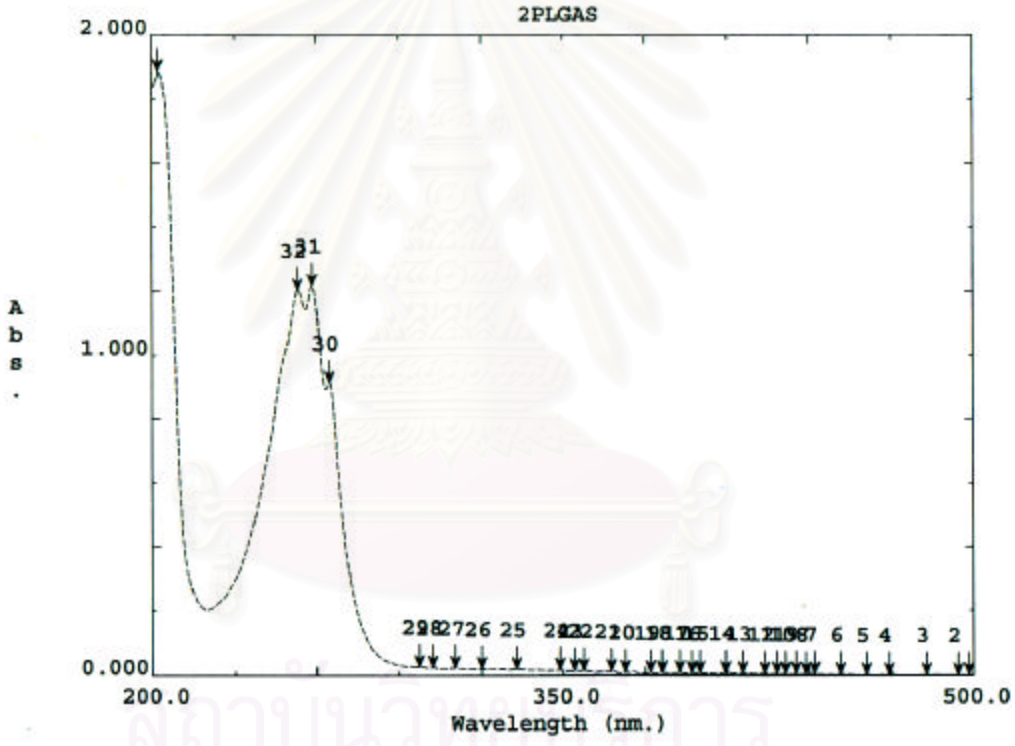
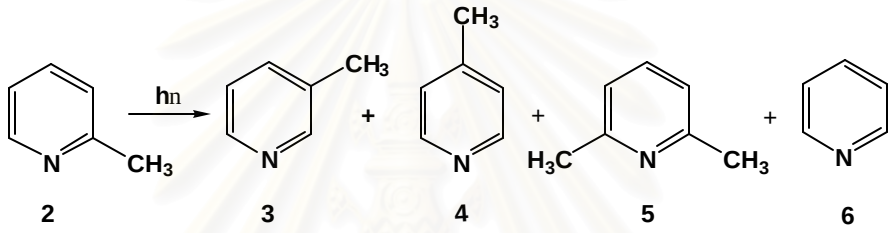


Figure 27: UV-absorption spectrum of 2-methylpyridine in vapor phase before irradiation

The vapor of **2** was irradiated at 254 nm for 24 hours. GLC analysis of the recovered mixture, shown in Figure 28a, showed the formation of 3-methylpyridine **(3)** and 4-methylpyridine **(4),** the phototransposition products, 2,6-dimethylpyridine **(5)**, a methylation product, and pyridine **(6)**, a demethylation product. These products are shown in Scheme 8. Quantitative gas chromatography (Figure 28a) revealed that 24 hours of irradiation resulted in the consumption of 6% of reactant and the formation of **3** and **4** in yields of 61 and 10% respectively. 2,6-Dimethylpyridine **(5)** and pyridine **(6)** were formed in only trace quantities and can only be detected under GC-PE 8500 system (Figure 28b)



Scheme 8: Photoreaction products from 2-methylpyridine

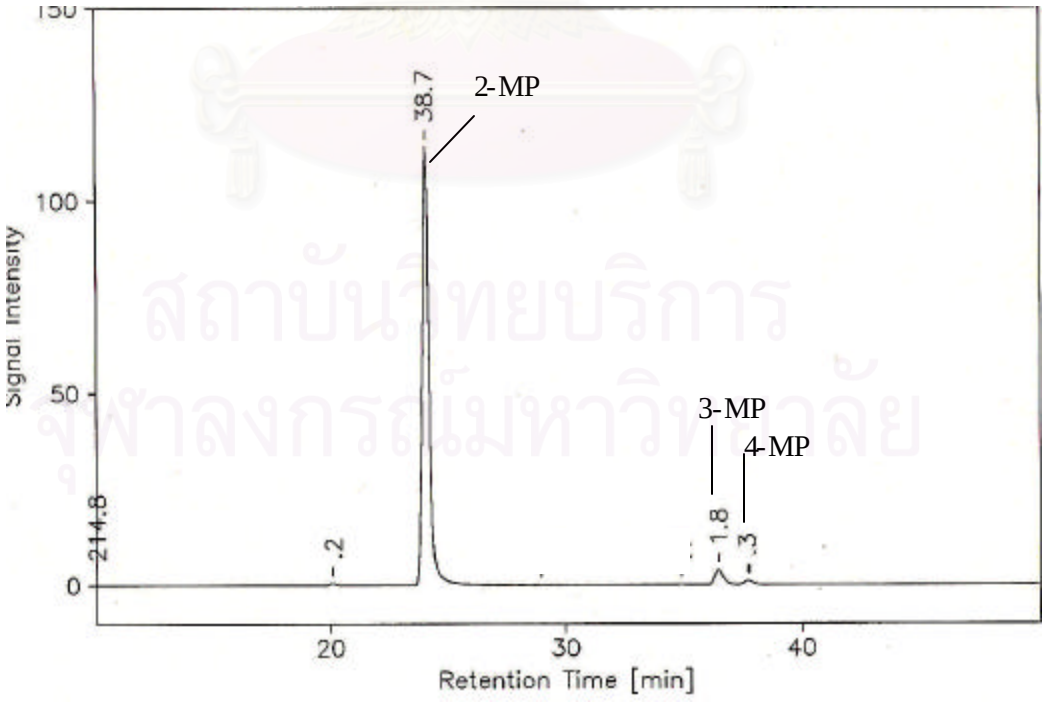


Figure 28a: GLC analysis of **2** after 24 hours of irradiation

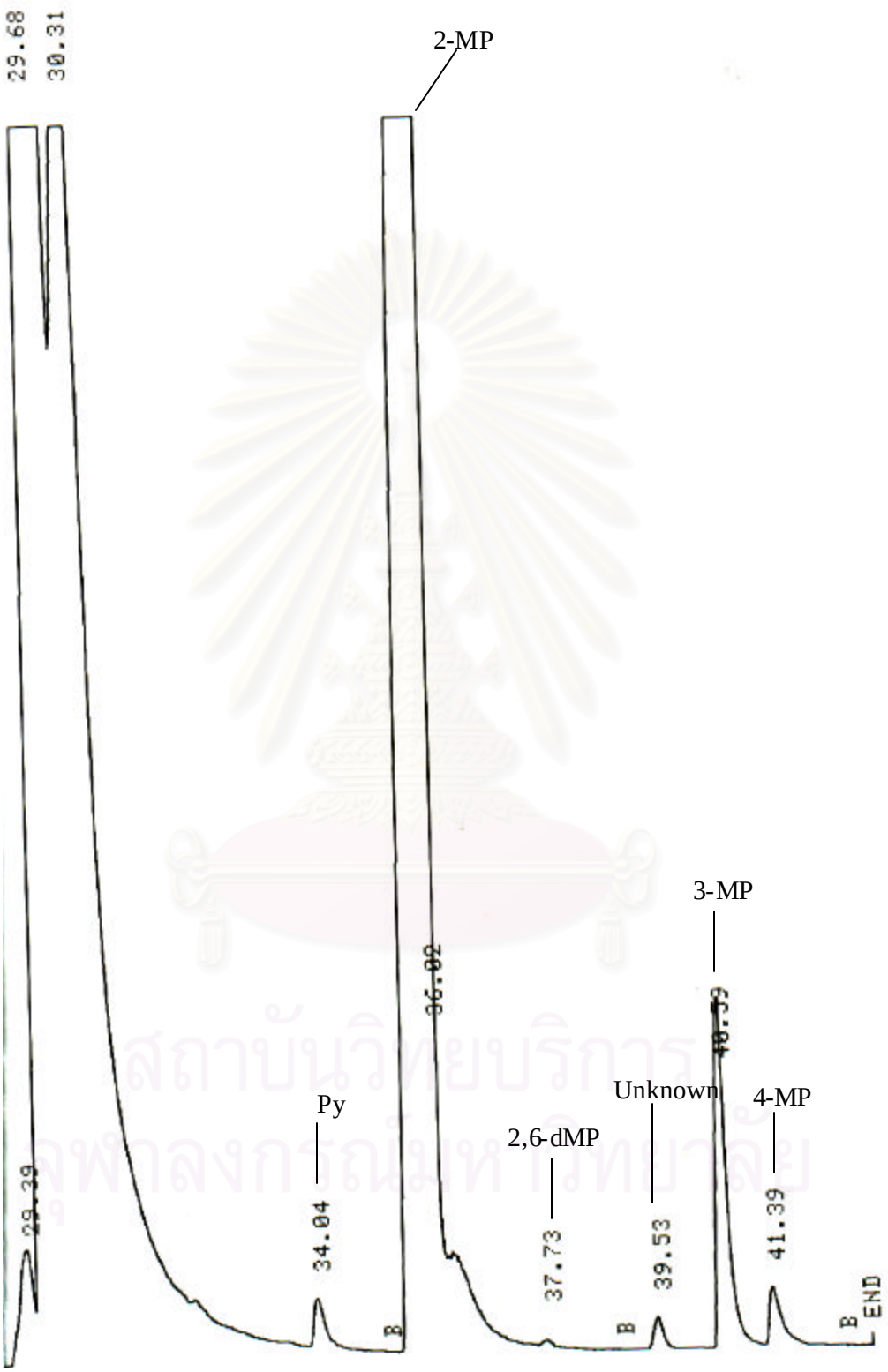


Figure 28b: GLC (PE8500) analysis of **2** after 24 hours of irradiation

In separate experiments, the vapor of **2** was also irradiated for 48, 72 and 96 hours. In each case the product mixtures were recovered and analyzed by quantitative GLC and by ^{1}H-NMR. The quantitative data for all of these irradiations is given in Table 10. The ^{1}H-NMR spectrum after 24 hours of irradiation is shown in Figure 30 while the ^{1}H-NMR spectra after 48, 72, and 96 hours of irradiation are given in appendix of this thesis.

The data in Table 10 shows that at all irradiation times the yield of 3-methylpyridine **3** is larger than the yield of 4-methylpyridine **4**. Figure 29 shows a plot of the ratio of the yields of **3**:**4** as a function of irradiation time. This plot shows that the ratio **3**:**4** decreases from 6.1 after 24 hours of irradiation to 4.1 after 96 hours of irradiation. Extrapolation back to zero irradiation time leads to a ratio of approximately 7. This shows that both the photoproducts are formed at very short irradiation times. The expected statistical ratio of photoproducts **3**:**4** would equal to 2 for primary photoproducts formed upon photolysis of **2**. The observed **3**:**4** ratio of approximately 7, at the early stage of irradiation, would, however, indicate that the formation of **3** and **4** are not due only to the primary photolysis **2**.

As shown in Table 10, although 6% of the reactant was consumed after 24 hours of irradiation, only 3% was consumed after 48 hours. The reaction thus becomes less efficient with time. This may be due to the film formed on the wall of the reactor which partially blocks the passage of light through the walls of the reactor.

It should be noted that the percentage yields in this reaction are difficult to determine due to the significant amounts of material loss (~ 50%) during recovery. This would lead to error in determination of the consumption yield of the starting material as well as the formation yields of the photoproducts. Moreover, the brown film formed upon photolysis has been shown (as discussed later) to contain the same components as observed in the vapor phase photoreacation of **2**. This brown film was coated on the reactor walls and was not recovered with the vapor reaction mixture. Thus, the formation of the brown film will contribute to additional error to the yield determinations. Although, determination of the yields in this vapor phase reaction are difficult and contain significant errors, the ratios of the product formation should be more accurate.

Table 10: Irradiation of **2** at 254 nm with 15 lamps at various irradiation times

Exp NO.	Sample (g)	Recover (g)	Irradiation (hrs)	Consumption 2-MP (%)	Formation 3-MP (%)	Formation 4-MP (%)	3MP:4MP
1	0.202	0.091	24	6	61	10	6.1
2	0.196	0.067	48	3	-	-	-
3	0.198	0.060	72	28.7	11	2	5.5
4	0.197	0.062	96	9	41	10	4.4

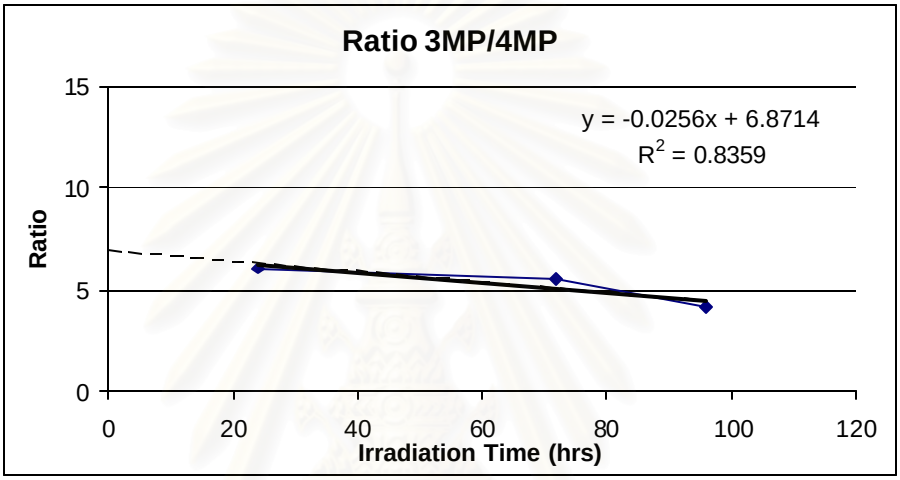
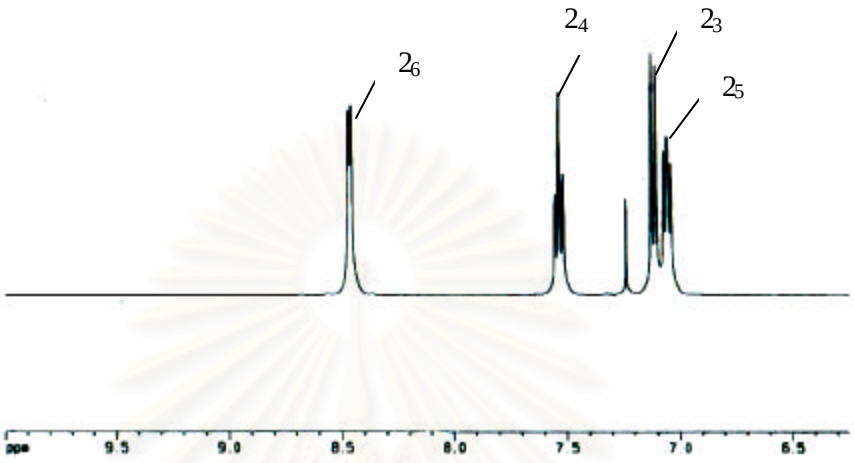


Figure 29: Ratio of **3/4**

The photoproduct mixture was also analyzed by ^{1}H-NMR spectroscopy. Figure 30 shows the ^{1}H-NMR spectrum in $CDCl_3$ solvent (a), before irradiation and b) after irradiation for 24 hours. Before irradiation the ^{1}H-NMR spectrum in figure 30a shows signals of **2** at δ 8.45 (H_6), 7.62 (H_4), 7.20(H_3) and 7.11(H_5). After irradiation, the ^{1}H-NMR spectrum, shown in figure 30b shows the same signals due to unconsumed reactant and small signals due to the formation of **3** as a doublet (J = 8 Hz) at δ 7.43 due to the H4 proton of 3-methylpyridine **(3)**. The small signal in the δ 8.35-8.45 portion of the spectrum is due to the overlapping absorptions of H2 and H6 of 3- and 4-methylpyridine **(4)**. Finally, the overlapping signals of H3 and H5 of 4-methylpyridine **(4)** and H5 of 2-methylpyridine **(2)** appear between δ 7.0 and 7.2.

30a



30b

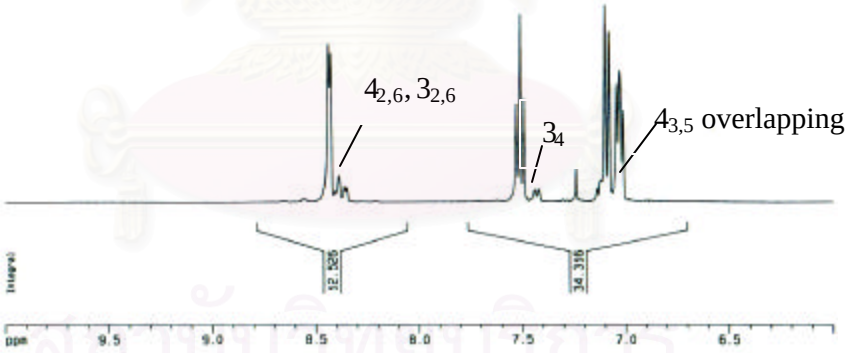


Figure 30: (a) ^{1}H-NMR of 2-methylpyridine before irradiation

(b) ^{1}H-NMR of 2-methylpyridine in $CDCl_3$ irradiated for 24 hours.

After irradiation, the walls of the reaction flask were coated with a brown film. This material was washed with acetone and the acetone extract was evaporated to dryness. The residue was recovered to give a brown viscous liquid (0.010 g) which was dissolved in dichloromethane and analyzed by ^{1}H-NMR and GLC. Figure 31 shows the GC trace of the brown film formed during the irradiation of **2**.

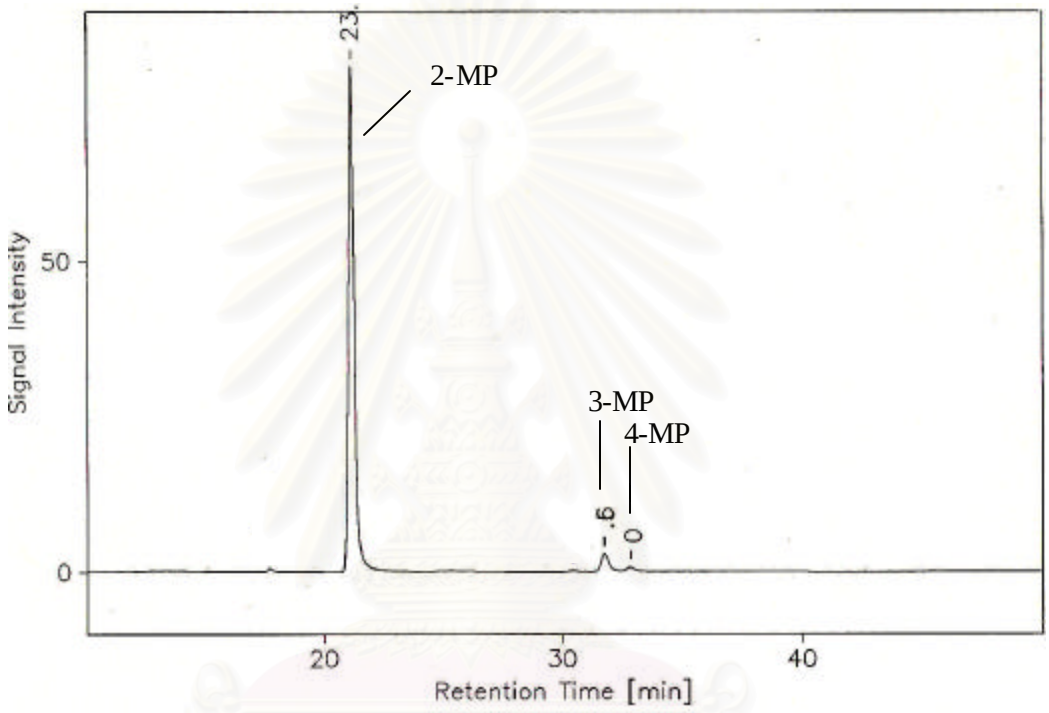


Figure 31: GC trace of brown polymer of 2-methylpyridine for 24 hours

GLC analysis of the brown film (Figure 31) shows the presence of three components eluted at retention time of 24, 36 and 37 min. Comparison with the GLC analysis of the 2-methylpyridine photoreaction (Figure 28) indicates that the components with retention times of 24, 36 and 37 correspond to 2-, 3- and 4-methylpyridine, respectively.

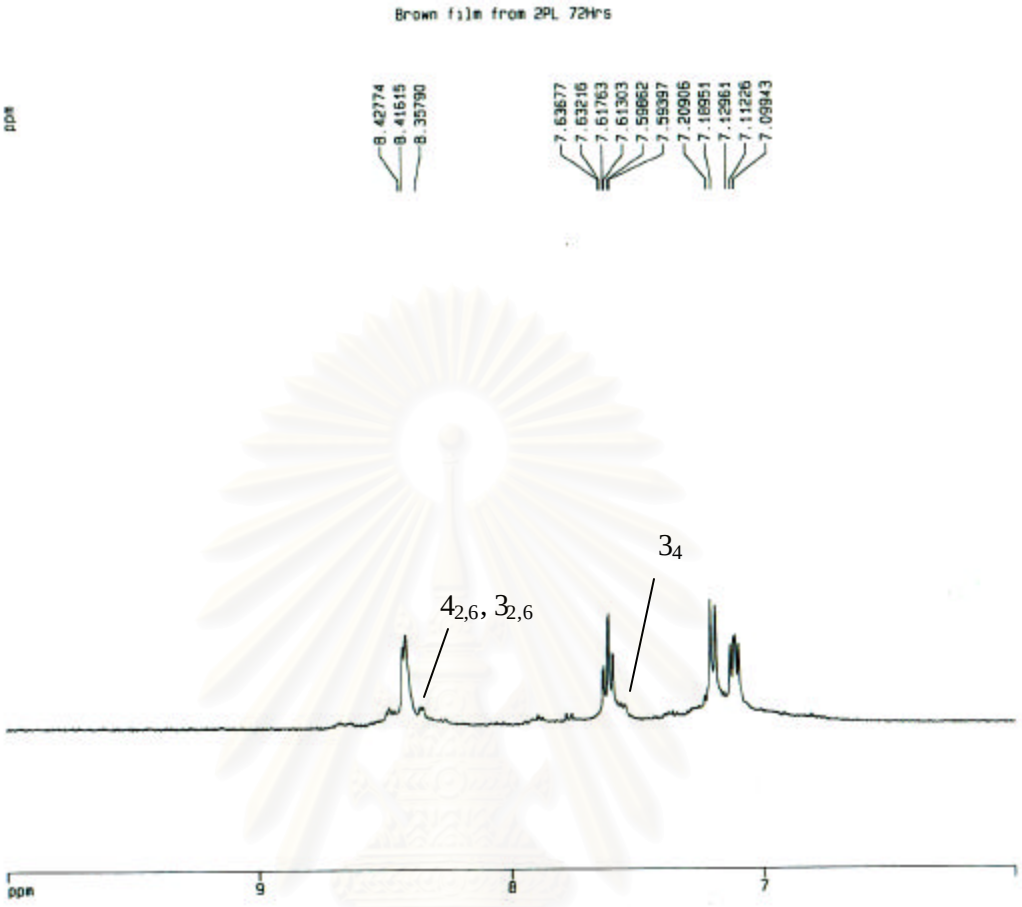


Figure 32 : ^{1}H-NMR of brown film from irradiation of **2**

The ^{1}H-NMR spectrum (acetone-d_6) of the brown film (Figure 32) shows the major signals at δ 8.5, 7.7, 7.2 and 7.1 corresponding with the proton signals of the starting material, **2**. The spectrum also reveals the signals due to the presence of 3- and 4-methylpyridine at δ 7.6 and 8.4. This indicates that the major components in the brown film are identical to the components in the photoreaction.

3.2.2 Vapor phase photochemistry of 3-methylpyridine

The UV absorption spectrum of 3-methylpyridine **(3)** in the vapor phase was recorded in a closed UV cell containing one drop of **3** which was allowed to stand at room temperature for 10 minutes. Figure 33 shows the UV absorption of vapor of **3** with two absorption maxima at 259 and 255 nm.

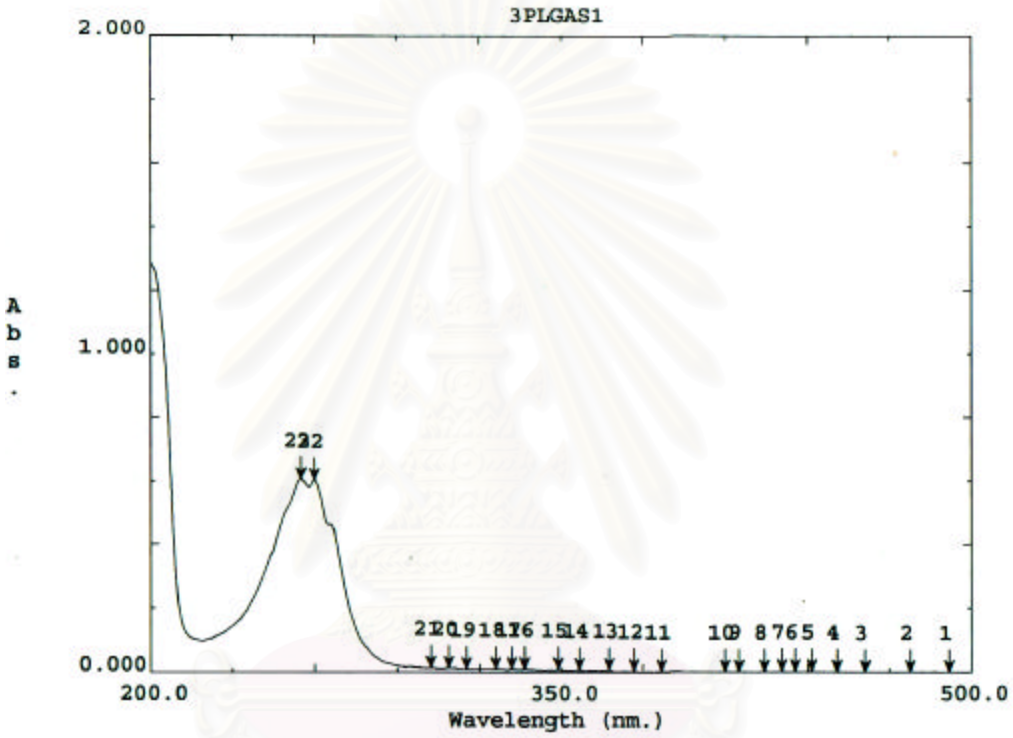
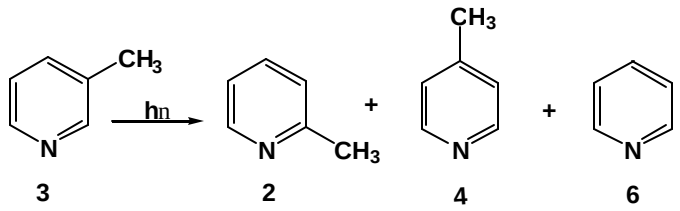


Figure 33: UV-absorption spectrum of 3-methylpyridine in vapor phase before irradiation

The vapor of **3** was irradiated for 24 hours. GC-analysis of the resulting mixture, shown in Figure 34, shows the formation of 2-methylpyridine **(2)** and 4-methylpyridine **(4)**, the phototransposition products, at retention time of 24 and 37 minutes respectively and to the formation of a trace quantity of pyridine **(6)**. No dimethylpyridine photoproduct was detected. The reaction is summarized in Scheme 9. Quantitative gas chromatography showed that after 24 hours of irradiation 31% of the reactant **3** was consumed and that **2** and **4** were formed in yield of 73% and 27% respectively.



Scheme 9: Photoreaction products from 3-methylpyridine

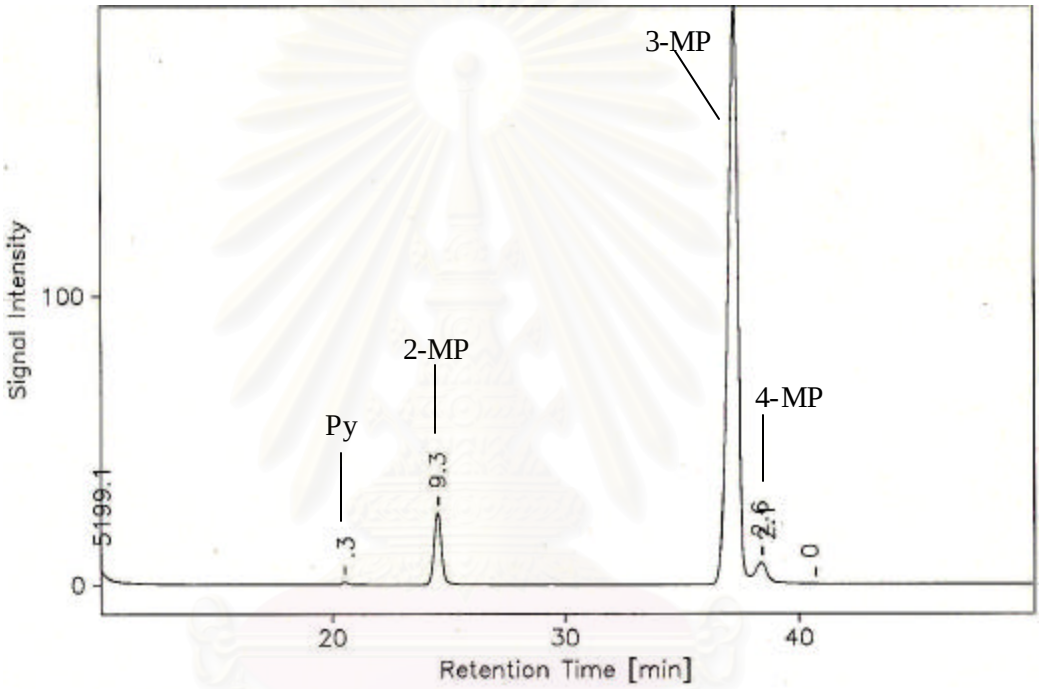


Figure 34: GLC analysis of photolysis of **3** after 24 hours of irradiation

In separate experiments, the vapor of **3** was also irradiated for 48, 72 and 96 hours. In each case the product mixture was recovered and analyzed by quantitative GLC and by ^{1}H-NMR. The quantitative data for all of these irradiations is given in Table 11. The ^{1}H-NMR spectrum after 24 hours of irradiation is shown in Figure 36 while the ^{1}H-NMR spectra after 48, 72, and 96 hours of irradiation are given in appendix of this thesis.

The data in Table 11 shows that at all irradiation times the yield of **2** is substantially greater than the yield of **4**. Figure 35 shows a plot of the ratio of the yields of **2**:**4** as a function of irradiation time. This plot shows that the ratio remains essentially constant with an average value of approximately 2.9. Extrapolation back to zero irradiation time leads to a ratio of approximately 2.8. This shows that both the photoproducts are formed at very short irradiation times. The statistical ratio of **2**:**4,** formed upon primary photolysis of **3**, would be expected at the ratio of 2:1. The experimental ratio of **2**:**4** is, however, observed at approximately 2.9:1 and remains constant for the entire irradiation period. This would again indicate that the observed formation of **2** and **4** are not due only to the primary photolysis of **3**.

As shown in Table 11, although 31% of the reactant was consumed after 24 hours of irradiation, only 35% was consumed after 48 hours and only 44 % was consumed after 96 hours. The reaction thus becomes less efficient with time. This may be due to the film formed on the wall of the reactor which partially blocks the passage of light through the walls of the reactor.

It should be noted again that the percentage yields in this reaction are difficult to determine due to the significant amounts of material loss (> 50%) during recovery. This would lead to error in determination of the consumption yield of the starting material as well as the formation yields of the photoproducts. Moreover, the brown film, formed upon photolysis, has been identified (as discussed later) to contain the same components as observed in the vapor phase photoreaction of **3**. This brown film was coated on the reactor walls and was not recovered with the vapor reaction mixture. Thus, the formation of brown film will contribute more error to the yield determinations. Although, determination of the yields in this vapor phase reaction are difficult and contain significant errors, the ratios of the product formation should be more accurate.

Table 11: Irradiation of **3** at 254 nm with 15 lamps at various irradiation times

Exp NO.	Sample (g)	Recover (g)	Irradiation (hrs)	consumption 3-MP (%)	Formation 2-MP (%)	%Formation 4-MP (%)	2MP:4MP
1	0.140	0.043	24	31	73	27	2.7
2	0.160	0.050	48	35	73	25	2.9
3	0.140	0.035	72	47	61	18	3.4
4	0.160	0.028	96	44	62	23	2.7

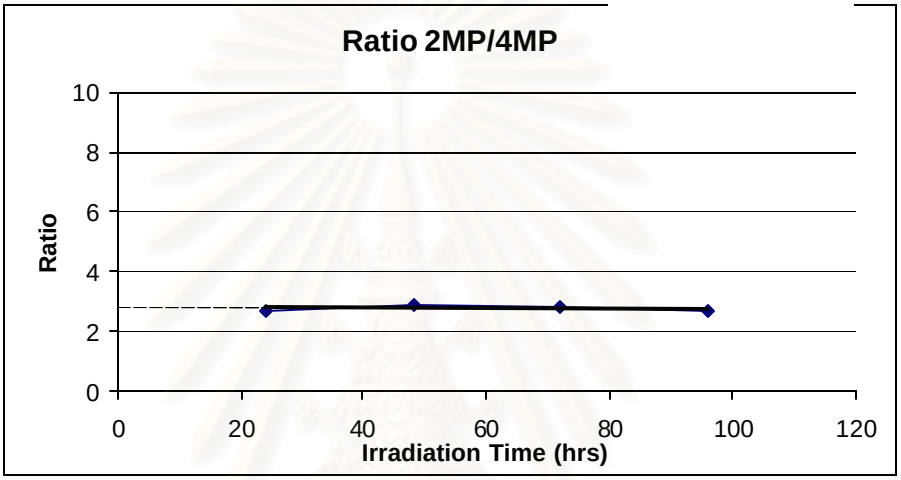


Figure 35 : Ratio of **2MP/4MP**

After irradiation the product mixture was also analyzed by ^{1}H-NMR. Figure 36 shows the ^{1}H-NMR spectrum in $CDCl_3$ a) before irradiation and b) after 24 hours irradiation. Before irradiation (Figure 36a) shows the spectrum of pure **3** with signals at δ 8.41 (H_2), 8.37 (H_6), 7.45 (H_4) and 7.14(H_5). After irradiation, the spectrum in Figure 36b shows the same signals due to unconverted reactant **3** and new small signals due to the photoproducts. Thus, the spectrum shows a triplet (J = 7.8 Hz) at δ 7.56 due to the H4 proton of 2-methylpyridine **2**. The region from δ 8.35-8.41 shows a doublet (J = 4.7 Hz) due to the proton at ring position 6 of **2**. The signals at δ 8.46 due to the equivalent protons at positions 2 and 6 of **4** is overlapping with the signal due to H2 of **3**. The region from δ 7.0-7.15 also shows the signal due to the equivalent H3 and H5 protons of **4** is overlapping with the signal due to the H5 proton of **2**.

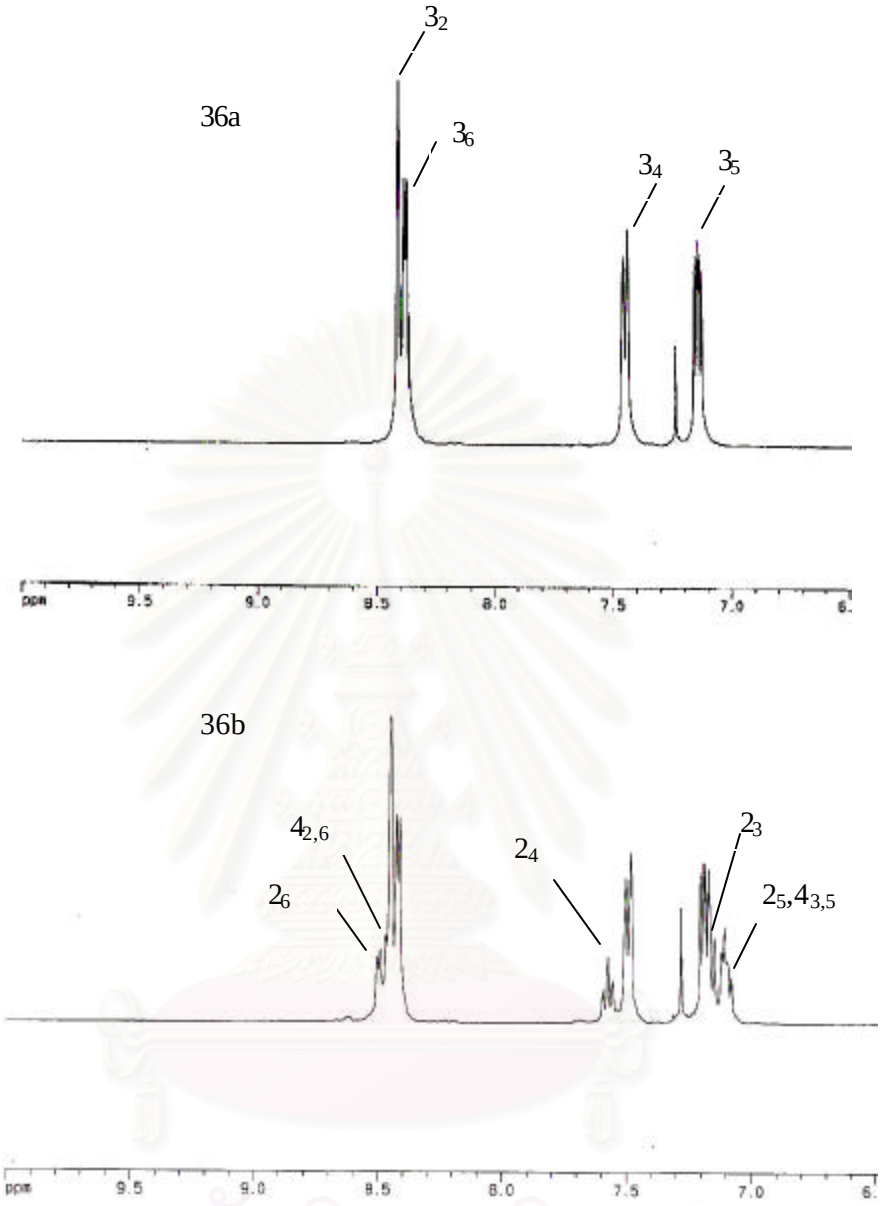


Figure 36 : (a) ^{1}H-NMR of 3-methylpyridine before irradiation.
(b) ^{1}H-NMR of 3-methylpyridine in $CDCl_3$ irradiated for 24 hours.

After irradiation, the walls of the reaction flask were again coated with a brown film. This material was washed with acetone and the acetone extract was evaporated to dryness. The residue was recovered to give brown viscous liquid (0.012 g) which was dissolved in dichloromethane and analyzed by GLC.

Figure 37 shows the GC trace of the brown film formed after 24 hours of irradiation of vapor of **3**.

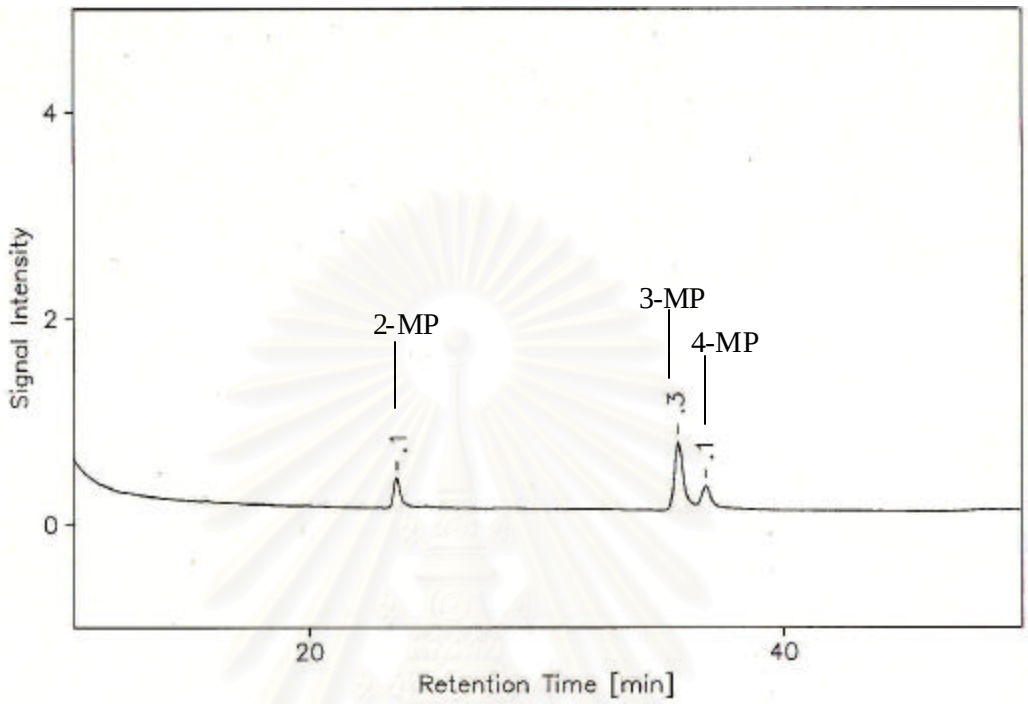


Figure 37: GC trace of brown film formed from irradiation of 3-methylpyridine for 24 hours

The GC trace analysis of the brown film (Figure 37) shows the presence of only three components at retention times of 24, 36 and 37 min. Comparison of this GC-trace with the GC-trace of photoreaction (Figure 34) indicates that this brown film consists of 2-, 3- and 4-methylpyridines.

3.2.3 Vapor phase photochemistry of 4-methylpyridine

The UV absorption spectrum of 4-methylpyridine **(4)** in the vapor phase was recorded in a closed UV cell containing one drop **4** which was allowed to stand at room temperature for 10 minutes in order to saturate the air in the cell. Figure 38 shows the UV absorption spectrum of vapor of **4** with only one absorption maximum at 253 nm.

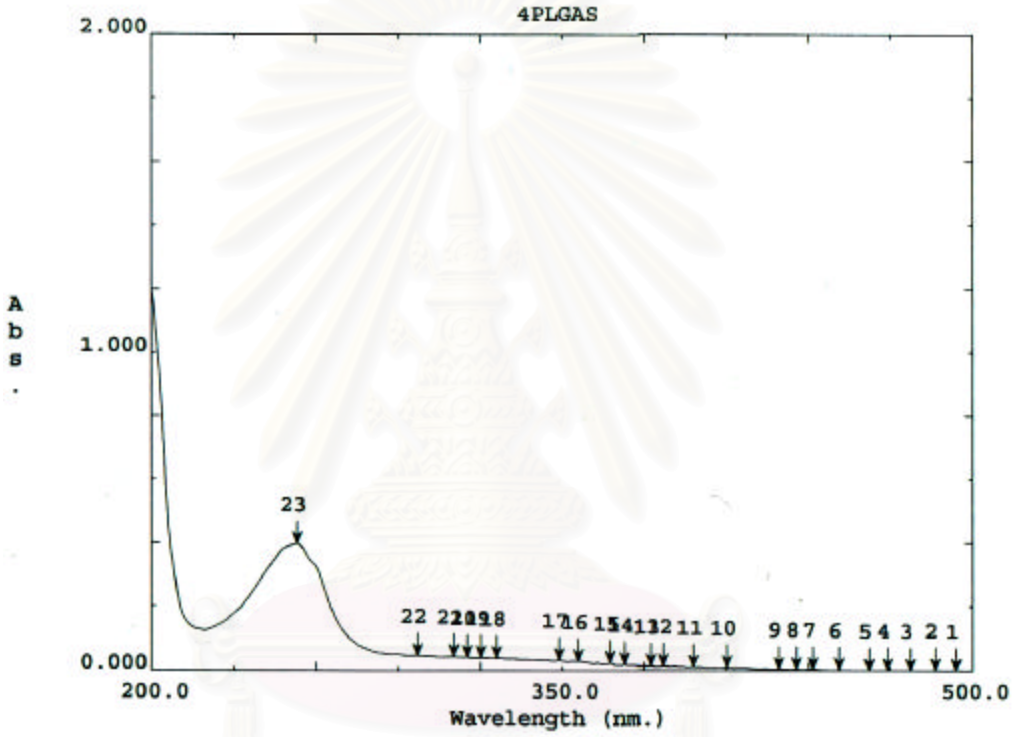
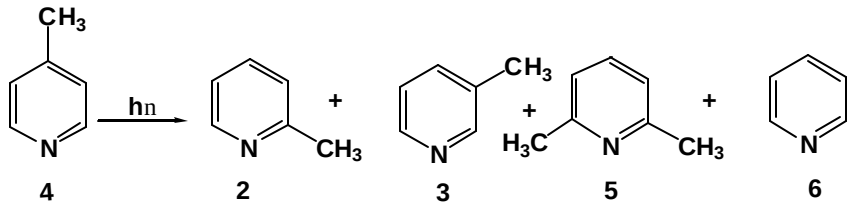


Figure 38: UV-absorption spectrum of 4-methylpyridine in vapor phase before irradiation

The vapor of **4** was irradiated for 24 hours at 254 nm. GLC analysis of the recovered mixture, shown in Figure 39a, showed the formation of **2** and **4,** the phototransposition products, 2,6-dimethylpyridine **(5),** a methylation product, and pyridine **(6)**, a demethylation product. These products are shown in Scheme 10. Quantitative gas chromatrography revealed that 24 hours of irradiation resulted in the consumption of 72% of the reactant, **4**, and the formation of **2** and **3** in yields of 5% and 6% respectively. 2,6-Dimethylpyridine **5** and pyridine **6** were formed in only trace quantities and can only be detected on GC-PE 8500 system (Figure 39b).



Scheme 10: Photoreaction products from 4-methylpyridine

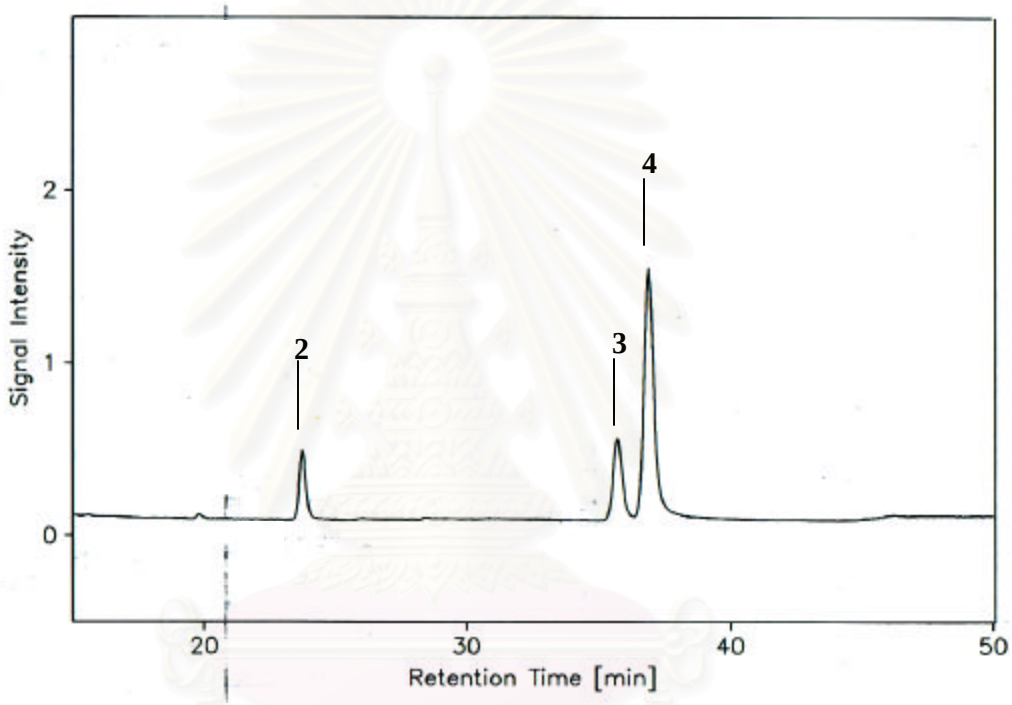


Figure 39a: GLC analysis of photolysis of **4** after 24 hours of irradiation

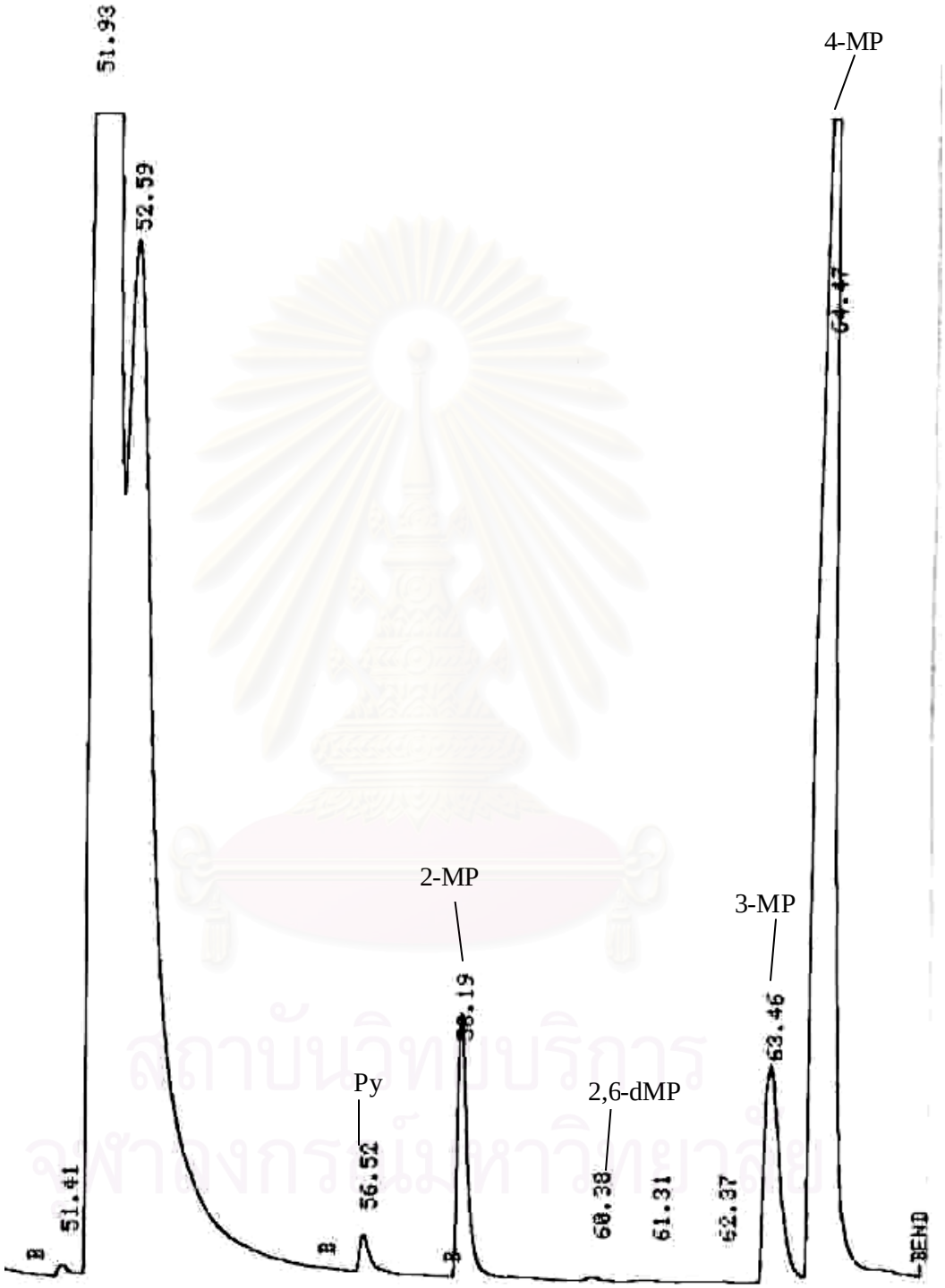


Figure 39b: GLC (PE8500) analysis of photolysis of **4** after 24 hours of irradiation

In separate experiments, the vapor of 4methylpyridine **4** was also irradiated for 48, 72 and 96 hours. In each case the product mixtures were recovered and analyzed by quantitative GLC and by ^{1}H-NMR. The quantitative data for all of these irradiations is given in Table 12. The ^{1}H-NMR spectrum after 24 hours of irradiation is shown in Figure 41 while the ^{1}H-NMR spectra after 48, 72, and 96 hours of irradiation are given in appendix of this thesis.

The data in Table 12 shows that at all irradiation times the yield of **3** is approximately equal to from of **4**. Figure 40 shows a plot of the ratio of the yields of 2:3 as a function of irradiation time. This plot shows that the ratio remains essentially constant with an average value of approximately 0.86. Extrapolation back to zero irradiation time leads to a ratio of approximately 0.82. This shows that both the photoproducts are formed at very short irradiation times. The statistical ratio of **2**:**3** would be expected to be of 1:1 for the primary photolysis of **4**. Thus, the observed ratio **2**:**3** of approximately 0.86 would suggest that the formation of **2** and **3** are not due only to the primary photolysis of **4**.

As shown in Table 12, although 72% of the reactant was consumed after 24 hours of irradiation, only 53% was consumed after 48 hours and only 58% was consumed after 96 hours. The reaction thus becomes less efficient with time. This may be due to the film formed on the wall of the reactor which partially blocks the passage of light through the walls of the reactor.

It should be noted again that the percentage yields in this reaction are difficult to determine due to the significant amounts of material loss (> 50%) during recovery. This would lead to error in determination of the consumption yield of the starting material as well as the formation yields of the photoproducts. Moreover, the brown film, formed upon photolysis, has been identified (as discussed later) to contain the same components as observed in the vapor phase photoreaction of **4**. This brown film was coated on the reactor wall and was not recovered with the vapor reaction mixture. Thus, the formation of brown film will contribute more error to the yield determinations. Although, determination of the yields in this vapor phase reaction are difficult and contain significant errors, the ratios of the product formation should be more accurate.

Table 12: Irradiation of **4** at 254 nm with 15 lamps at various irradiation times

Exp NO.	Sample (g)	Recover (g)	Irradiation (hrs)	Consumption 4-MP (%)	Formation 2-MP (%)	%Formation 3-MP (%)	2MP: 3MP
1	0.150	0.043	24	72	5	6	0.83
2	0.146	0.044	48	53	16	19	0.84
3	0.168	0.032	72	65	9	10	0.9
4	0.160	0.047	96	58	14	16	0.87

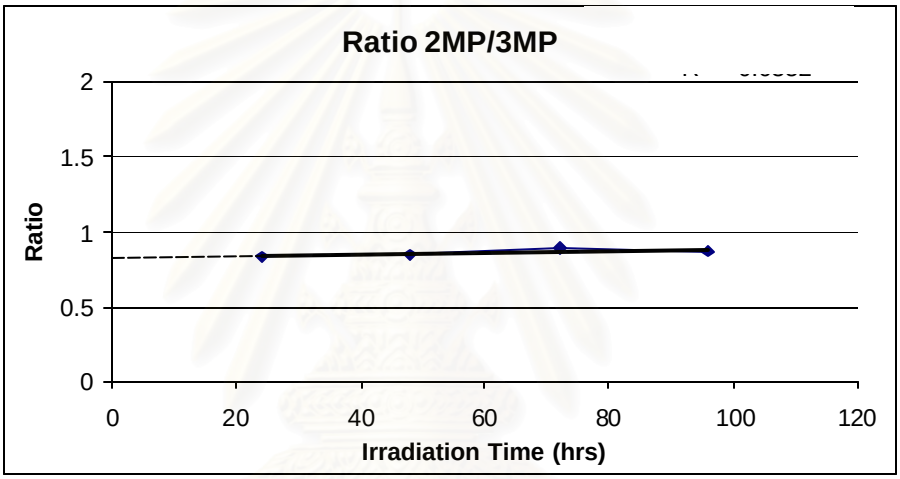


Figure 40: Ratio of **2**/**4**

After irradiation the product mixture was also analyzed by ^{1}H-NMR. Figure 41 shows the ^{1}H-NMR spectrum in $CDCl_3$ solvent a) before irradiation and b) after 24 hours of irradiation. Before irradiation the ^{1}H-NMR in Figure 41a shows the equivalent protons of **4** at δ 8.42 ($H_{2,6}$), 7.06 ($H_{3,5}$). After irradiation, the ^{1}H-NMR spectrum shown in Figure 41b shows same signals due to unconsumed reactant **4** and weak intensity signals due to the photoproducts. Thus, the spectrum shows a triplet (J = 7.8 Hz) at δ 7.54 is due to H4 of 2-methylpyridine **2** and a doublet (J = 8 Hz) at δ 7.47 due to H4 proton of **3**. The region from δ 8.35-8.5 shows small signals due to the overlapping signal of H6 of **2** and absorption of H2 and H6 of **3** due to overlapping with the H2 and H6 absorption of reactant. Finally, the overlapping signals of H3 and H5 of 2-methylpyridine and H5 of **3** appear between δ 7.0-7.17.

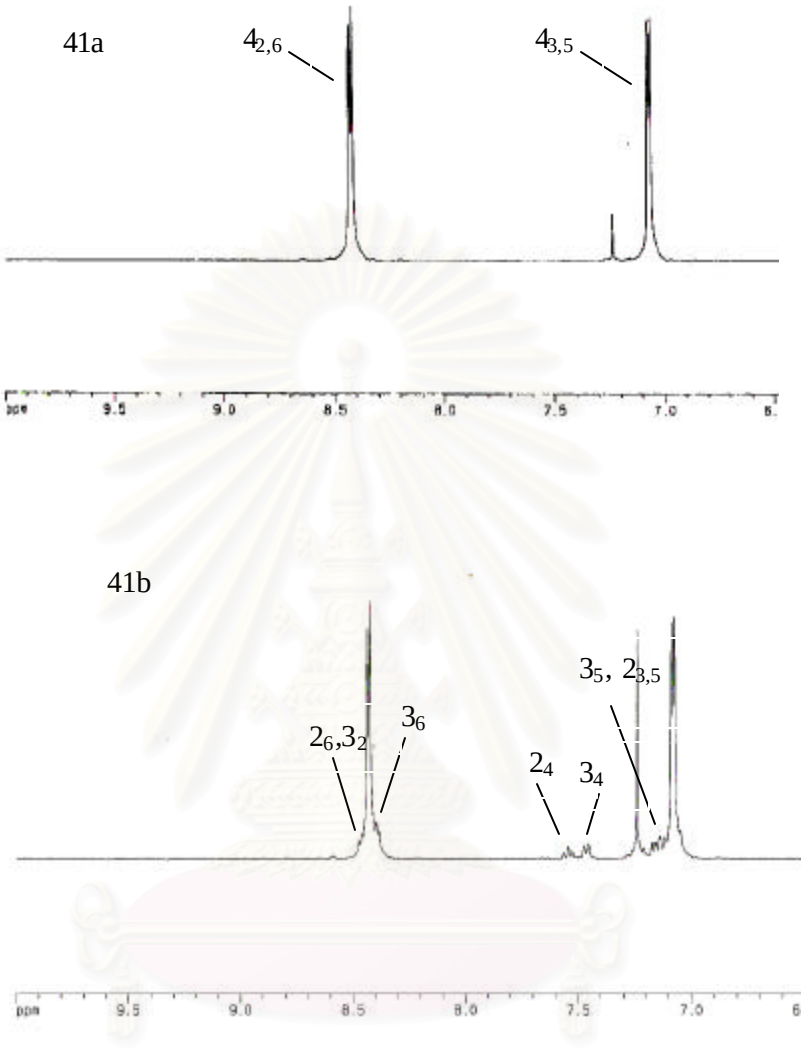


Figure 41: (a) ^{1}H-NMR of 4-methylpyridine before irradiation
(b) ^{1}H-NMR of 4-methylpyridine irradiated for 24 hours in $CDCl_3$

After irradiation, the walls of the reaction flask were coated with a brown film. This material was washed with acetone and the acetone extract was evaporated to dryness. The residue was recovered to give (0.010 g) which was dissolved in dichloromethane and analyzed by and GLC. Figure 42 shows the GC trace of the film formed during the irradiation of 4-methylpyridine **4**.

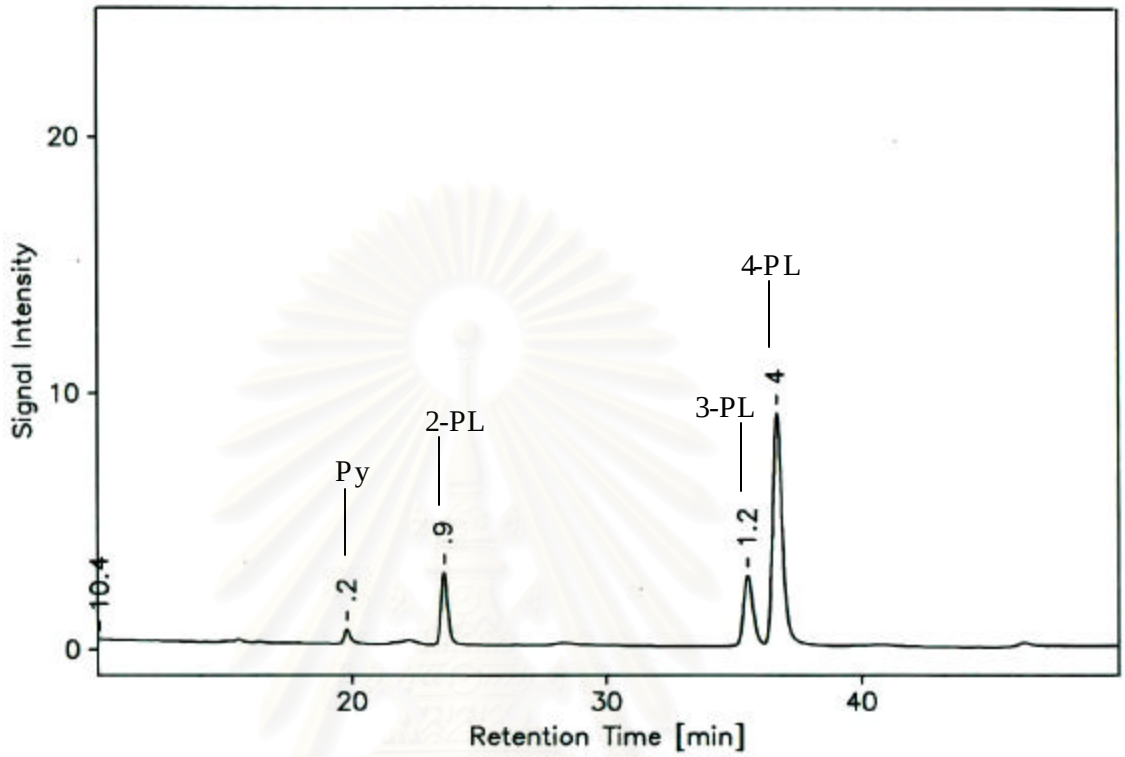
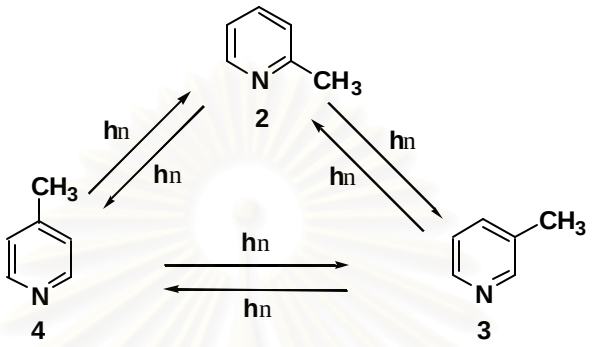


Figure 42: GC trace of brown film formed from irradiation of 4-methylpyridine for 24 hours

The GC-trace of the brown film (Figure 42) exhibits the presence of three components eluted with retention times of 24, 36 and 37 min. Comparison between Figure 42 and 39a indicates that the components, in this brown film, at retention times of 24, 36 and 37 correspond to 2-, 3- and 4-methylpyridine.

3.2.4 Mechanistic discussion

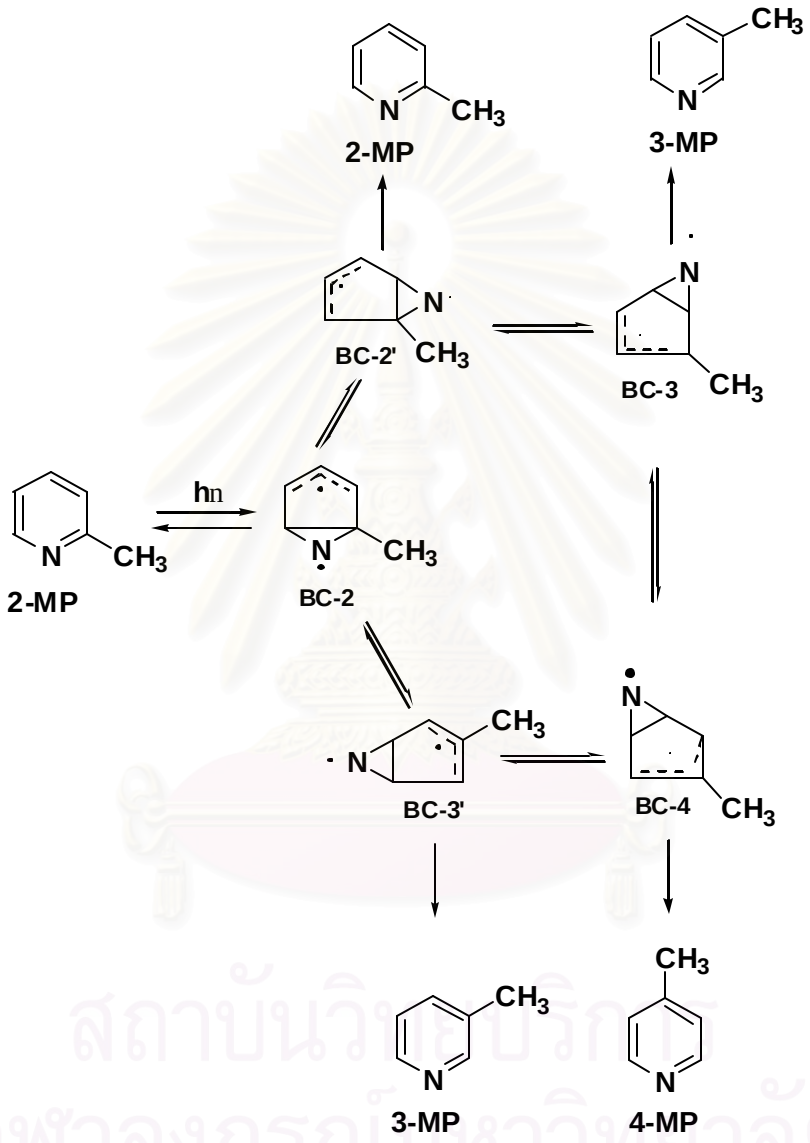
In this study, the results show that irradiation of any one of the isomeric methylpyridines in the gas phase results in the formation of the other two isomers.



These interconversions are consistent with a mechanism involving 2,6-bonding, nitrogen migration around five sides of cyclopentenyl ring and rearomatization as shown in Scheme 11.

The products formed by irradiation of 2-methylpyridine **(2-MP)** are those predicted by the electrocyclic ring closure–heteroatom migration mechanism suggested for these reactions. As shown in Scheme 11, nitrogen migration occurs around all five sides of the cyclopentenyl ring. Photochemical excitation of **2-MP** results in electrocyclic ring closure and the formation of the preazafulvene species, **BC-2**. Nitrogen migration can occur in either clockwise or counterclockwise direction. Counterclockwise migration converts **BC-2** to **BC-2'** and rearomatization of **BC-2'** results in the formation of **2-MP**. Thus, at this level of labeling the product from one N-migration and rearomatization cannot be distinguished from the reactant. The second nitrogen migration converts **BC-2'** to **BC-3** and rearomatization of **BC-3** leads to the formation of **3-MP**. The third nitrogen migration converts **BC-3** to **BC-4** and rearomatization of **BC-4** results in the formation of **4-MP.** The fourth nitrogen migration converts **BC-4** to **BC-3'** and rearomatization of BC-3 leads to **3-MP.** The formation of **3-MP** from rearomatizton of **BC-3** and **BC-3',** again, cannot be distinguished at this level of labeling. The final nitrogen migration converts **BC-3'** to

BC-2 and rearomatization of **BC-2** lead to **2-MP.** All of these nitrogen migrations can also occur in the opposite direction as shown in Scheme 11.



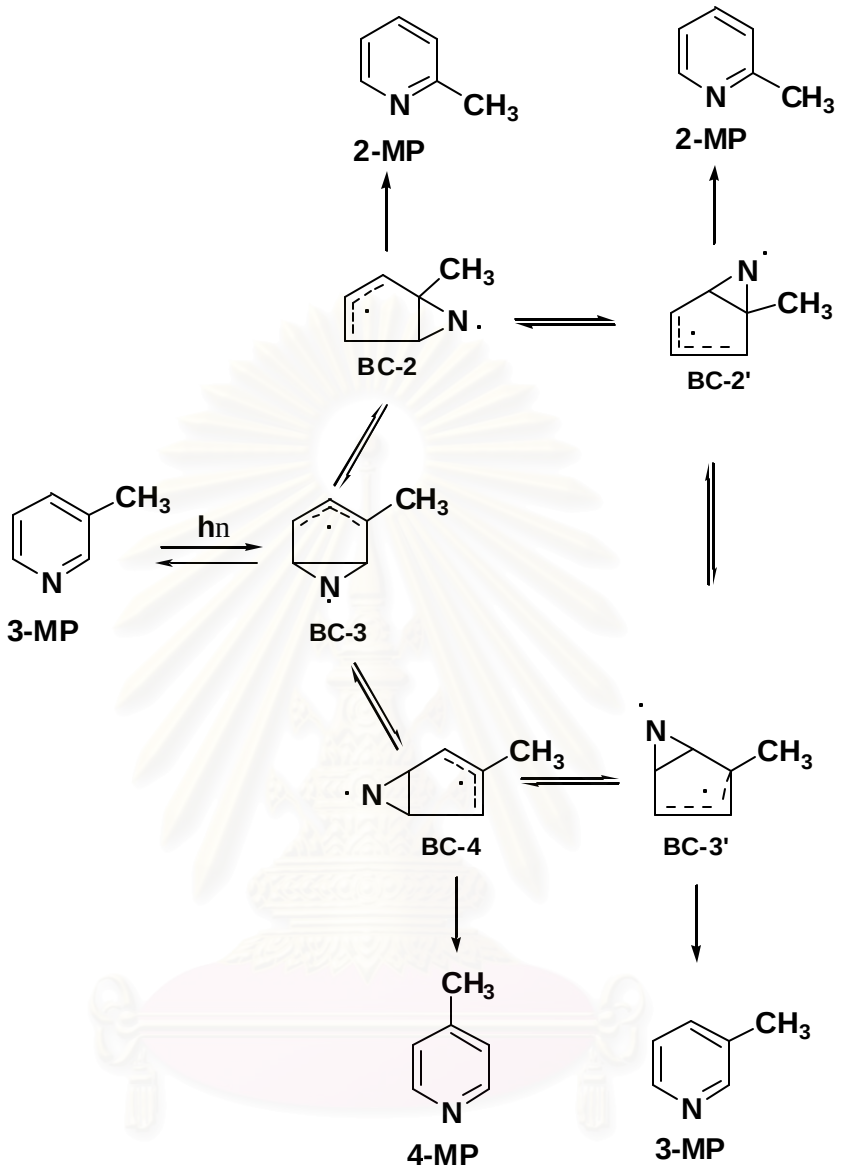
Scheme 11: Proposed mechanism for the formation of phototransposition products from **2-MP**

The mechanism in Scheme 11 suggests that photolysis of **2-MP** would result in the formation of **3-MP** and **4-MP** in the statistical ratio **3-MP**:**4-MP** of 2:1. Quantitative analysis of this vapor phase photoreaction showed that only 6% of **2-MP** had been consumed after 24 hours of irradiation and the yield of **3-MP** formed was approximately six-fold greater than **4-MP** resulting in the ratio **3-MP**:**4-MP** of 6:1. This observed **3-MP**:**4-MP** ratio is not consistent with the statistical ratio suggested in Scheme 11. Consideration of the relative stability of the preazafulvene intermediates, however, reveals that **BC-3** and **BC-3¢** are allylic radicals with a methyl substitution on the allylic carbon and would therefore be more stable than **BC-4** or **BC-2** in which the methyl is not in a position to stabilize the radicals. Thus, rearomatization of **BC-3** or **BC-3¢** leading to the formation of **3-MP** would be the more favorable pathway. The effect of methyl substitution on the relative stability of **BC-3** or **BC-3¢** would result in the formation of more **3-MP** than statistically predicted and would result in **3MP**:**4-MP** ratio greater than 2:1. This is consistent with the observed ratio of 6:1 instead of 2:1.

The observed **3-MP**:**4-MP** ratio decreased from approximately 7:1 observed at an early stage of irradiation to 4:1 after 96 hours of irradiation. This result suggests that secondary photolysis had occurred during this irradiation period. Quantitative analysis revealed that **4-MP** is the most reactive isomer upon irradiation at 254 nm. The observed **3-MP**:**4-MP** ratio of 7:1 observed at an early stage of irradiation suggests, however, that at this stage of the reaction, the amount of **3-MP** was formed in approximately seven-fold larger than **4-MP**. Since the mixture contains more **3-MP** than **4-MP**, **3-MP** would be better able to compete for photons than **4-MP**. Because of this, as the concentration of **3-MP** increases it is more likely to undergo secondary photolysis to **2-MP** and **4-MP**. The result would be to decrease the concentration of **3-MP** and to increase the concentration of **4-MP** and thus decrease the value of the **3-MP**:**4-MP** ratio.

The products formed by irradiation of 3-methylpyridine **3-MP** are those predicted by the electrocyclic ring closure–heteroatom migration mechanism suggested for these reactions. As shown in Scheme 12, nitrogen migration can occur around all five sides of the cyclopentenyl ring.

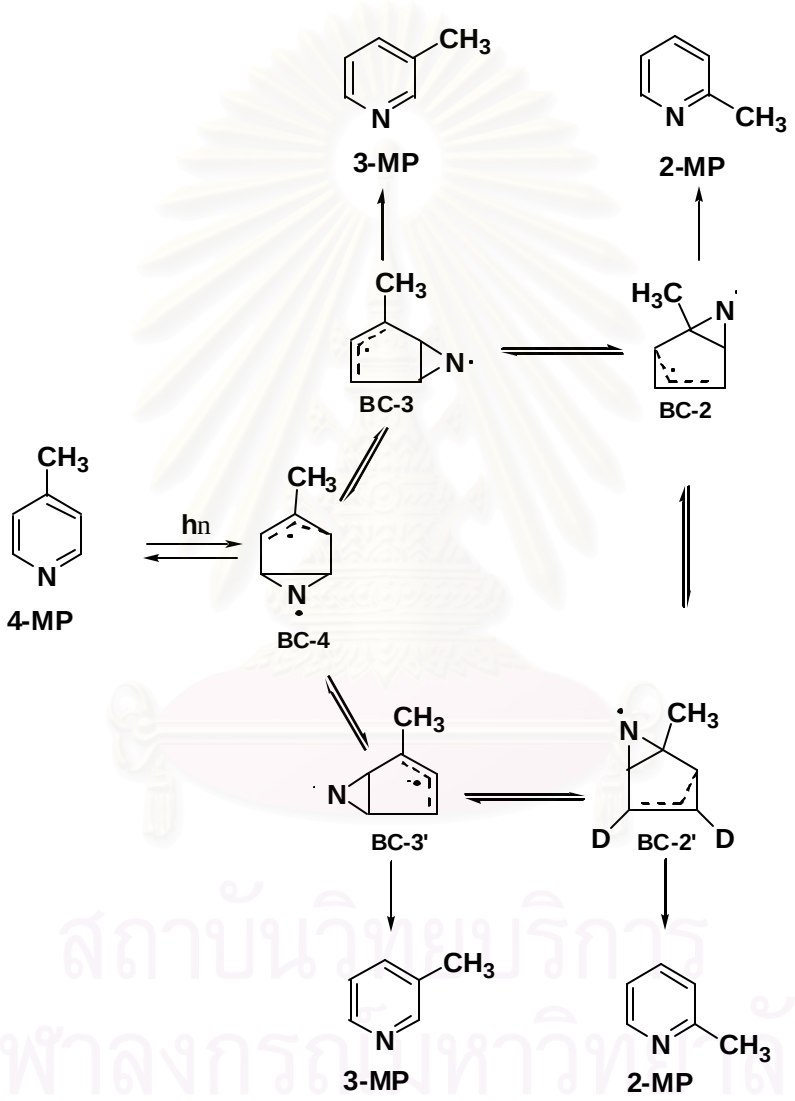
Photochemical excitation of **3-MP** results in electrocyclic ring closure and the formation of the preazafulvene species, **BC-3**. Nitrogen migration can occur in either clockwise or counterclockwise direction. Counterclockwise migration converts **BC-3** to **BC-2** and rearomatiztion of **BC-2** gives **2-MP**. The second nitrogen migration converts **BC-2** to **BC-2'** and rearomatization of **BC-2'** leads to the formation of **2-MP**. Thus, at this level of labeling the products from one and two N-migration cannot be distinguished. The third nitrogen migration converts **BC-2'** to **BC-3'** and rearomatization **BC-3'** results in the formation of **3-MP**. At this level of labeling, formation of **3-MP** cannot be distinguished from the reactant. The fourth nitrogen migration converts **BC-3'** to **BC-4** and rearomatization of **BC-4** leads to the formation of **4-MP**. The final nitrogen migration converts **BC-4** to **BC-3** and rearomatization of **BC-3** gives **3-MP**. All of these nitrogen migrations can also occur in the opposite direction as shown in Scheme 12. The mechanism in Scheme 12 suggests that photolysis of **3-MP** would result in the formation of **2-MP** and **4-MP** in the statistical ratio of 2:1. Quantitative analysis of this vapor phase photoreaction showed that 31% of **3-MP** had been consumed after 24 hours of irradiation and the formation of **2-MP** was approximately three-fold greater than **4-MP** resulting in the **2-MP**:**4-MP** ratio of approximately 3:1. This observed **2-MP**:**4-MP** ratio is not consistent with the statistical ratio suggested in Scheme 12. This indicates that the formation of **2-MP** would not only arise from the primary photolysis of **3-MP**. Quantitative analysis revealed that **4-MP** is the most reactive isomer and **2-MP** is the least reactive isomer upon irradiation at 254 nm. At the very early stage of reaction, the yield of **2-MP** would be formed in approximately twice the yield of **4-MP**, but the much more reactive **4-MP** would undergo secondary photolysis to yield **2-MP** and **3-MP**. This would lead to an increase in the observed amount of **2-MP** and a decrease in the observed amount of **4-MP** which would increase the observed **2-MP**:**4-MP** ratio to 3:1 instead of 2:1. The **2-MP**:**4-MP** ratio remained constant during the entire period of irradiation. This indicates that the primary and secondary photolyses were in equilibrium.



Scheme 12: Proposed mechanism for the formation of phototransposition products from **3-MP**

The products formed by irradiation of 4-methylpyridine **4-MP** are those predicted by the electrocyclic ring closure – heteroatom migration mechanism suggested for these reactions. Scheme 13 shows that nitrogen migration can occur around all five sides of the cyclopentenyl ring. Photochemical excitation of **4-MP** results in electrocyclic ring closure and the formation of the preazafulvene species, **BC-4.** Nitrogen migration can occur in either clockwise or counterclockwise direction. Counterclockwise migration converts **BC-4** to **BC-3** and rearomatiztion of **BC-3** leads to the formation of **3-MP**. The second nitrogen migration converts **BC-3** to **BC-2** and rearomatiztion of **BC-2** results in the formation of **2-MP**. The third nitrogen migration converts **BC-2** to **BC-2'** and rearomatiztion of **BC-2'** results in the formation of **2-MP**. The fourth nitrogen migration converts **BC-2'** to **BC-3**, and rearomatiztion of **BC-3** leads to the formation of **3-MP**. The final nitrogen migration converts **BC-3** to **BC-4** and rearomatization of **BC-4** gives **4-MP**. This mechanistic scheme reveals that at this level of labeling it is impossible to distinguish between the formation of **2-MP** from two and three N-migrations or the formation of **3-MP** from one or four N-migrations. All of these nitrogen migrations can also occur in the opposite direction as shown in Scheme 13. This mechanism in Scheme 13, suggests that photolysis of **4-MP** would result in the formation of **2-MP** and **3-MP** in the statistical ratio of 1:1. Quantitative analysis of this vapor phase photoreaction showed that 72 % of **4-MP** had been consumed after 24 hours of irradiation and the observed **2-MP**:**3-MP** ratio was approximately 0.8:1. This ratio indicated that more **3-MP** was formed than was statistically expected. As shown in Scheme 13, the first nitrogen migration from **BC-4** in either clockwise or counterclockwise direction leads to the formation of **BC-3** or **BC-3¢** which were previously argued to be more stable than **BC-2** or **BC-2¢**. Therefore, the rearomatization of **BC-3** or **BC-3¢** to **3-MP** would be more favorable than the conversion of **BC-3** to **BC-2** leading to a larger amount of **3-MP** than **2-MP** and thus resulting in the observed **2-MP**:**3-MP** ratio of 0.8:1. Upon prolong irradiation secondary photolysis of **3-MP** would occur which would lead to a decrease in the observed amount of **3-MP**, an increase in the observed amount of **2-MP,** and finally the **2-MP**:**3-MP** ratio would become 1:1 or more than 1:1. Since **4-MP** is the most reactive isomer, primary photolysis of **4-MP** would be expected to be more efficient than the secondary photolysis of **3-MP**. Thus, at

prolong irradiation period, the primary and secondary photolyses would be in equilibrium leading to the observed constant **2-MP**:**3-MP** ratio of 0.8:1 as the function of irradiation time.



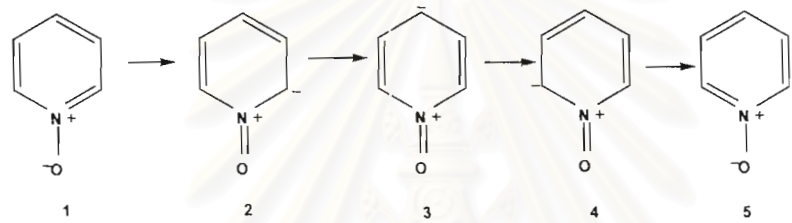
Scheme 13: Proposed mechanism for the formation of phototransposition products from **4-MP**

3.3 Photochemistry of 4,6-dideuterio-2-trideuteriomethylpyridine

3.3.1 Synthesis of 4,6-dideuterio-2-trideuteriomethylpyridine

3.3.1.1 Synthesis of 6-deuterio-2-trideuteriomethylpyridine *N*-oxide

Pyridine *N*-oxide has been reported to undergo base catalyzed hydrogen deuterium exchange selectively at the 2-and 6-ring positions. This reaction is believed to occur by way of a transient pyridinium ylide intermediate.



1 2 3 4 5

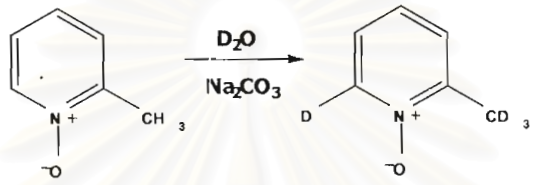
The methylpyridine N-oxides are also known to undergo exchange of the ring protons at positions 2 and 6. The methyl protons of 2- and 4-methylpyridines *N*-oxide are also activated toward exchange. For 2-methylpyridine *N*-oxide, ∝-proton exchange accompanied exchange of the methyl protons of 2- and 4-methylpyridine *N*-oxides. For 2-methylpyridine *N*-oxide, ∝-proton exchange accompanied methyl proton exchange when the *N*-oxide was treated with sodium carbonate or sodium deuterioxide. The relative amount of ring and side chain exchange varied with the reaction time and base. For example, 66% of the ∝-proton of the hetero ring was exchanged after 5 hours of this reaction with sodium carbonate and deuterium oxide.

These results show that hydrogen-exchange at C-6 of 2-methylpyridine will be accompanied by hydrogen deuterium exchange in the methyl group as well. Since exchange in the methyl group will not hinder this study, this procedure was followed.

Lalinsky(6) reported the general procedure for the exchange reaction. This involved treating the *N*-oxide (5 g) and base in deuterium oxide (15 mL) at reflux for an appropriate time. The resulting mixture is then extracted with chloroform. Removal of the chloroform gives the deuterated *N*-oxide in 87% yield. According to

this synthetic method described by Lalinsky(6), 2-methylpyridine *N*-oxide was treated with sodium carbonate in refluxing deuterium oxide in for 12 hours.

The yellow liquid product was identified by GC-MS, ^{1}H- and ^{13}C-NMR spectroscopy. The GC trace of the sample, given in Figure 43a, shows only one of compound which eluted with a retention time of 8 minutes. The mass spectrum (Figure 43b) exhibits a molecular ion at m/z 113 corresponding to the molecular weight of 6-deuterio-2-trideuteriomethylpyridine *N*-oxide.



Scheme 14: Synthesis of 6-deuterio2-methylpyridine

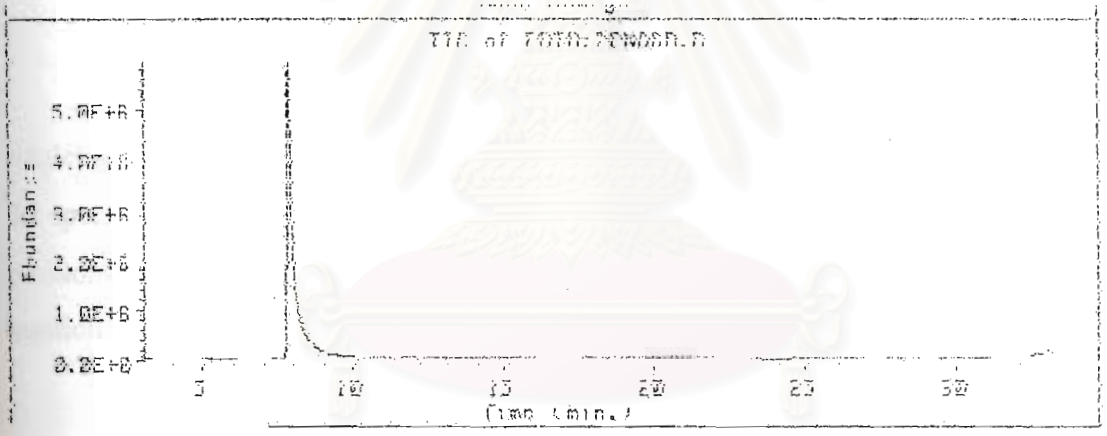


Figure 43a: GC trace of the synthesized 6-deuterio-2-trideuterio methylpyridine *N*-oxide

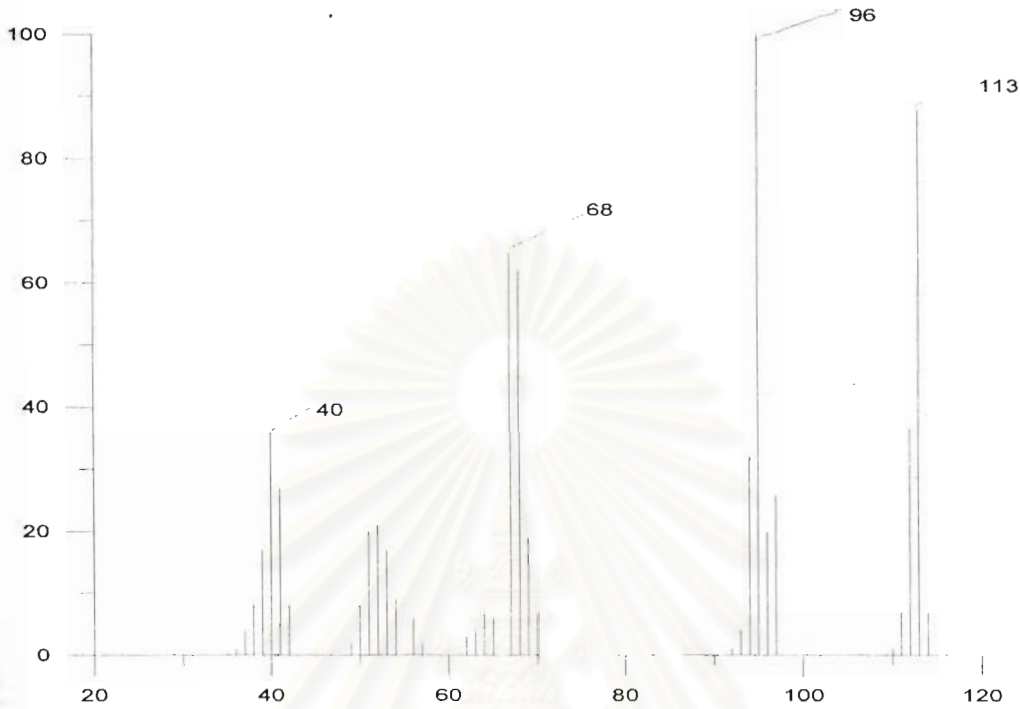


Figure 43b: Mass spectrum of the peak at 8 minutes

The ^{1}H-NMR spectrum of this compound shown in Figure 44, exhibits a small singlet at δ 2.6 due to residual proton of the trideuteriomethyl group. The region of the spectrum between δ 7.0-7.2 consists of a multiplet which is due to the proton at positions 3, 4 and 5. The very small doublet at δ 8.2 is due to residual proton at position 6.

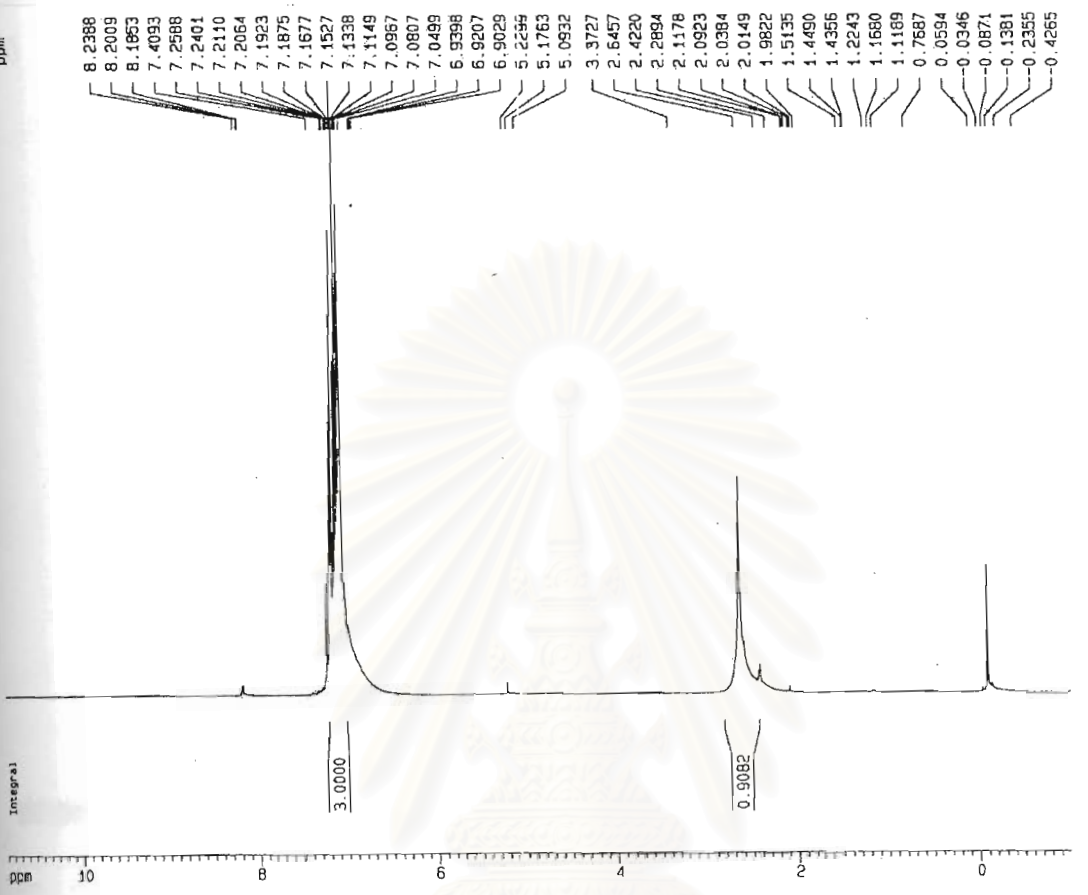


Figure 44: The ^{1}H-NMR spectrum of 6-deuterio-2-trideuteriomethylpyridine *N*-oxide

The ^{13}C-NMR spectrum, shown in Figure 45, exhibits a multiplet signal due to the trideuteriomethyl carbon at δ 17.5 which is coupling with deuterium atoms. The four singlets at δ 123.9, 126.3, 126.9 and 149.4 were assigned to the carbon at positions 5, 3, 4 and 2 respectively. The carbon at δ 139.5 appears as a triplet (J = 28.4 Hz) and is due to carbon at position 6 which is coupling with the attached deuterium atom.

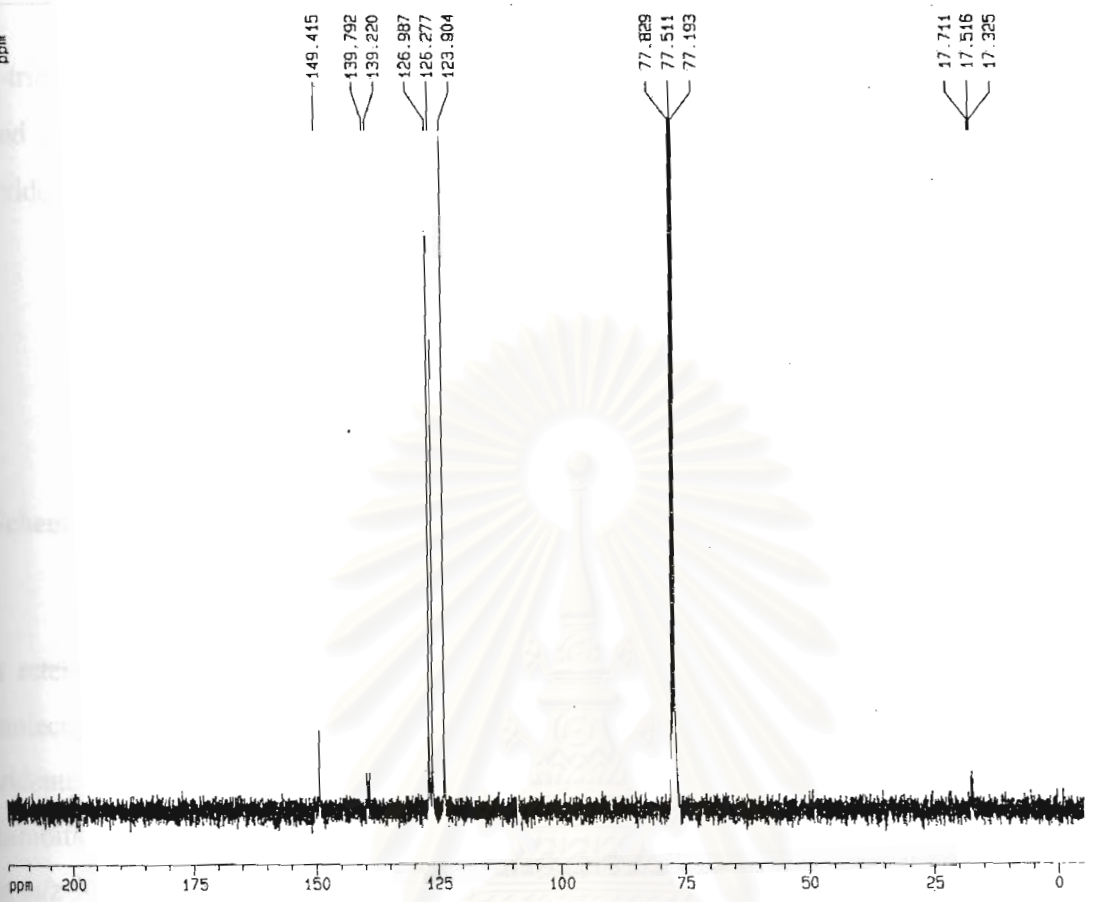
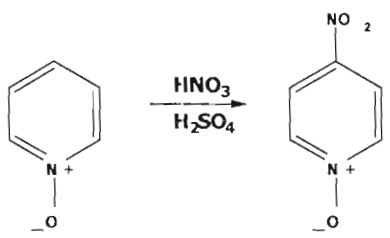


Figure 45: The ^{13}C-NMR spectrum of 6-deuterio-2-trideuteriomethylpyridine N-oxide

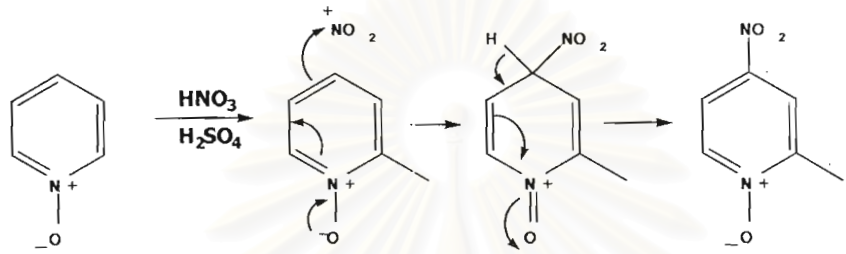
3.3.1.2 Synthesis of 6-deuterio-4-nitro-2-trideuteriomethylpyridine *N*-oxide

Nitration of pyridine *N*-oxide by reaction with sulphuric acid and fuming nitric acid at 90°C to give 4-nitropyridine *N*-oxide as a yellow liquid (mp 153 -154°C) in high yield (85-90%) as shown in scheme 15. A very small amount of 2-nitropyridine *N*-oxide is also formed.



Scheme 15: Nitration of pyridine *N*-oxide.

Therefore, according to the method described by Ochai(7), 2-trideuteriomethylpyridine *N*-oxide-6d was heated with concentrated sulphuric acid and concentrated nitric acid at 100°C to give 4-nitro-2-dideuteriomethylpyridine *N*-oxide-6d in 48% yield.



Scheme 16: Mechanism for the formation 6-deuterio-4-nitro-2-methylpyridine *N*-oxide

GC analysis (Figure 46a) of this product shows only one peak, which eluted at a retention time of 17.5 minutes. The mass spectrum (Figure 46b) exhibits a molecular ion at m/z 158 consistent with the molecular weight of 4-nitro-2-trideuteriomethylpyridine *N*-oxide-6d (MW 158). Moreover, the mass spectrum exhibits an intense peak at m/z 142 due to the elimination of oxygen and a base peak at m/z 96 is due to the elimination of the nitro group.

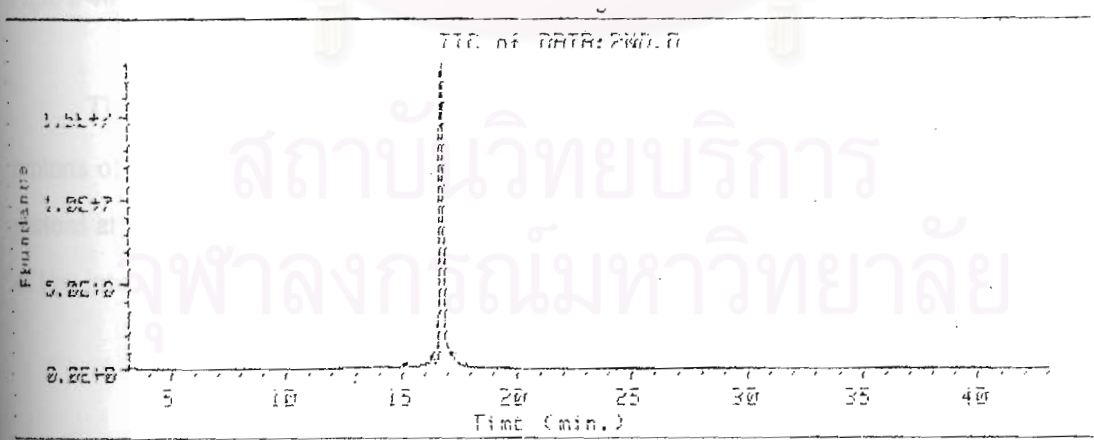


Figure 46a: GC trace of the synthesized 6-deuterio-4-nitro-2-trideuteriomethylpyridine *N*-oxide.

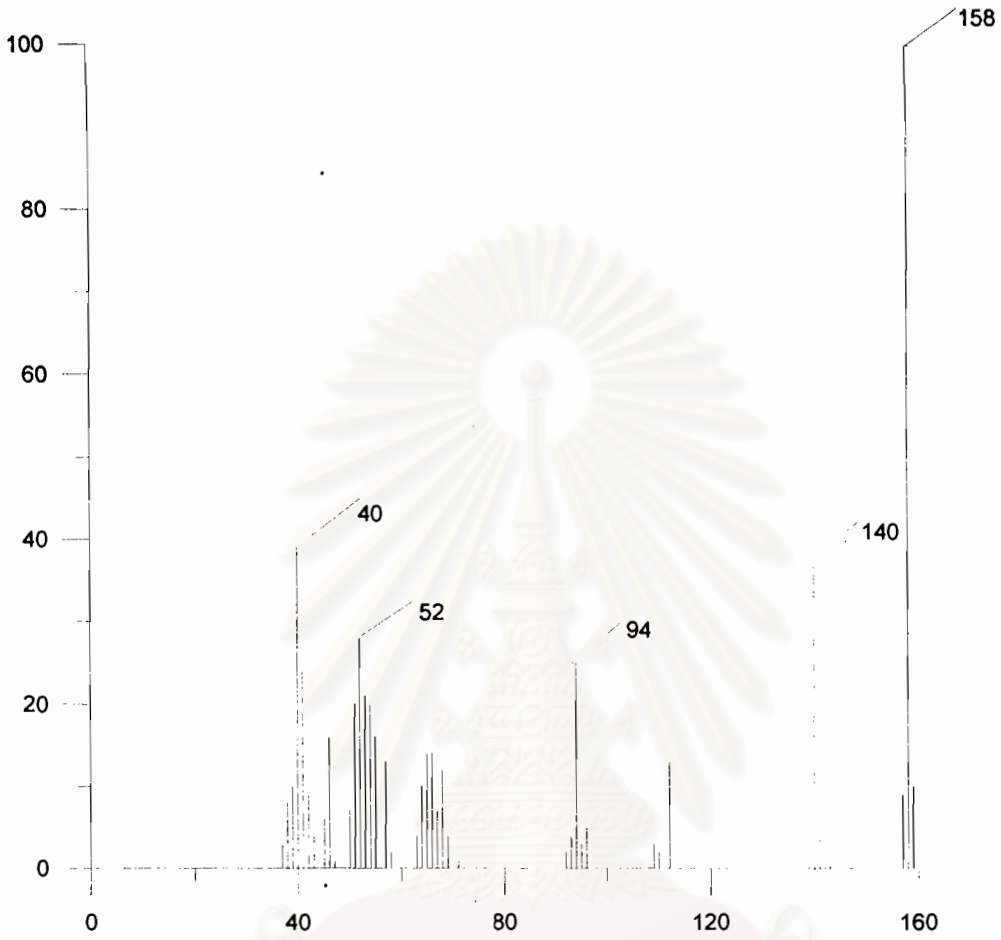


Figure 46b: Mass spectrum of 6-deuterio-4-nitro-2-trideuteriomethylpyridine *N*-oxide

The ^{1}H-NMR spectrum (Figure 47) shows a singlet at δ 2.5 due to the residual protons of the trideuteriomethyl group. The singlets at δ 7.9 and 8.1 are due to the protons at C-5 and C-3 respectively. In addition, the spectrum also exhibits a doublet of low intensity at δ 8.2 which is due to the residual proton at position 6.

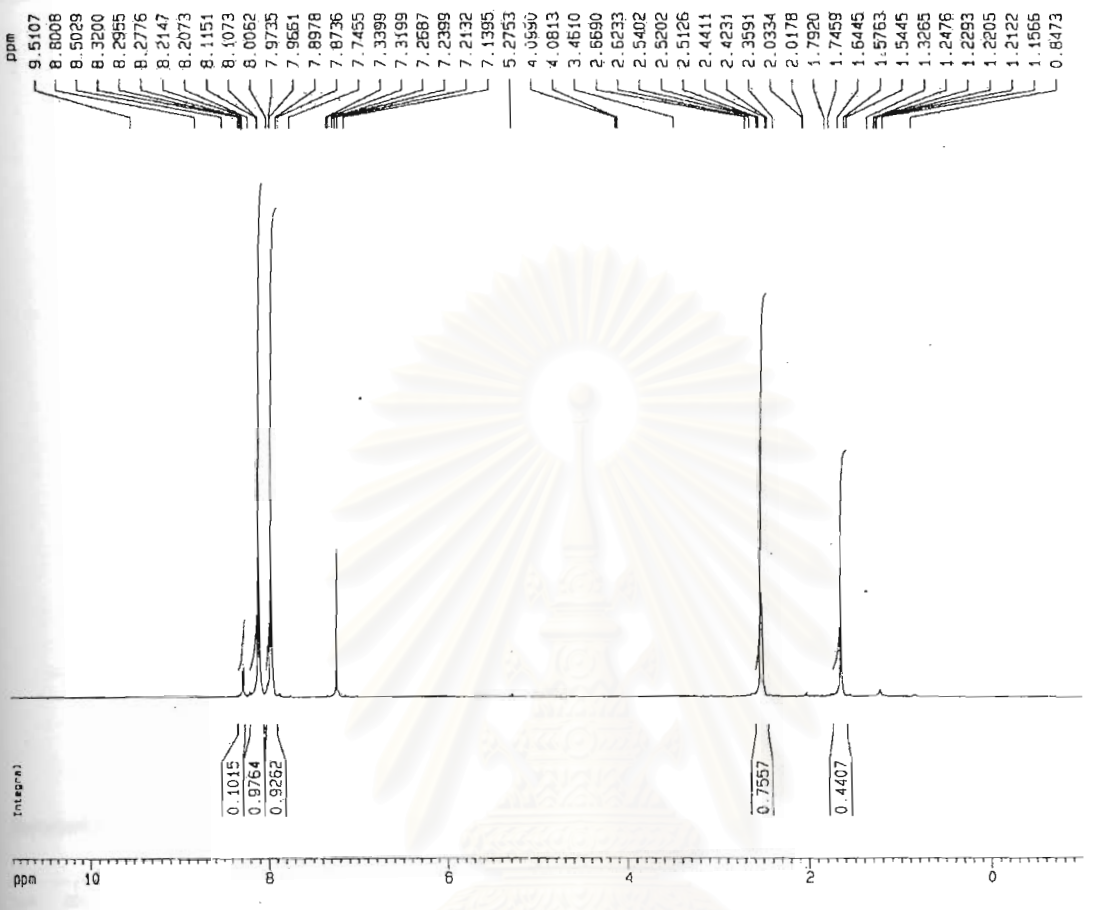


Figure 47: The ^{1}H-NMR spectrum of 6-deuterio-4-nitro-2-methylpyridine *N*-oxide

The ^{13}C-NMR spectrum, shown in Figure 48, exhibits a signal due to the trideuteriomethyl carbon at δ 17.1 which is coupling with deuterium atoms. The four singlets at δ 117.5, 120.2, 141.2 and 150.0 were assigned to the carbons at positions 5, 3, 4 and 2 respectively. In addition, the carbon at δ 139.3 appears as a triplet (J = 29.9 Hz) which is due to carbon at position 6 which is coupling with the attached deuterium atom.

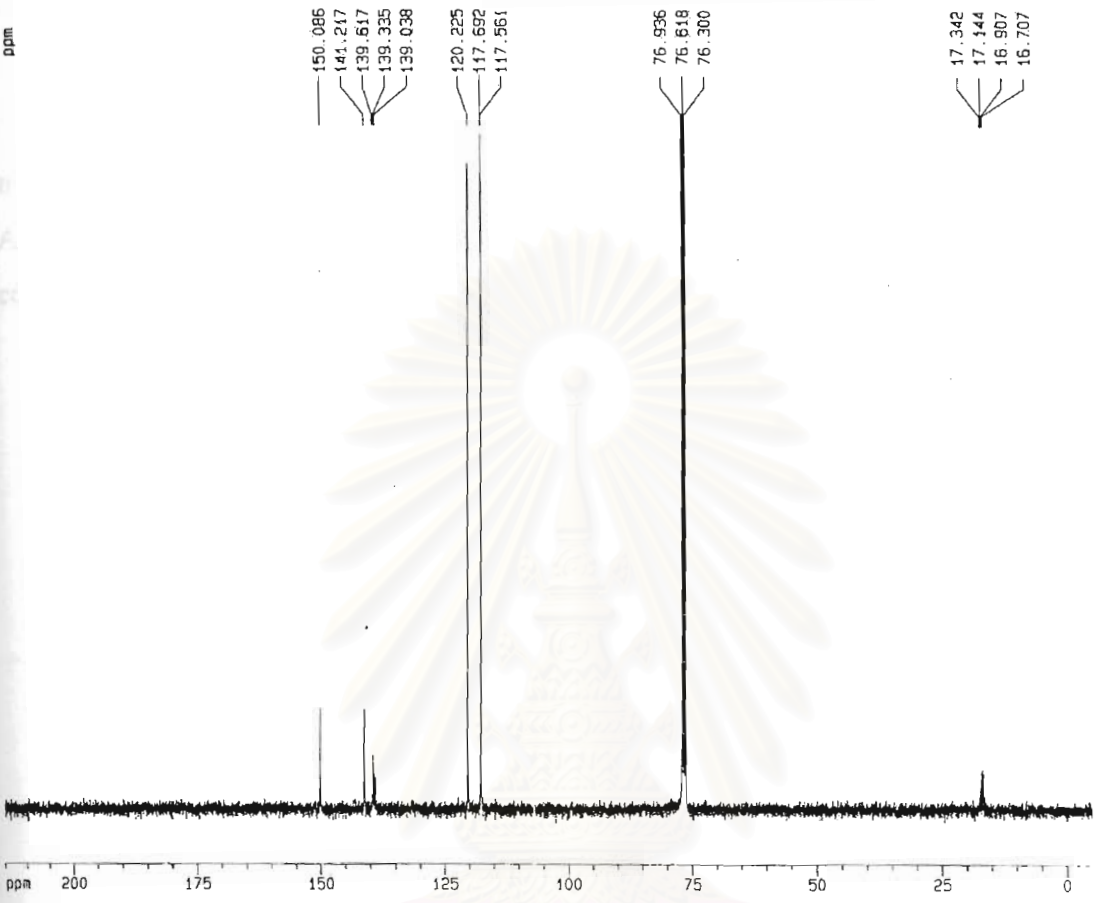
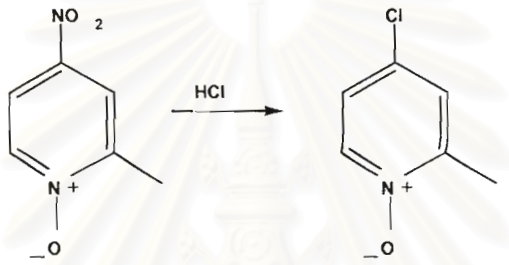


Figure 48: The ^{13}C-NMR spectrum of 6-deuterio-4-nitro-2-trideuteriomethylpyridine *N*-oxide.

3.3.1.3 Synthesis of 4-chloro-6-deuterio-2-trideuteriomethylpyridine *N*-oxide

Barnes and colleagues(8) described the conversion of 4-nitro-2-methylpyridine to 4-chloro-2-methylpyridine using concentrated hydrochloric acid. According to their procedure, 4-nitro-2-methylpyridine *N*-oxide-6d was treated with concentrated hydrochloric acid.



Scheme 17: The synthesis of 4-chloro-2-trideuteriomethylpyridine *N*-oxide-6d

The product from this reaction was analyzed by GC. As shown in Figure 49a the GC trace shows a single peak with a retention time of 10.5 minutes. The mass spectrum of this peak (Figure 49b) exhibited a molecular ion at m/z 147 which corresponds to the molecular weight of the desired product, 4-chloro-2-trideuteriomethylpyridine *N*-oxide-6d.

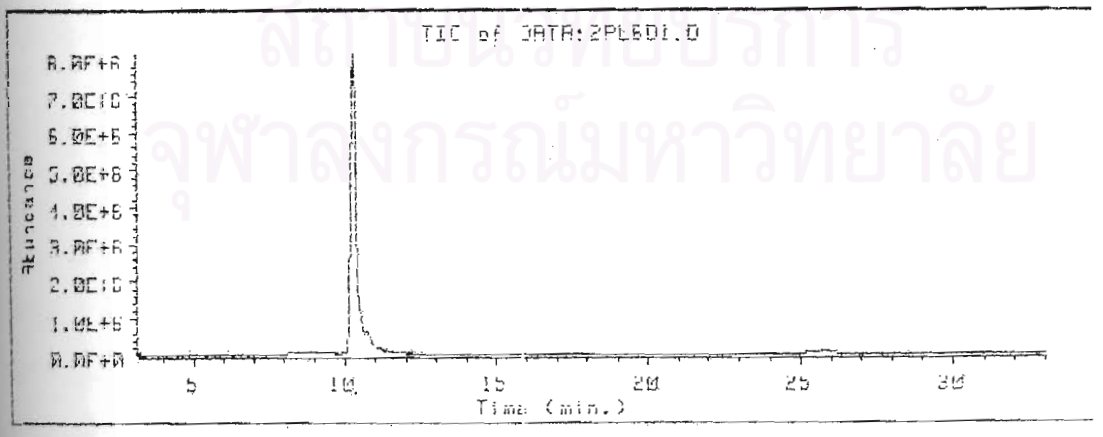


Figure 49a: GC trace of 4-chloro-2-trideuteriomethylpyridine *N*-oxide-6d

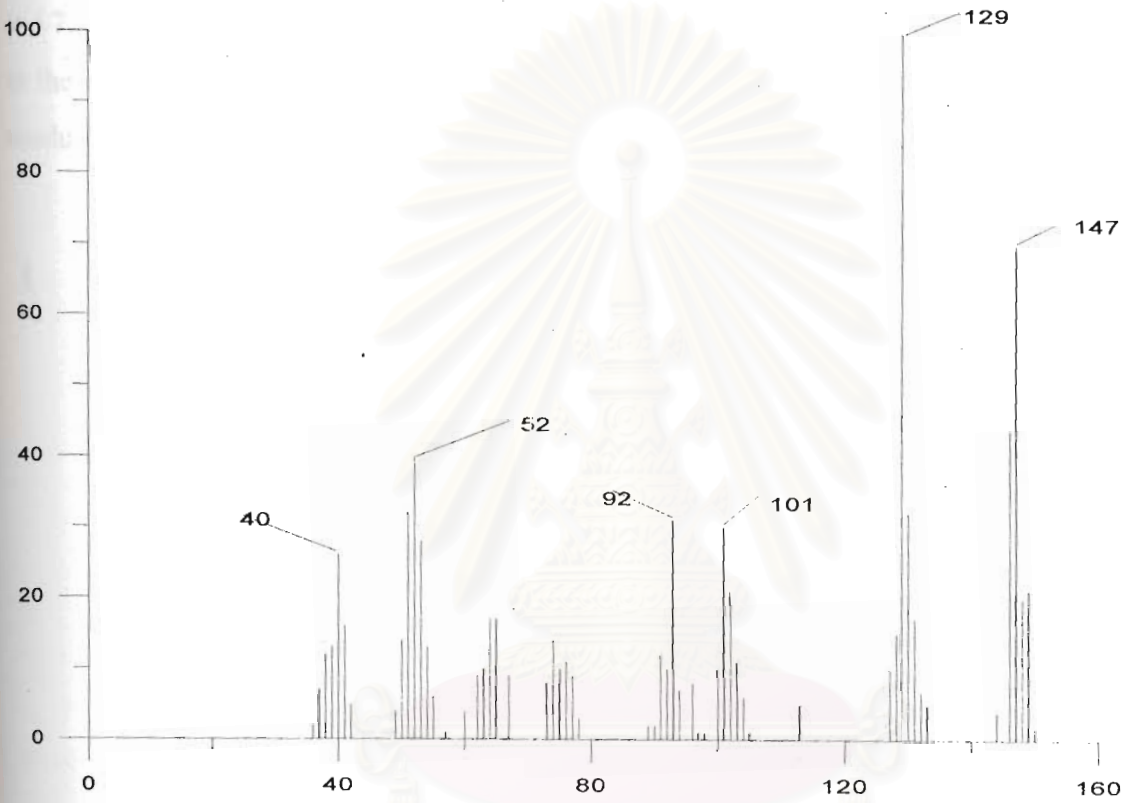


Figure 49b: Mass spectrum of 4-chloro-2-trideuteriomethylpyridine *N*-oxide-6d

The ^{1}H-NMR spectrum of this product (Figure 50) shows two singlets at δ 7.0 and 7.2 which are due to protons at positions 3 and 5, a very small doublet at 8.1 due to the residual proton at position 6, and a singlet of low intensity at δ 2.3 due to residual protons in the trideuteriomethyl group.

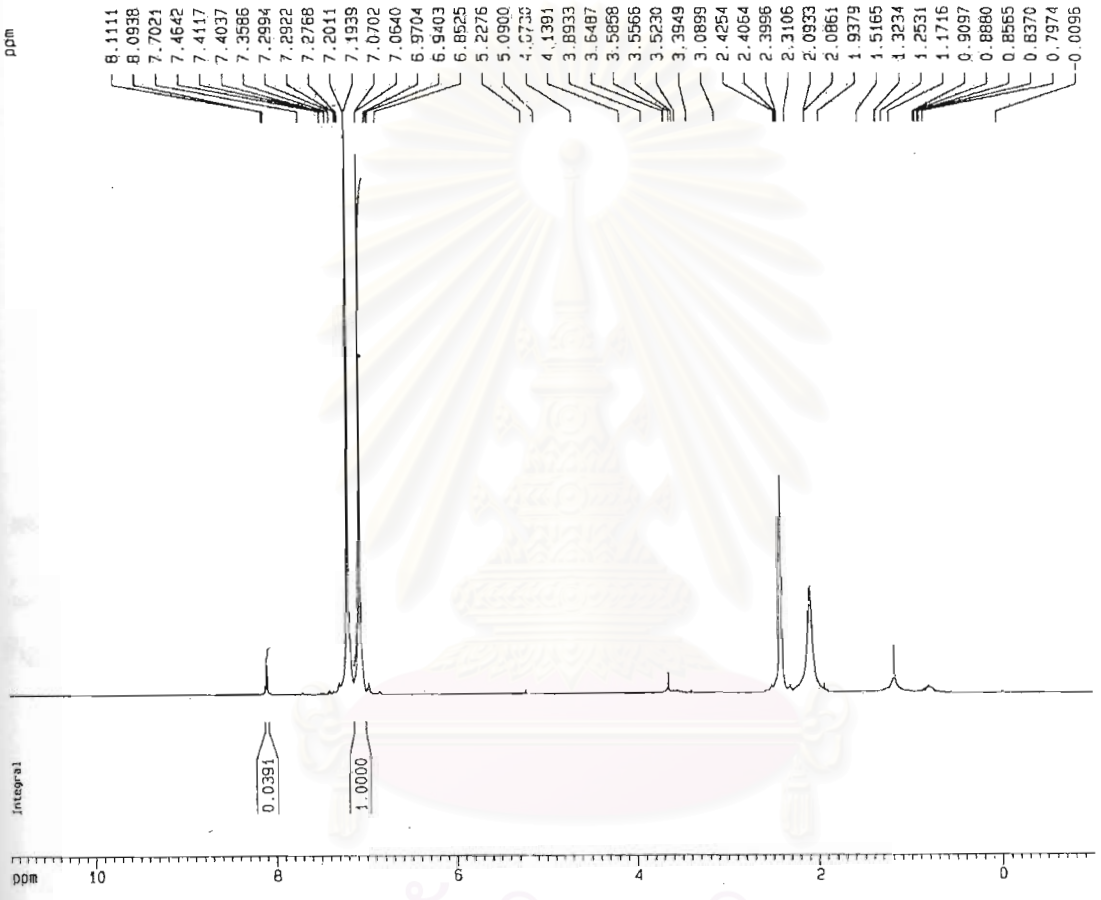


Figure 50: The ^{1}H-NMR spectrum of 4-chloro-2-trideuteriomethylpyridine *N*-oxide-6d

The ^{13}C-NMR spectrum (Figure 51) reveals the carbon of the trideuteriomethyl group at δ 17.5 as a multiplet due to coupling with the derterium atoms. The two ring carbons at positions 3 and 5 on methylpyridine ring absorb at δ 126.8 and 124.2 The signal at δ 131.7 is due to the carbon at position 4. The signal downfield at 150.4 is due to the carbon at position 2. The signal at 140.1 still appears as a triplet (J = 29.1 Hz) due to the C6 carbon coupling with the deuterium atom.

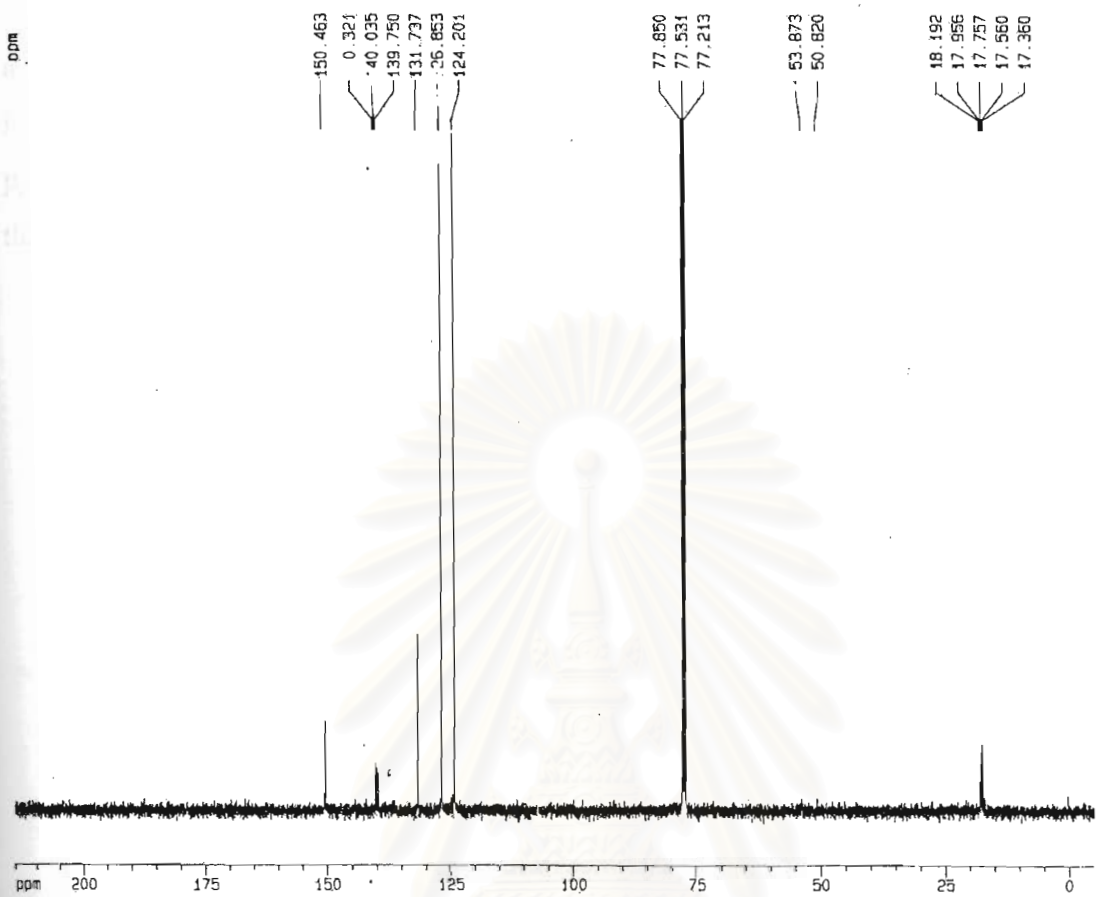
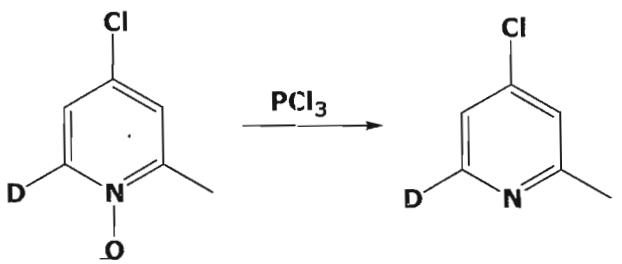


Figure 51: The ^{13}C-NMR spectrum of 4-chloro-2-trideuteriomethylpyridine N-oxide-6d

3.3.1.4 Synthesis of 4-chloro-6-dideuterio-2-trideuteriomethylpyridine

Pyridine N-oxide can be reduced to pyridine by reaction with phosphorous trichloride. Using this procedure described by Ochiai(7), 6-deuterio-4-chloro-2-trideuteriomethylpyridine *N*-oxide was treated with phosphorous trichloride in refluxing dichloromethane to give 4-chloro-6-dideuterio-2-trideuteriomethylpyridine as a yellow liquid.



Scheme 18: Synthesis of 4-chloro-6-dideuterio-2-trideuteriomethylpyridine

GC analysis of this product (Figure 52a) showed only one peak which eluted at a retention of 5.5 minutes. The mass spectrum (Figure52b) exhibits a molecular ion at m/z 131 consistent with the molecular weight of 4-chloro-2-trideuteriomethyl pyridine-6d. The mass spectrum also exhibits a base peak at m/z 96 which indicates that 4-chloro-2-trideuteriomethylpyridine undergoes elimination of a chlorine atom.

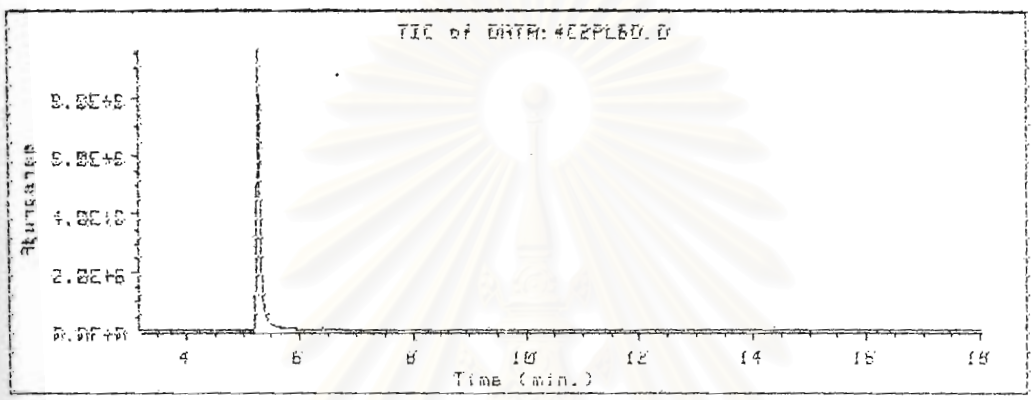


Figure 52a: GC trace of 4-chloro-2-trideuteriomethylpyridine-6d

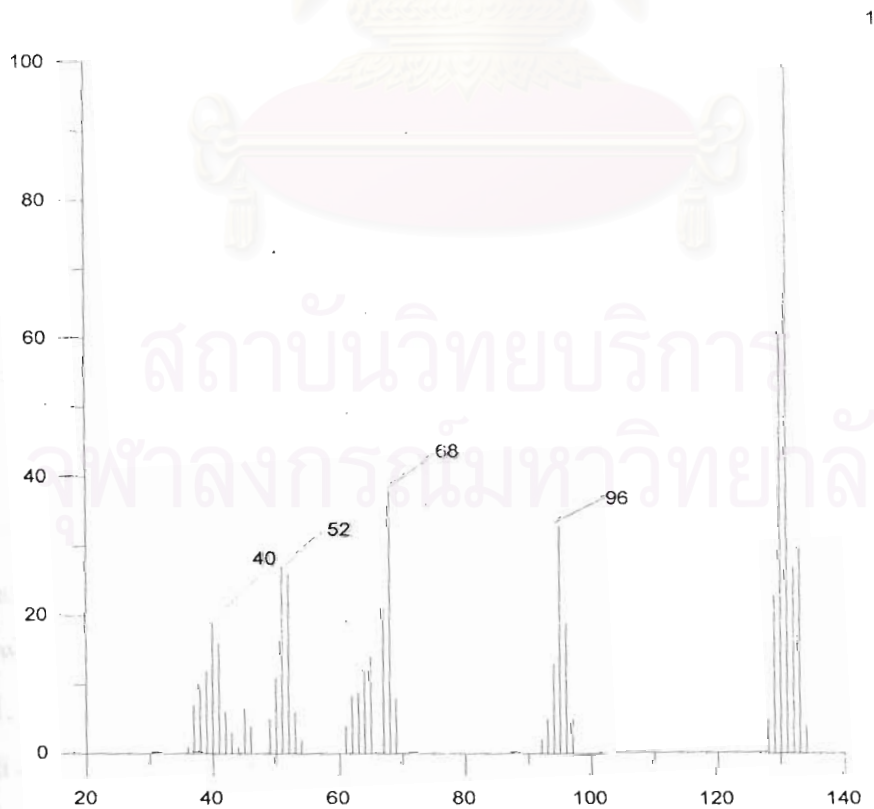


Figure 52b: The mass spectrum of 4-chloro-2-trideuteriomethylpyridine-6d

The ^{1}H-NMR spectrum of this liquid (Figure 53) shows a singlet at δ 2.5 due to the residual protons of the trideuteriomethyl group. The singlets at δ 7.1 and 7.2 are due to the protons at positions 5 and 3. In addition, the spectrum also exhibits a doublet of low intensity at δ 8.2 which is due to residual proton at position 6.

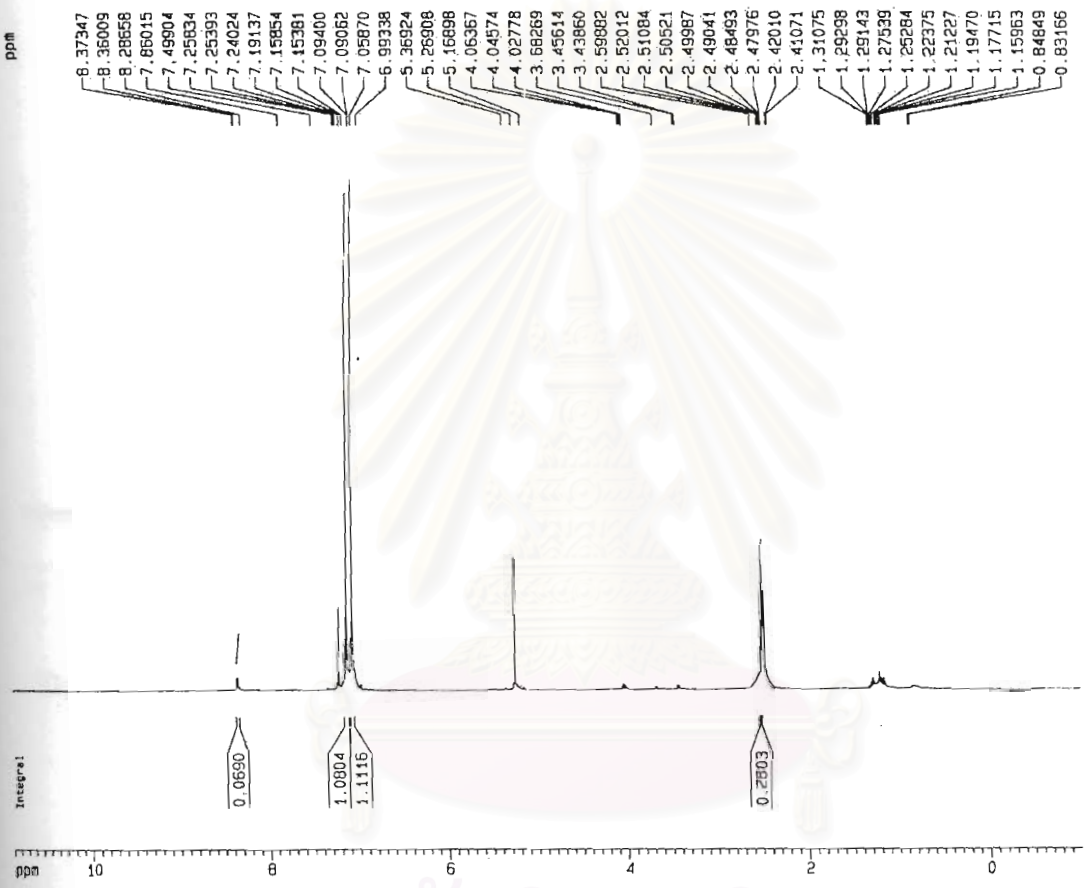


Figure 53: The ^{1}H-NMR spectrum of 4-chloro-6-deuterio-2-trideuteriomethylpyridine

The ^{13}C-NMR spectrum of this liquid (figure 54) also show signals consistent with the structure of 4-chloro-6-deuterio-2-trideuteriomethylpyridine. The signal at δ 23.9 was assigned to the carbon of the trideuteriomethyl group. The three signals at δ 121.1, δ 123.5 and δ 144.1 were assigned to the carbons at ring positions 5, 3 and 4 respectively. The spectrum also shows a triplet (J = 27.1Hz) at δ 149.7 due to the C6 carbon coupling with the attached deuterium atom.

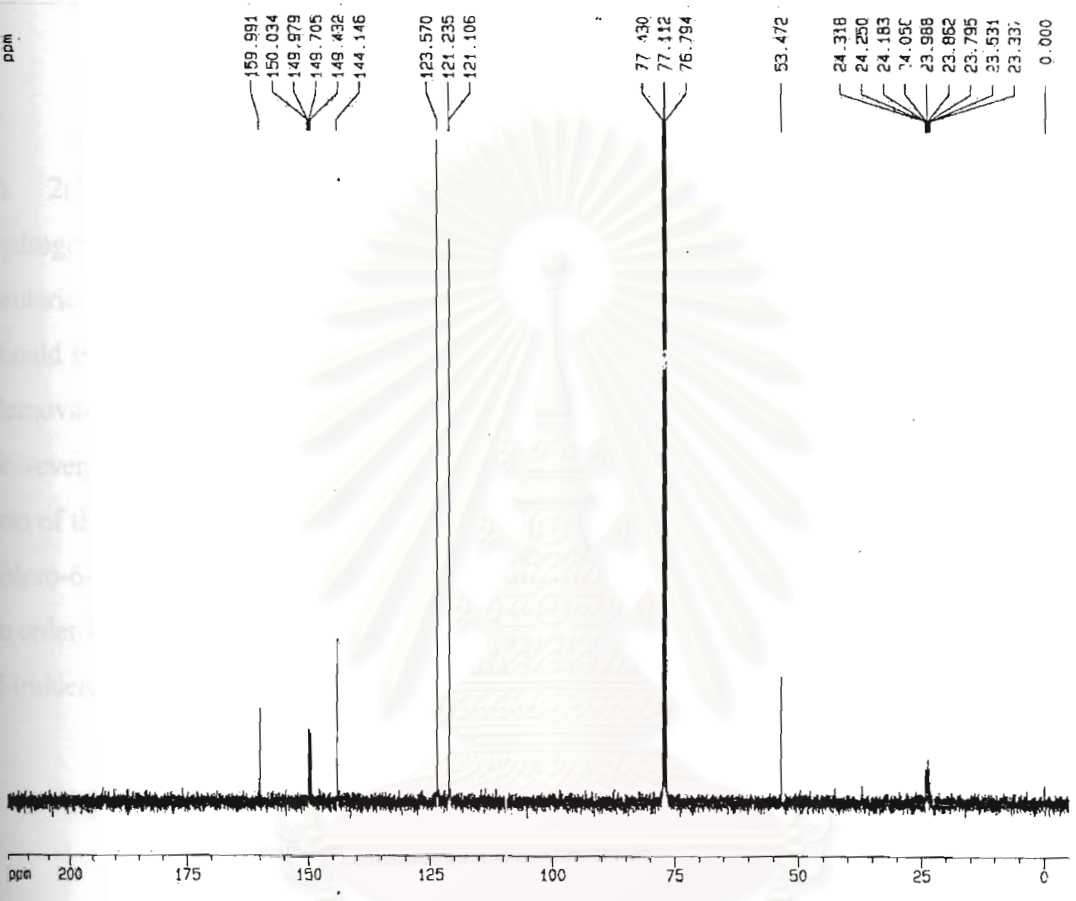
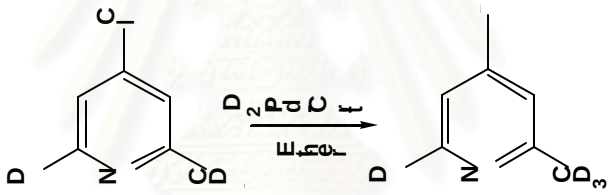


Figure 54: The ^{13}C-NMR spectrum of 4-chloro-2-trideuteriomethylpyridine-6d

3.3.1.5 Synthesis of 4,6-dideuterio-2-trideuteriomethylpyridine

Azzam(9) reported that dehalohydrogenolysis of 5-chloro-2(1*H*)-pyrazinones to 2(1*H*)-pyrazinones can be achieved in good yields by using 10% Pd-C and hydrogen gas in methanol solvent. Thus, dehalohydrogenolysis of 4-chloro-6-deuterio-2-trideuteriomethylpyridine to 4,6-dideuterio-2-trideuteriomethylpyridine should be possible under these conditions employing D_2 gas instead of hydrogen gas. Removal of methanol solvent from the deuterated methylpyridine final product would, however, be difficult since the methylpyridine is very volatile. This would result in loss of the desired deuterated methylpyridine. Therefore, dehalohydrogenolysis of 4-chloro-6-deuterio-2-trideuteriomethylpyridine was carried out in diethyl ether solvent in order to minimize this problem. Scheme 19 shows the synthesis of 4,6-dideuterio-2-tridueteriomethylpyridine.



Scheme 19: The synthesis of 4,6-dideuterio-2-trideuteriomethylpyridine

GC analysis of the product from this reaction (Figure 55a) shows the presence of only one peak which eluted at a retention of 8.8 minutes. The mass spectrum of this material (Figure 55b) exhibited a molecular ion at m/z 98 consistent with the molecular weight of 4,6-dideuterio-2-trideuteriomethylpyridine. The signals with substantial intensities at m/z 97 and 96 are most likely due to the presence of 2-dideuteriomethylpyridine and 2-monodeuteriomethylpyridine in the sample due to incomplete H/D exchange in the C2 methyl group. This will not interfere with photochemical studies.

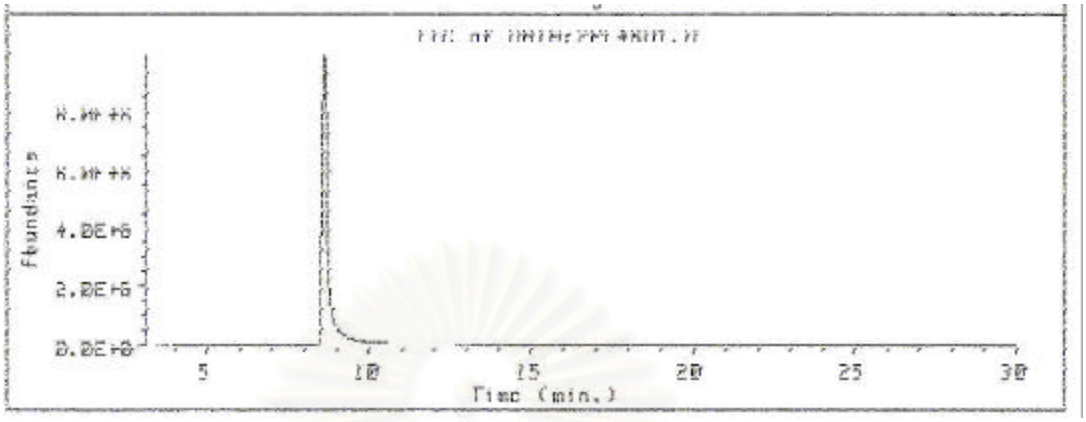


Figure 55a: GC trace of 4,6-dideuterio-2-trideuteriomethylpyridine before irradiation

The mass spectrum also exhibits an intense peak at m/z 70 due to the loss of DCN and a peak at m/z 71 would result from eliminate of HCN from the molecular ion.

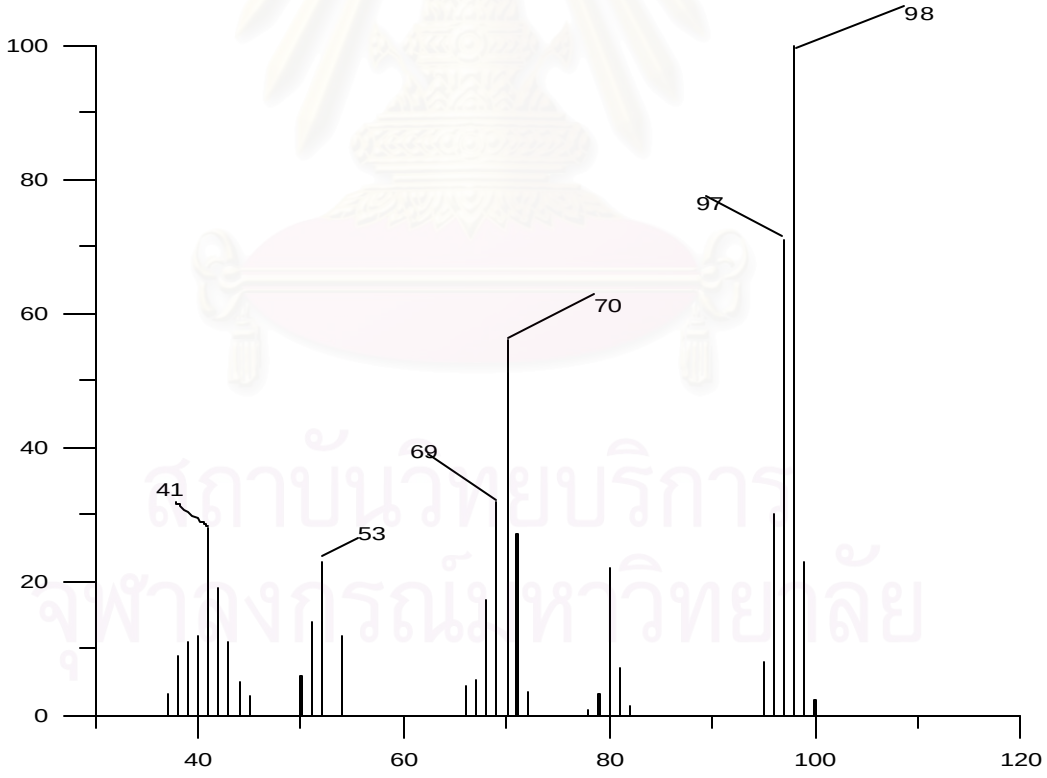


Figure 55 b: The mass spectrum of 4,6-dideuterio-2-trideuteriomethylpyridine

The ^{1}H-NMR spectrum (Figure 56) shows a singlet at δ 2.5 due to the residual protons of the trideuteriomethyl group. The singlets at δ 7.06 and 7.13 are due to protons at ring positions 5 and 3 respectively. In addition, the spectrum also exhibits two doublets of low intensity at δ 7.55 and 8.4, which are due to residual protons at ring positions 4 and 6.

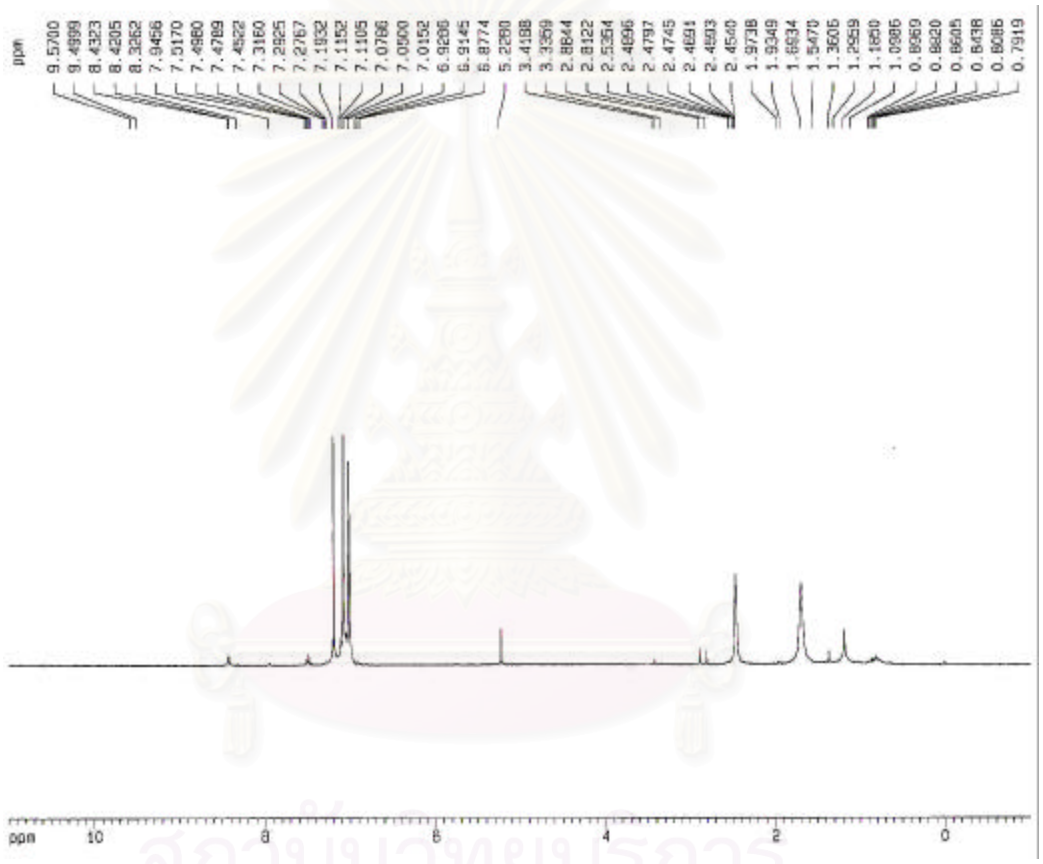


Figure 56: The ^{1}H-NMR of 4,6-dideuterio-2-trideuteriomethylpyridine

The ^{13}C-NMR spectrum (acetone-d_6;Figure 57) exhibits a signal for a quaternary carbon at 159.4 and was therefore assigned to the C2 carbon of the pyridine ring. The spectrum also exhibits triplets at δ149.9 (J = 27.6 Hz) and at δ 136.9 (J = 28.3 Hz) which can be assigned to C2 and C4 of the pyridine ring. Since these signals appear as triplets, this confirms that these carbon atoms are bonded to deuterium. The signals at δ 124.0 and 121.6 can be assigned to C3 and C5 respectively. Finally, the carbon of the trideuteriomethyl group appears at δ 24.1 as a multiplet due to coupling with deuterium atoms.

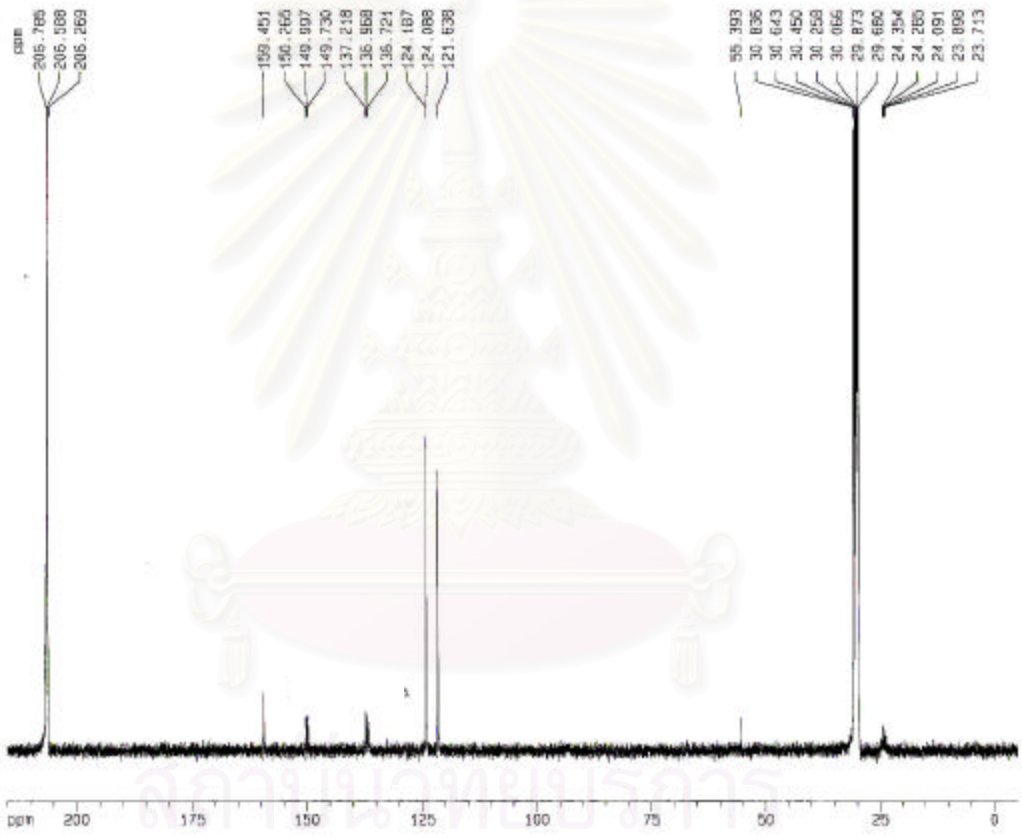
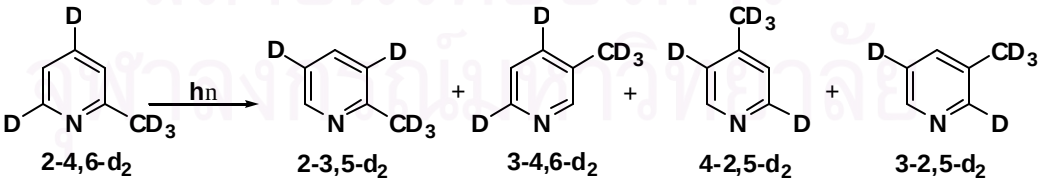


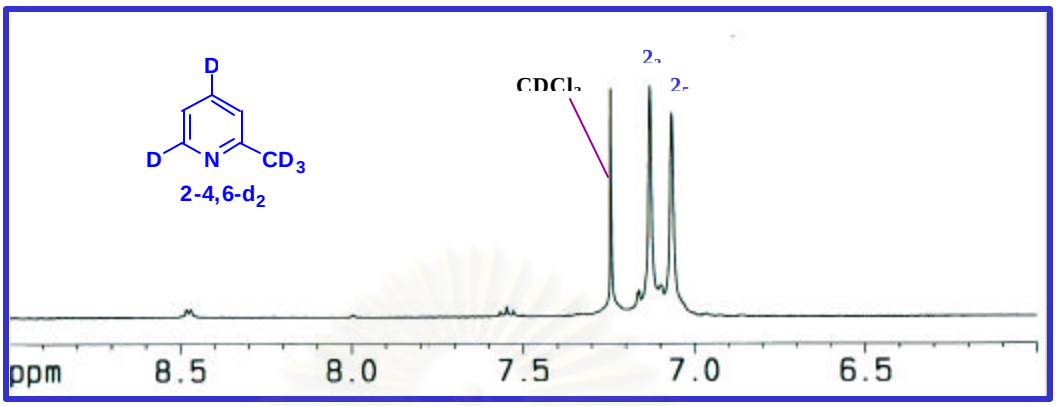
Figure 57: The ^{13}C-NMR spectrum of 4,6-dideuterio-2-trideuteriomethylpyridine

3.3.2 Vapor phase photochemistry of 4,6-dideuterio-2-trideuteriomethylpyridine

In the initial photochemical experiment, a sample of 4,6-dideuterio-2-trideuteriomethylpyridine was allowed to vaporize into the 3L quartz flask at 25°C to a final pressure of 3.0 Torr. This was then irradiated in the Rayonet reactor at 254 nm using 15 low pressure mercury arc lamps for 24 hours. Figure 58 shows a portion of the ^{1}H-NMR spectrum from 6-10 ppm in $CDCl_3$ of the reactant a) before irradiation and b) after irradiation of the sample at 254 nm for 24 hours. After irradiation, the ^{1}H-NMR spectrum shows signals at δ 7.13 and δ 7.06 due to the H3 and H5 protons of unreacted 4,6-dideuterio-2-trideuteriomethylpyridine and eight new singlets due to the formation of photoproducts. Since each trideuteriomethylpyridine photoproduct will bear two deuterium atoms and two protons bonded to ring positions, the formation of eight singlets means that four different trideuteriomethylpyridine isomers have been formed in this photoreaction. These new singlets can be assigned by comparison with the known chemical shift for the ring protons in 2-, 3-, and 4-methylpyridine as discussed in section **2** of this thesis. Thus, as shown on figure 58b, the two singlets at δ 7.52 and 8.44 can be assigned to H4 and H6 of 2-trideuteriomethylpyridine-3,5-d_2; the two singlets at δ 8.40 and 7.15 can be assigned to H2 and H5 of 3-trideuteriomethylpyridine-4,6-d_2; the two singlets at δ 7.45 and 8.36 can be assigned to H4 and H6 of 3-trideuteriomethylpyridine-2,5-d_2; and the two singlets at δ 7.05 and 8.41 can be assigned to H3 and H6 of 4-trideuteriomethylpyridine. The overall phototransposition reaction is thus shown in the equation below.



58a)



58b)

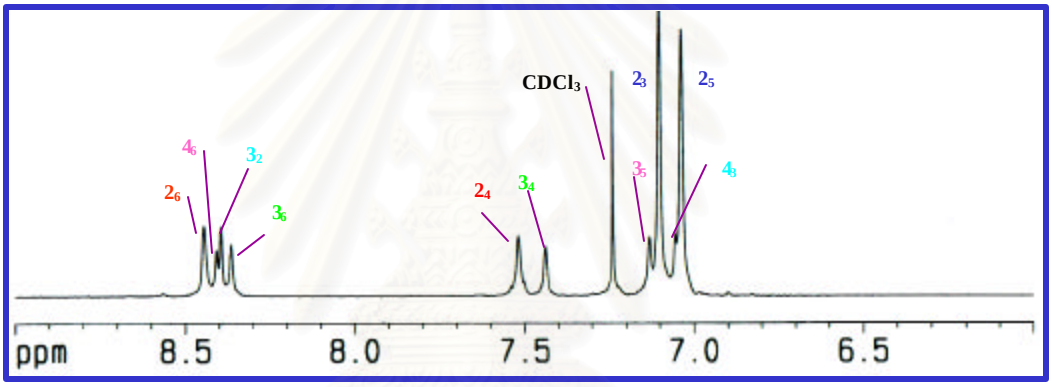


Figure58 : a) 4,6-Dideuterio-2-trideuteriomethylpyridine before irradiation
b) After irradiation of 4,6-dideuterio-2-trideuteriomethylpyridine at 254 nm for 24 hours

The product mixture was also analyzed by GC- mass spectroscopy. Figure 59a shows the GC trace obtained from this instrument which exhibits a peak at 8.9 minutes which would be due to the unreacted 2-trideuteriomethylpyridine-4,6-d_2 and 2-trideuteriomethylpyridine-3,5-d_2 formed in the reaction and a smaller peak at 12 minutes due to the mixture of 3-trideuteriomethylpyridine-2,5-d_2, 3-trideuteriomethylpyridine-4,6-d_2 and 4-trideuteriomethylpyridine-2,5-d_2 since on this column (15m×3μm carbowax 20M), 3-and 4-methylpyridines cannot be separated. Figure 59b shows the mass spectrum of the mixture that eluted at 8.9 minutes.

Comparison of this spectrum with the mass spectrum of the reactant before photolysis as shown in Figure 55b shows that the two spectra both exhibit molecular ions at 98 and that the two spectra have very similar fragmentation patterns. Figure 59C shows the mass spectrum of the mixture that eluted at 12 minutes which also exhibits a molecular ion at m/z = 98.

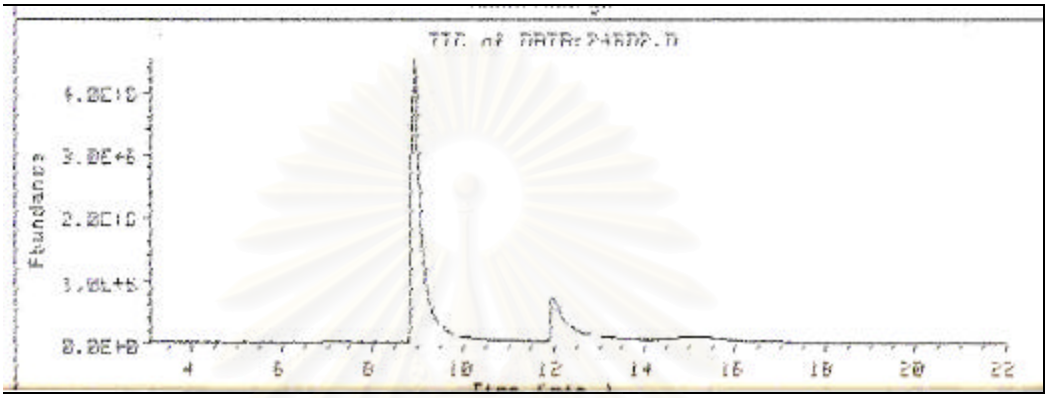


Figure 59a: GC trace of 4,6-dideuterio-2-trideuteriomethylpyridine after irradiation for 24 hours.

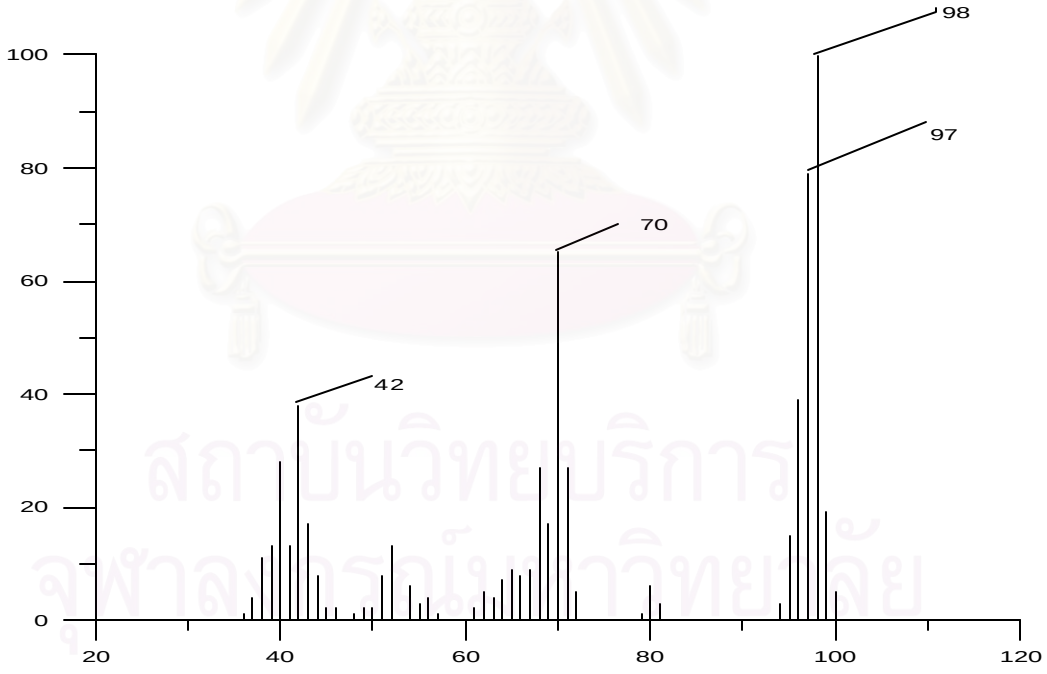


Figure 59b: The mass spectrum of 4,6-dideuterio-2-trideuteriomethylpyridine at 9 minutes after irradiation for 24 hours.

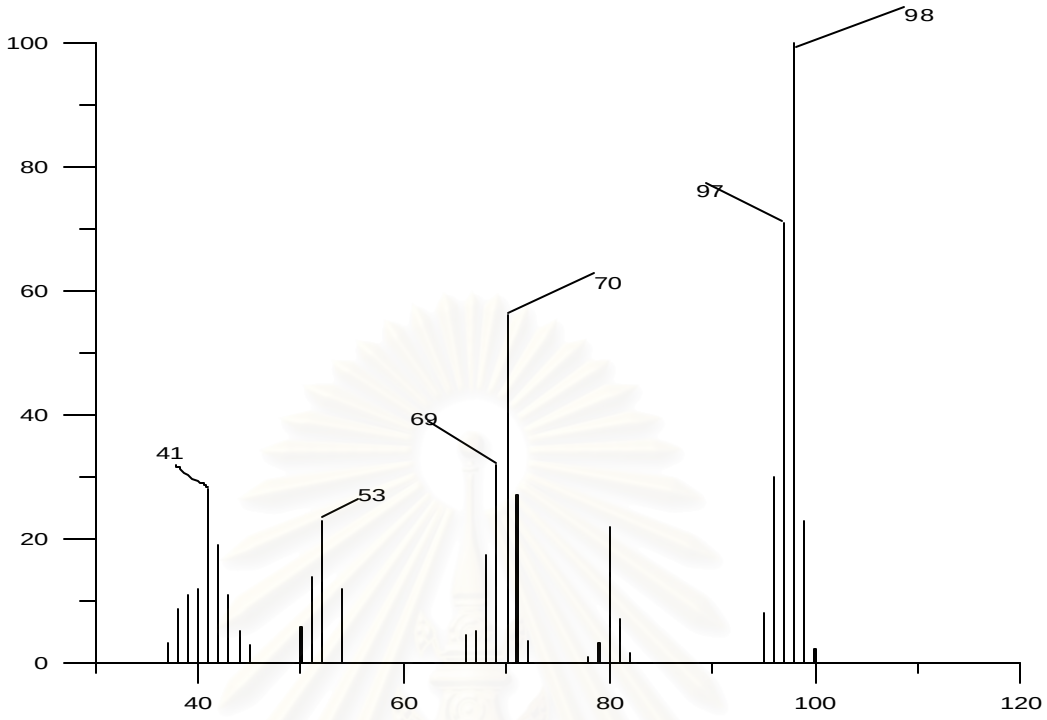


Figure 59c: The mass spectrum of photoproducts at 12 minutes after irradiation for 24 hours.

After irradiation, the walls of the reaction flask were again coated with a film. This material was washed with acetone and the acetone extract was evaporated to dryness and the residue (0.007 g) analyzed by ^{1}H-NMR in $CDCl_3$. The ^{1}H-NMR spectrum which is shown in Figure 60 exhibits signals at δ 7.52 (s, H_4) and 8.44 (s, H_6) due to 2-trideuteriomethylpyridine-3,5-d_2; signals at δ 8.4 (s, H_2) and 7.15 (s, H_5) due to 3-trideuteriomethylpyridine-4,6-d_2; signals at δ 7.45 (s, H_2) and 8.36 (s, H_5) due to 3-trideuteriomethylpyridine-2,5-d_2; and signals at δ 7.05 (s, H_3) and 8.41 (s, H_6) due to 4-trideuteriomethylpyridine-2,5-d_2. These are the same products that were observed in the condensed vapor after irradiation

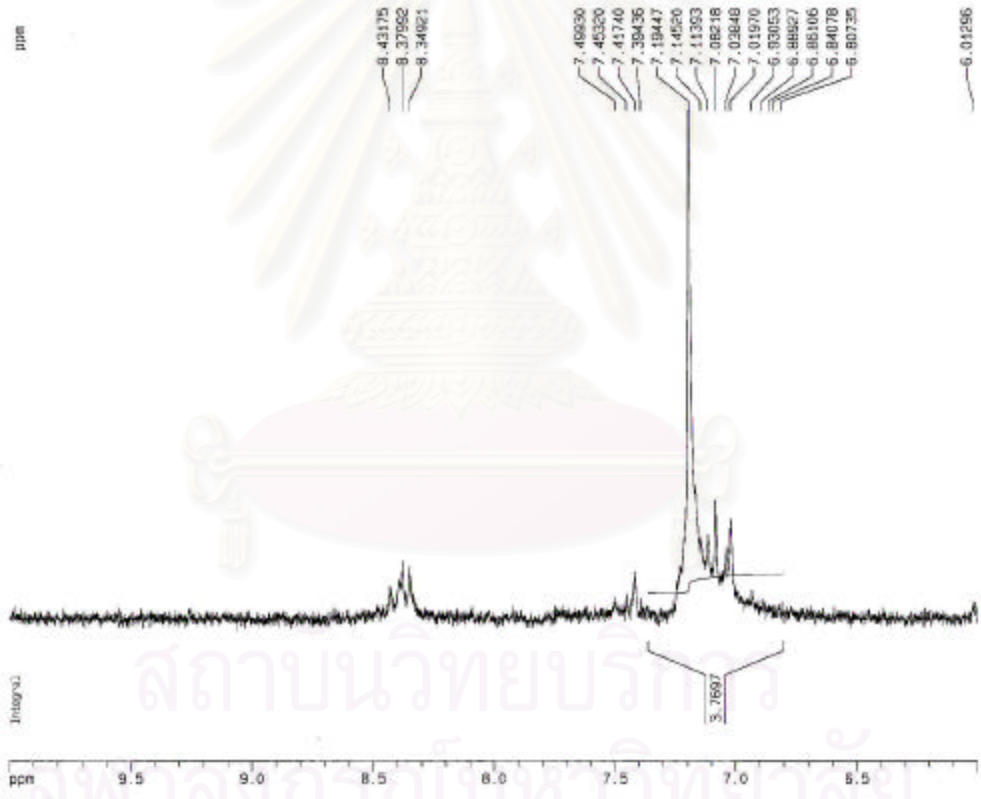
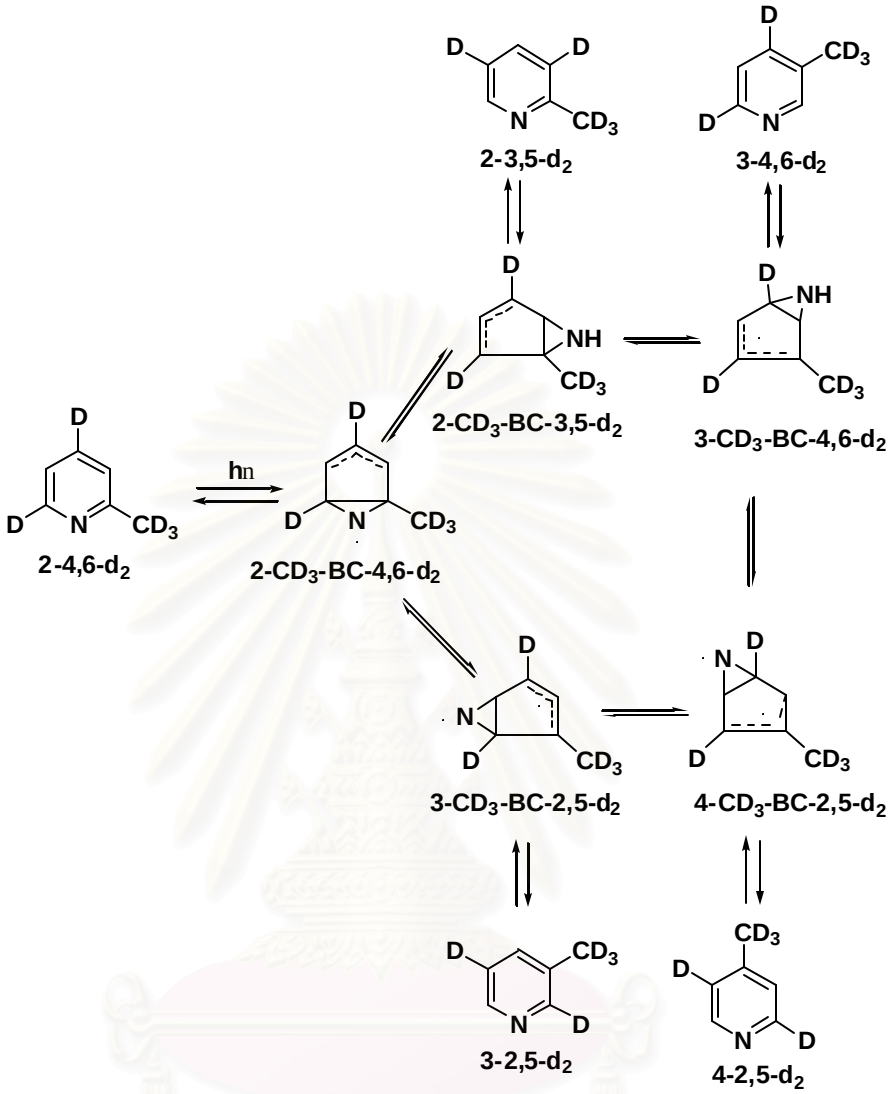


Figure 60 : ^{1}H-NMR of the polymeric materials from

These products formed by irradiation of 2-trideuteriomethylpyridine-4,6-d_2 are those predicted by the electrocyclic ring closure – heteroatom migration mechanism previously suggested for these reactions. As shown in Scheme 20, detection of all four products shows that nitrogen migration occurs around all five sides of the cyclopentenyl ring. As shown in Scheme 20, irradiation of **2-4,6-d_2** results in electrocyclic ring closure and the formation of the preazafulvene species, **2-CD_3-BC-4,6-d_2.** From this species, nitrogen migration can occur in either clockwise or counterclockwise direction. Clockwise migration converts **2-CD_3-BC-4,6-d_2** to **3-CD_3-BC-2,5-d_2**. This species can either rearomatize to form one of the observed products, **3-2,5-d_2**, or it can undergo a second nitrogen migration to form **4-CD_3-BC-2,5-d_2**. Rearomatization at this point leads to a second observed product, **4-2,5-d_2**. Alternatively, **4-CD_3-BC-2,5-d_2** could undergo another nitrogen migration to yield **3-CD_3-BC-4,6-d_2** which could rearomatize to the observed product, **3-4,6-d_2**, or isomerize to **2-CD_3-BC-3,5-d_2**, the precursor of the final product, **2-3,5-d_2**. All of these nitrogen migrations can also occur in the opposite direction as shown in Scheme 20.



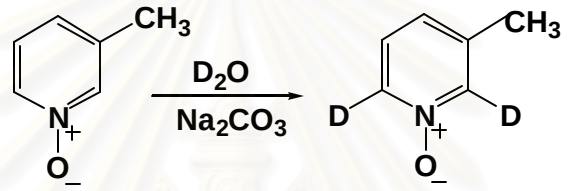
Scheme 20: Proposed mechanism for the formation of phototransposition products form **2-4,6-d_2**

3.4 Photochemistry of 2,6-dideuterio-3-methylpyridine

3.4.1 Synthesis of 2,6-dideuterio-3-methylpyridine

3.4.1.1 Synthesis of 2,6-dideuterio-3-methylpyridine *N*-oxide

3-Methylpyridine *N*-oxide was allowed to react with deuterium oxide in the presence of sodium carbonate in order to exchange the protons at ring positions 2 and 6 for deuterium. Scheme 21 shows the synthesis of 2,6-dideuterio-3-methylpyridine.



Scheme 21: Synthesis of 2,6-dideuterio-3-methylpyridine *N*-oxide

The ^{1}H-NMR spectrum of the product from this reaction in D_2O solvent is shown in Figure 61. As expected for 2,6-dideuterio-3-methylpyridine the spectrum shows a 3H singlet at δ 2.0 for the methyl protons and two 1H doublets at δ 7.0 (J = 8.08 Hz) and δ 7.1 (J = 8.08 Hz) for the protons at ring positions 5 and 4 respectively. In addition, very small signals can be seen at δ 7.8 and 7.9 for residual unexchanged protons at ring positions 2 and 6.

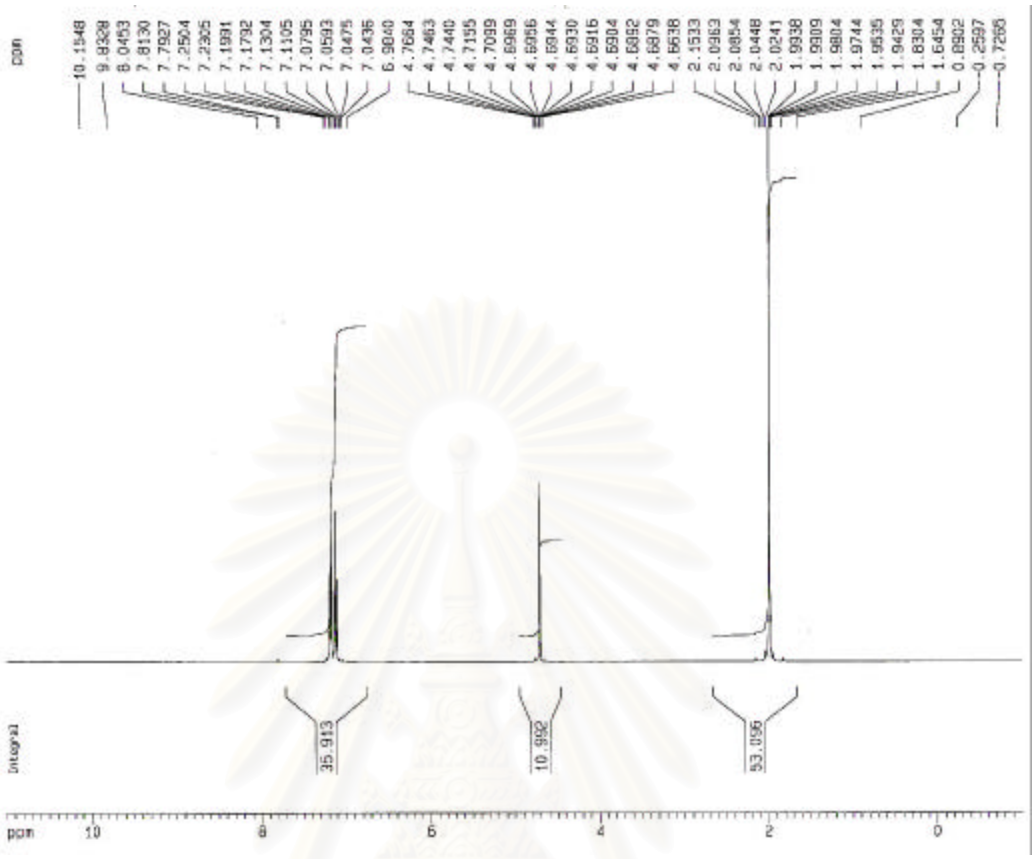


Figure 61: The ^{1}H-NMR spectrum of 2,6-dideuterio-3-methylpyridine *N*-oxide in D_2O

The ^{13}C-NMR spectrum, shown in Figure 62, exhibits a signal due to the methyl carbon at δ 18.3. The three singlets at δ 123.6, 127.8 and 136.8 were assigned to the carbons at positions 5, 4 and 3 respectively. The spectrum also exhibits triplets at δ 136.5 (J = 28.6 Hz) and at 138.8 (J = 28.3 Hz) which can be assigned to C6 and C2 of the pyridine ring.

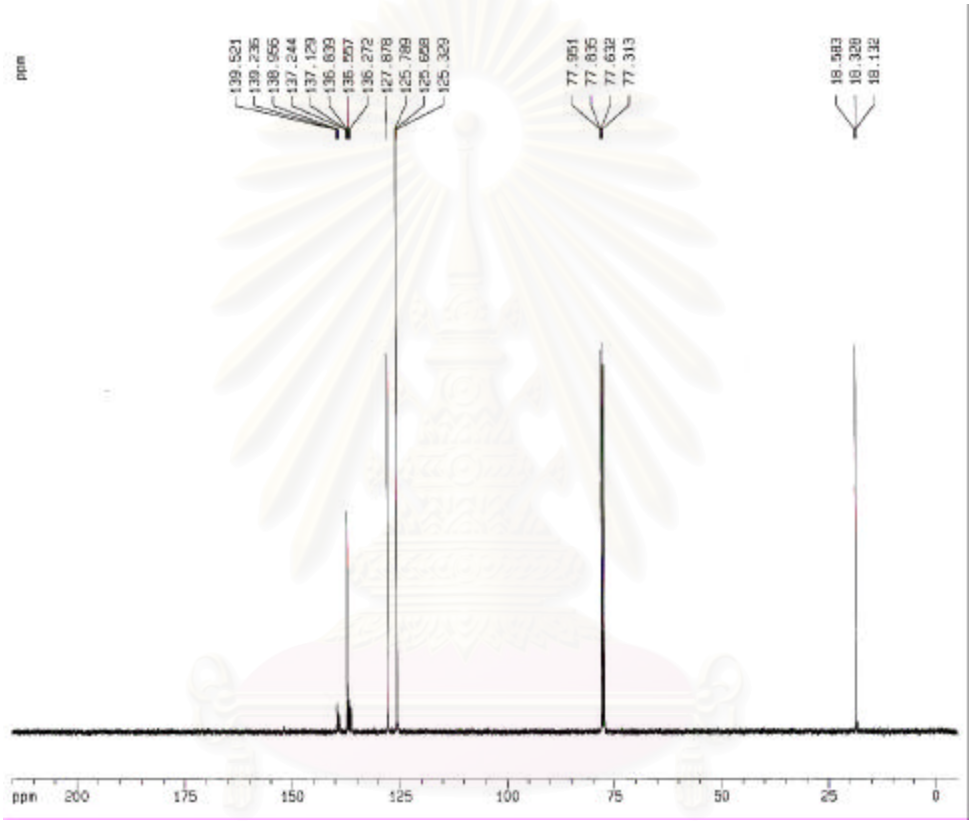
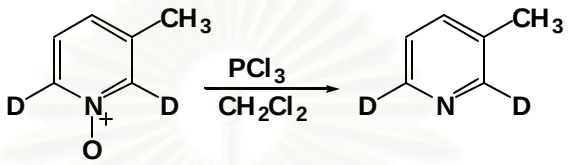


Figure 62: The ^{13}C-NMR spectrum of 2,6-dideuterio-3-methylpyridine *N*-oxide in $CDCl_3$.

3.4.1.2 Synthesis of 2,6-dideuterio-3-methylpyridine

The reduction of 3-methylpyridine *N*-oxide-2,6-d_2 using phosphorus trichloride to yield 3-methylpyridine-2,6-d_2, as shown in scheme 22, was carried out using the method described by Ochai[7]. The product was obtained as a colorless liquid in 69% yield.



Scheme 22: Synthesis of 2,6-dideuterio-3-methylpyridine.

The structure of the liquid product was confirmed by GC-MS, ^{1}H- and ^{13}C-NMR spectroscopy. The GC-MS analysis of the sample, as shown in Figure 63a, shows only one of compound. The mass spectrum of this peak, which eluted with the retention time of 12 minutes (Figure 63b), exhibits a molecular ion at m/z 95 corresponding to the molecular weight of 2,6-dideuterio-3-methylpyridine.

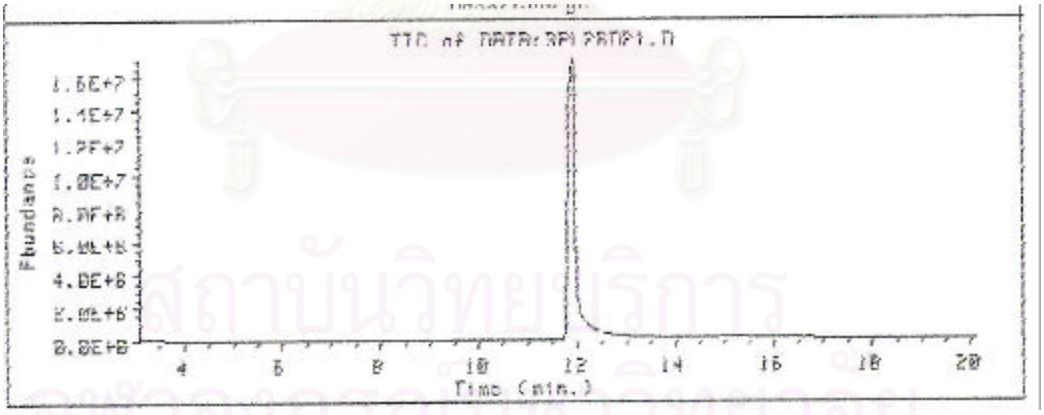


Figure 63 a: GC trace of 2,6-dideuterio-3-methylpyridine

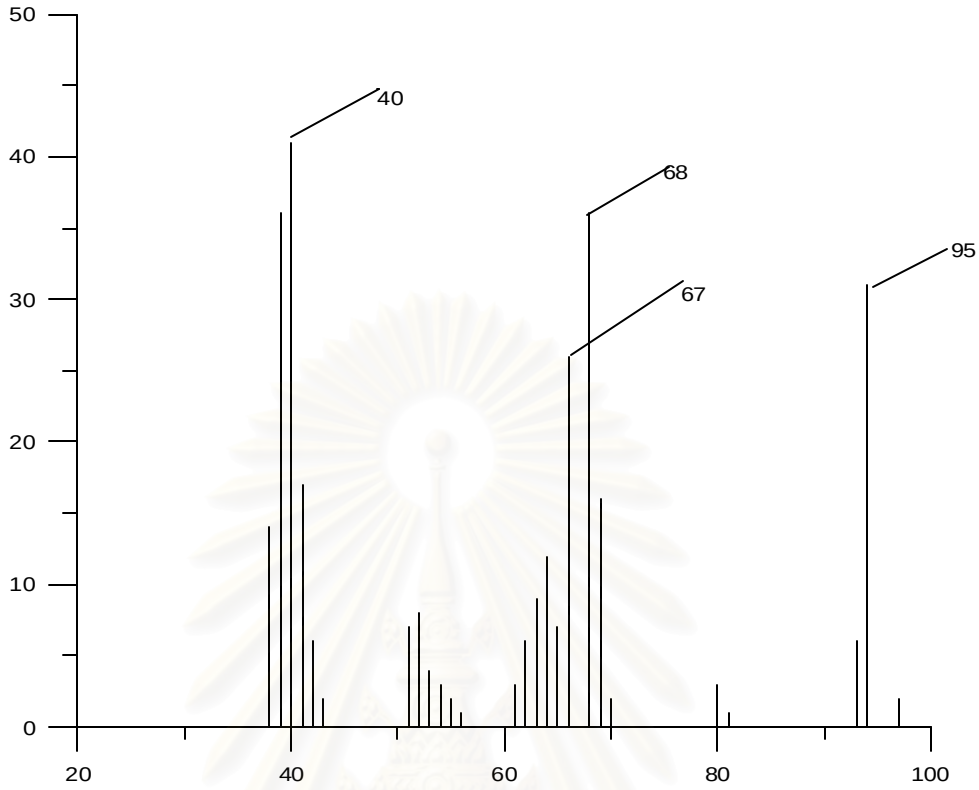


Figure 63b: The mass spectrum of the peak at 12 minutes

The ^{1}H-NMR spectrum of this compound, as shown in Figure 64, exhibits the expected 3H singlet at δ 2.2 for the protons of the methyl group and two 1H doublets at δ 7.4 (J = 7.58 Hz) and 7.18 (J = 7.58 Hz) for the protons at ring positions 4 and 5 respectively. Very small signals are also visible at δ 8.38 and 8.37 due to unexchanged residual protons at ring position 2 and 6.

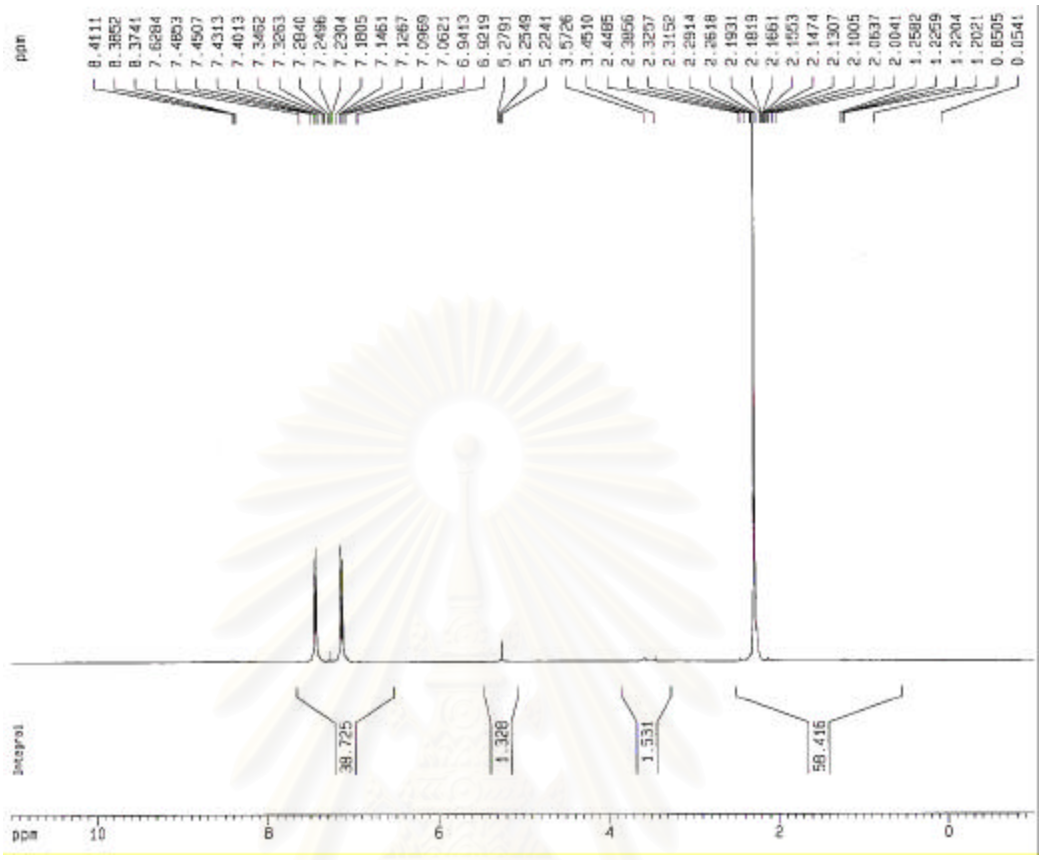


Figure 64: The ^{1}H-NMR spectrum of 2,6-dideuterio-3-methylpyridine.

The ^{13}C-NMR spectrum, shown in Figure 65, exhibits a signal due to the methyl carbon at δ 17.5. The three singlets at δ 123.4, 133.3 and 136.8 were assigned to the carbons at positions 5, 3 and 4 respectively. The spectrum also exhibits triplets at δ 150.2 (J = 28.4 Hz) and at δ 146.9 (J = 28.3 Hz) which can be assigned to C2 and C6 of the pyridine ring. This confirms that deuterium is bonded to these atoms.

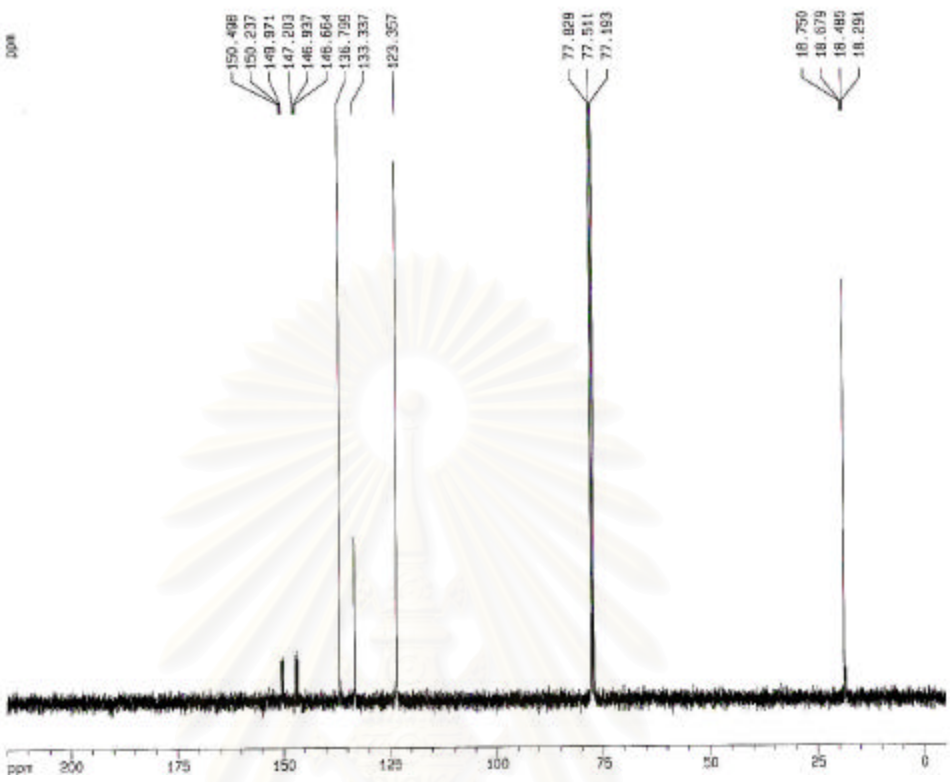
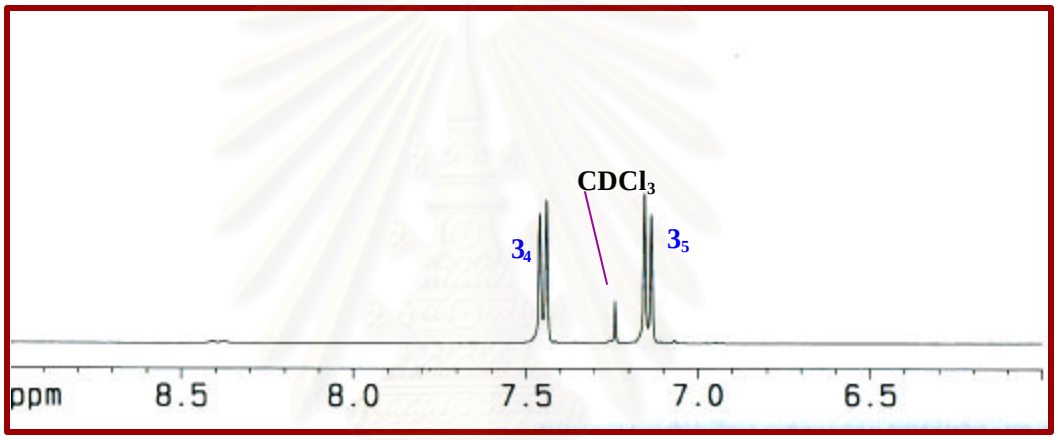


Figure 65: The ^{13}C-NMR spectrum of 2,6-dideuterio-3-methylpyridine

3.4.2 Vapor phase photochemistry of 3-methylpyridine-2,6-d_2

In the photochemical experiment, the vapor of 3-methylpyridine-2,6-d_2 (4.0 Torr) was obtained by vaporizing the sample into the 3L quartz flask at 25°C. This was then irradiated in the Rayonet reactor at 254 nm using 15 low pressure mercury arc lamps for 24 and 48 hours. Figure 66 shows a portion of the ^{1}H-NMR spectrum from 6-10 ppm in $CDCl_3$ a) before irradiation and b) after irradiation of the sample at 254 nm for 24 hours.

66a)



66b)

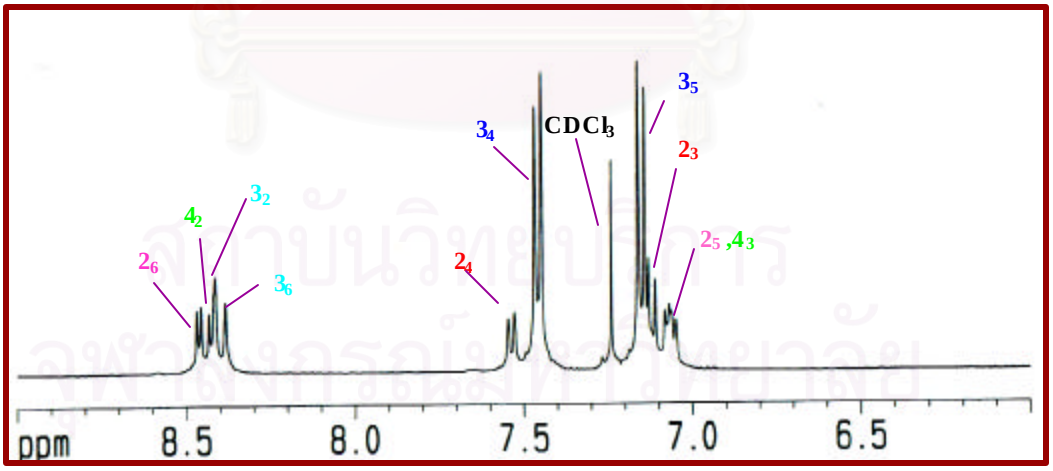
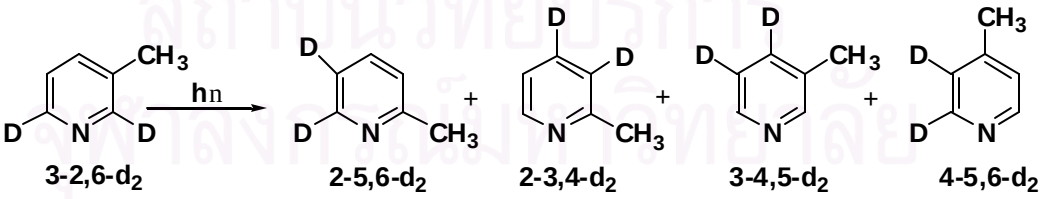


Figure 66: a) 2,6-Dideuterio-3-methylpyridine before irradiation
b) After irradiation of 2,6-dideuterio-3-methylpyridine at 254 for 24 hours

After irradiation, the ^{1}H-NMR spectrum of the photoproducts shows two doublets at δ 7.15 (J = 7.83 Hz) and δ 7.46 (J = 7.83 Hz) due to the H3 and H5 protons of unreacted 2,6-dideuterio-3-methylpyridine and eight new signals due to the formation of photoproducts. Since each methylpyridine photoproduct will bear two deuterium atoms and two protons bonded to the ring, the formation of eight signals means that four different methylpyridine isomers have been formed in this photoreaction. These new signals can be assigned by comparison with the known chemical shifts for the ring protons in 2-,3- and 4-methylpyridine as discussed in section 2 of this synthesis. Thus, as shown on figure 66b, the two doublets at δ 7.12 (J = 7.58 Hz) and 7.54 (J = 7.58 Hz) can be assigned to H3 and H4 of 2-methylpyridine-5,6-d_2; the doublet at δ 8.45 (J = 4.88 Hz) can be assigned to H6 of 2-methylpyridine-3,4-d_2 but the doublet for H5 at δ 7.07 is overlapping with the doublet at δ 7.05 for H3 of 4-methylpyridine-5,6-d_2; the doublet for H2 of 4-methylpyridine-5,6-d_2 is overlapping with the singlet due to the H2 of 3-methylpyridine-4,5-d_2 in the δ 8.40-8.41 region as was also observed in the ^{1}H-NMR spectrum of the authentic mixture of 3- and 4-methylpyridine shown in Figure 25 of section **2** of this thesis while the doublet for H3 of 4-methylpyridine -5,6-d_2 at δ 7.05 is overlapping with the doublet at δ 7.07 for H5 of 2-methylpyridine -3,4-d_2 as mentioned above. The two singlets at δ 8.41 and 8.39 can be assigned to H2 and H6 of 3-methylpyridine-4,5-d_2; and the two signals at δ 8.43 and 7.05 can be assigned to H2 and H3 of 4-methylpyridine-5,6-d_2. The overall phototansposition reaction is thus shown in the equation below.



Gas chromatographic analysis of the product mixture (Figure 67a) showed one peak at 8.9 minutes retention time due to a mixture of 2-methylpyridine-5,6-d_2 and 2-methylpyridine-4,5-d_2 and a second much larger peak at 12.7 minutes due to

unreacted 3-methylpyridine-2,6-d_2 and photoproducts 3-methylpyridine-4,5-d_2 and 4-methylpyridine-5,6-d_2. The mass spectrum exhibits peaks at m/z 95 as shown in Figure 67b and 67C.

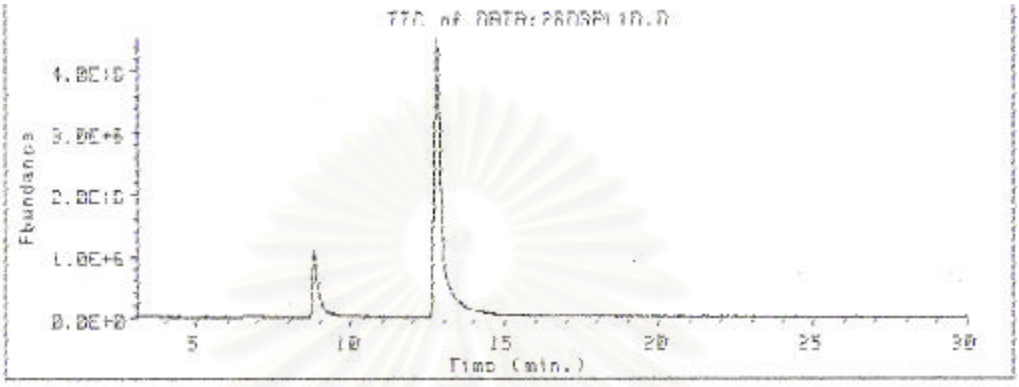


Figure 67a: The GC-MS analysis of 2,6-dideuterio-3-methylpyridine after irradiation for 24 hour

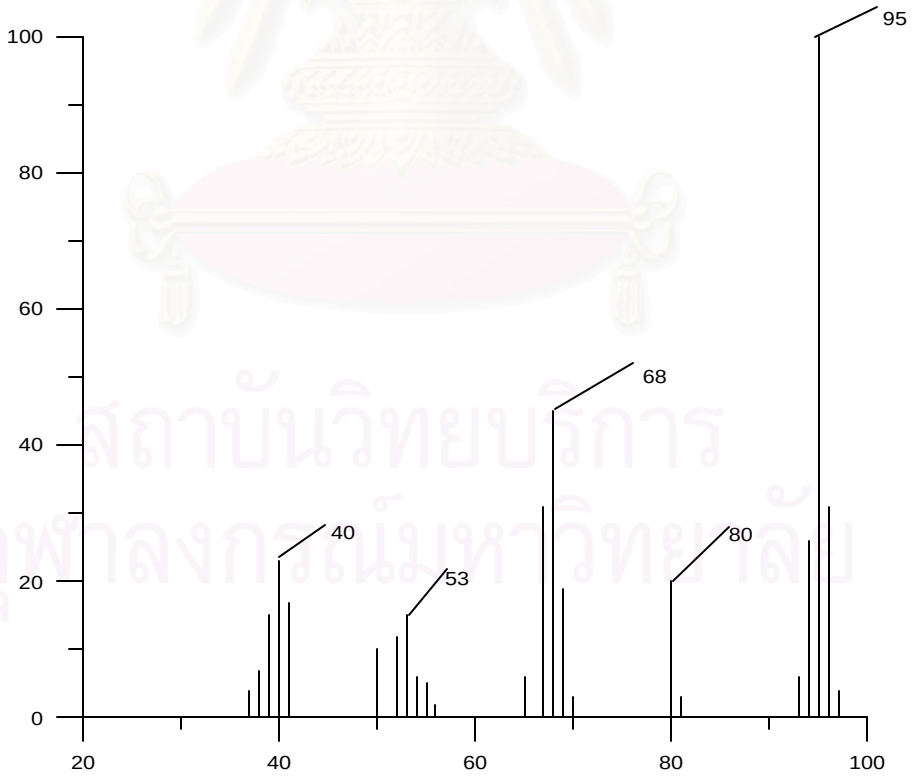


Figure 67b: The mass spectrum at 8.9 minutes after irradiation for 24 hours.

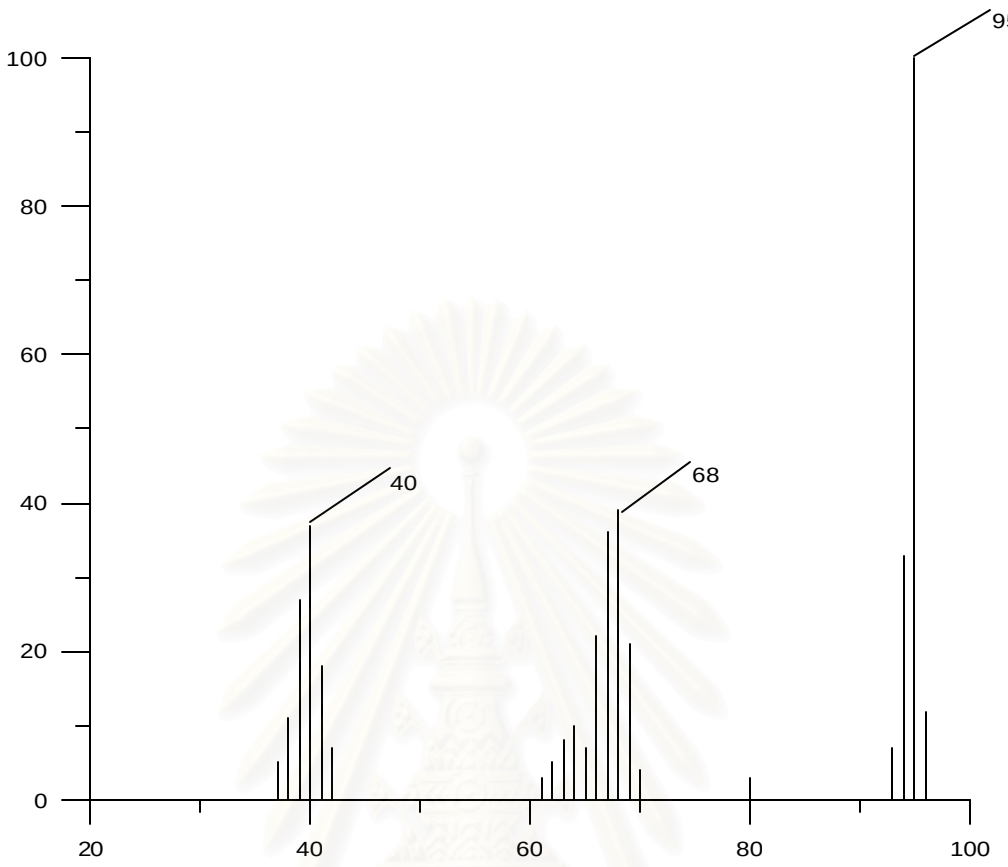


Figure 67c: The mass spectrum at 12.7 minutes after irradiation for 24 hours

After irradiation, the walls of the reaction flask were again coated with a brown film. This material was washed with acetone and the acetone extract was evaporated to dryness. The residue was recovered to give (0.011 g) yield then the residue analyzed by ^{1}H-NMR in $CDCl_3$. The ^{1}H-NMR spectrum which is shown in Figure 68 exhibits signals at δ 7.12 (s, H_3) and 7.54 (s, H_4) due to 2-methylpyridine-5,6-d_2; signals at δ 8.47 (s, H_6) and 7.07 (s, H_5) due to 2-methylpyridine-3,4-d_2; signals at δ 8.41 (s, H_2) and 8.39 (s, H_6) due to 3-methylpyridine-4,5-d_2; and signals at δ 7.05 (s, H_3) and 8.43 (s, H_6) due to 4-methylpyridine-5,6-d_2. These are the same products that were observed in the condensed vapor after irradiation

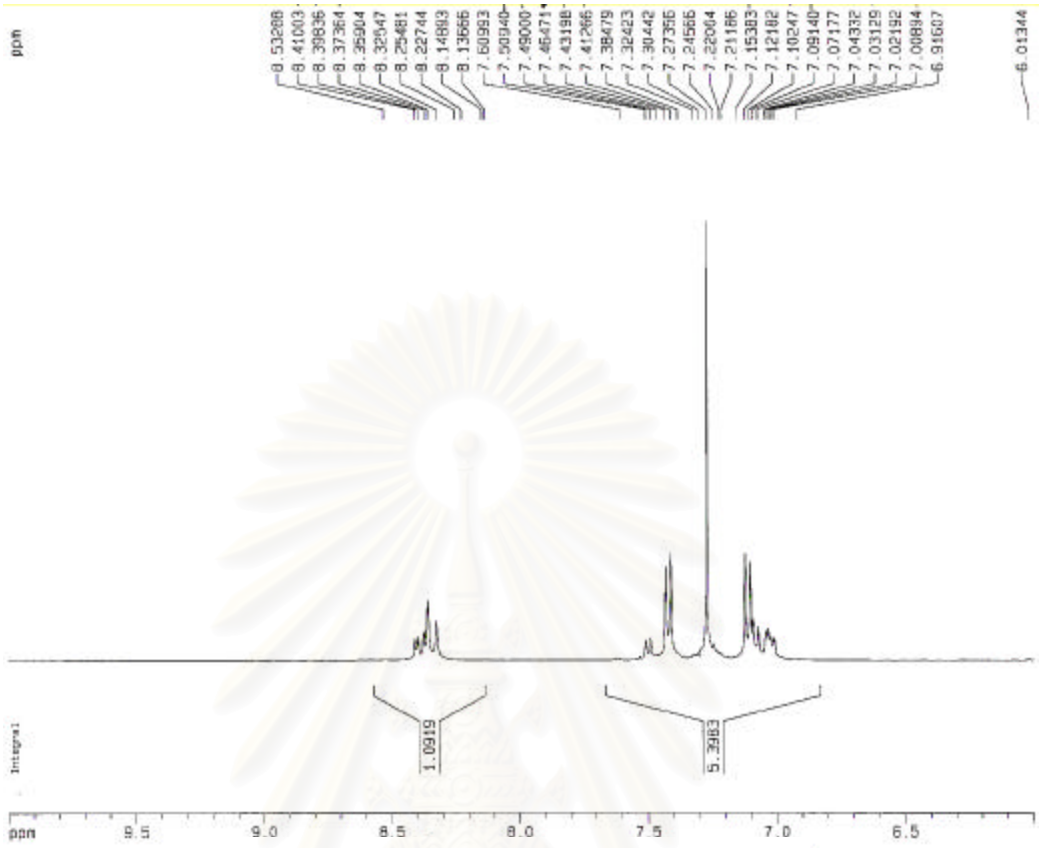


Figure 68: The ^{1}H-NMR of brown film

The brown polymer was analyzed also by GC-MS. GC trace (Figure 69a) indicated the three peaks which eluted at retention of 8.8, 10 and 12 minutes.

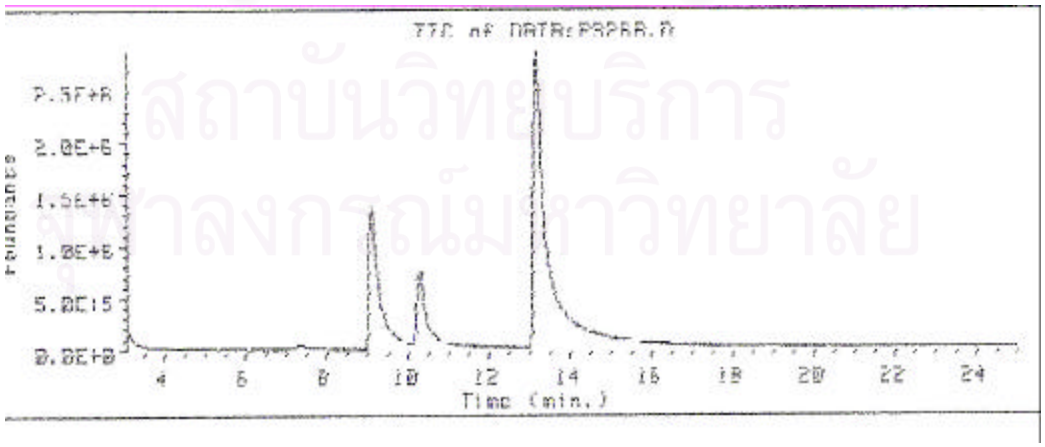


Figure 69 a: GC trace of the brown polymer

The mass spectrum at 8.8 minutes (Figure 69b) shows a molecular ion at m/z 95 consistent with molecular weigh of 2-methylpyridine-5,6d_2 and 2-methylpyridine-3,4-d_2 (MW 95) as photoproducts.

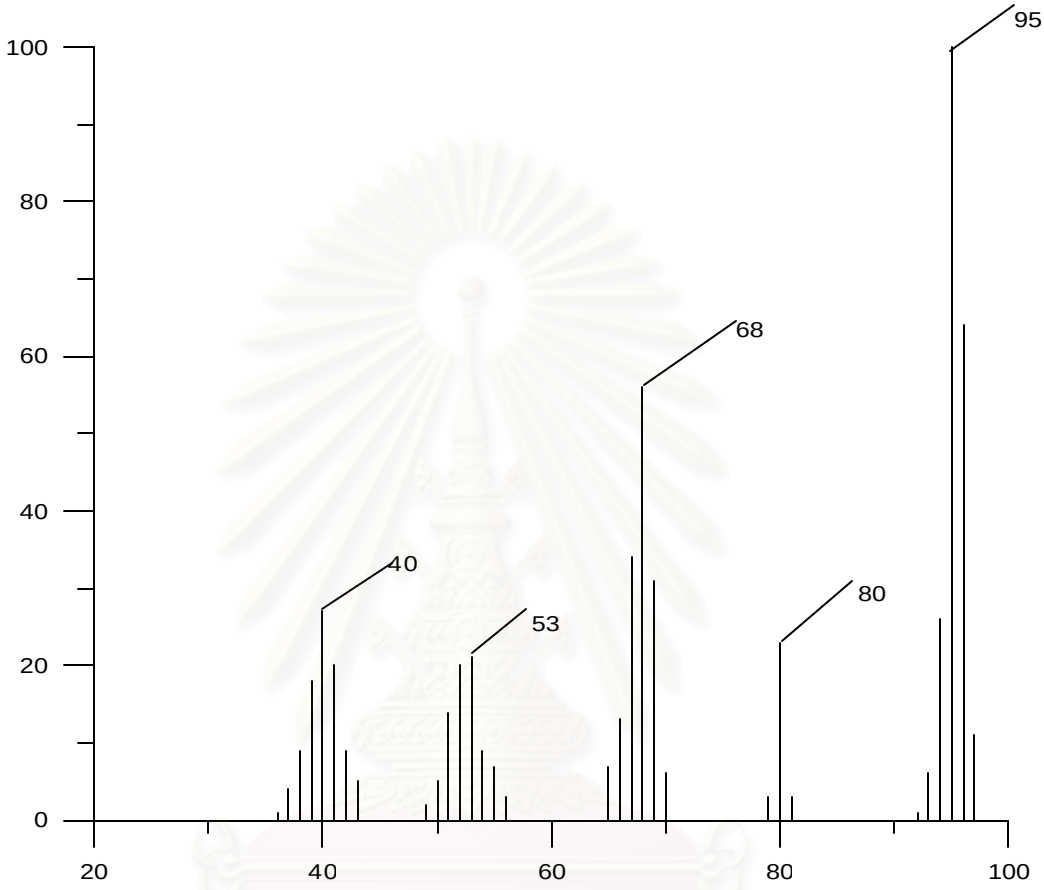


Figure 69b: The mass spectrum at 8.9 minutes

The mass spectrum at 10 minutes (Figure 69c) shows a molecular ion at m/z 101 is due to unknown.

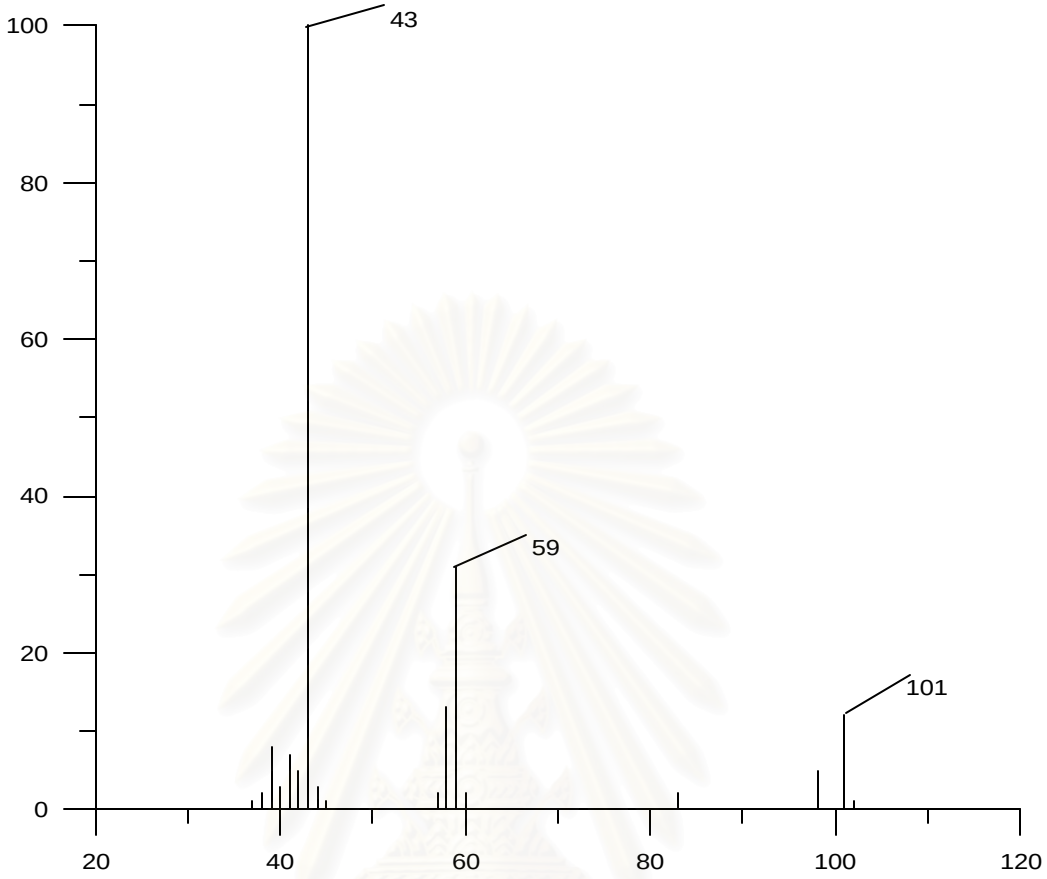


Figure 69c: The mass spectrum at 10 minutes

The mass spectrum exhibits peaks at m/z 95 eluted at 12 minutes as shown in Figure 69d, which consistent with the molecular weight of 3-methylpyridine-4,5-d_2, 3-methylpyridine-2,6-d_2 and 4-methylpyridine-5,6-d_2. Therefore, the peak exhibits a molecular ion at 95.

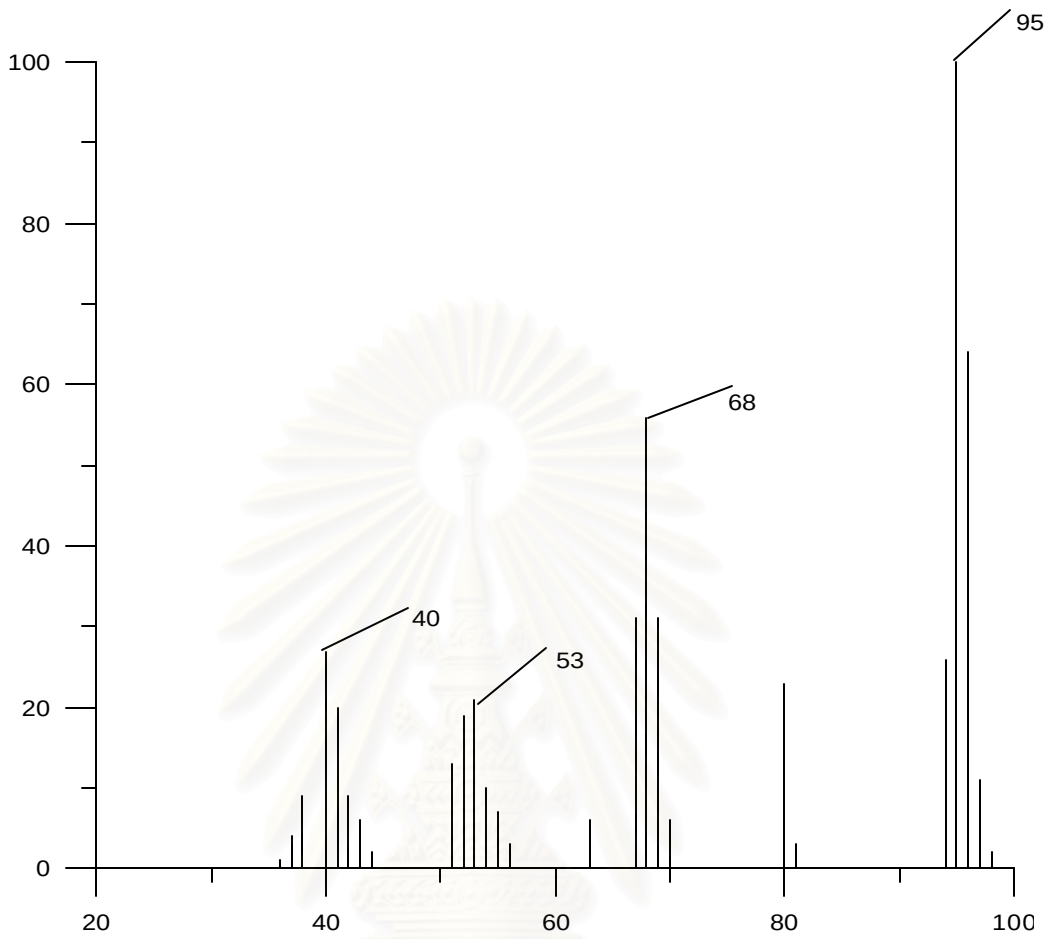
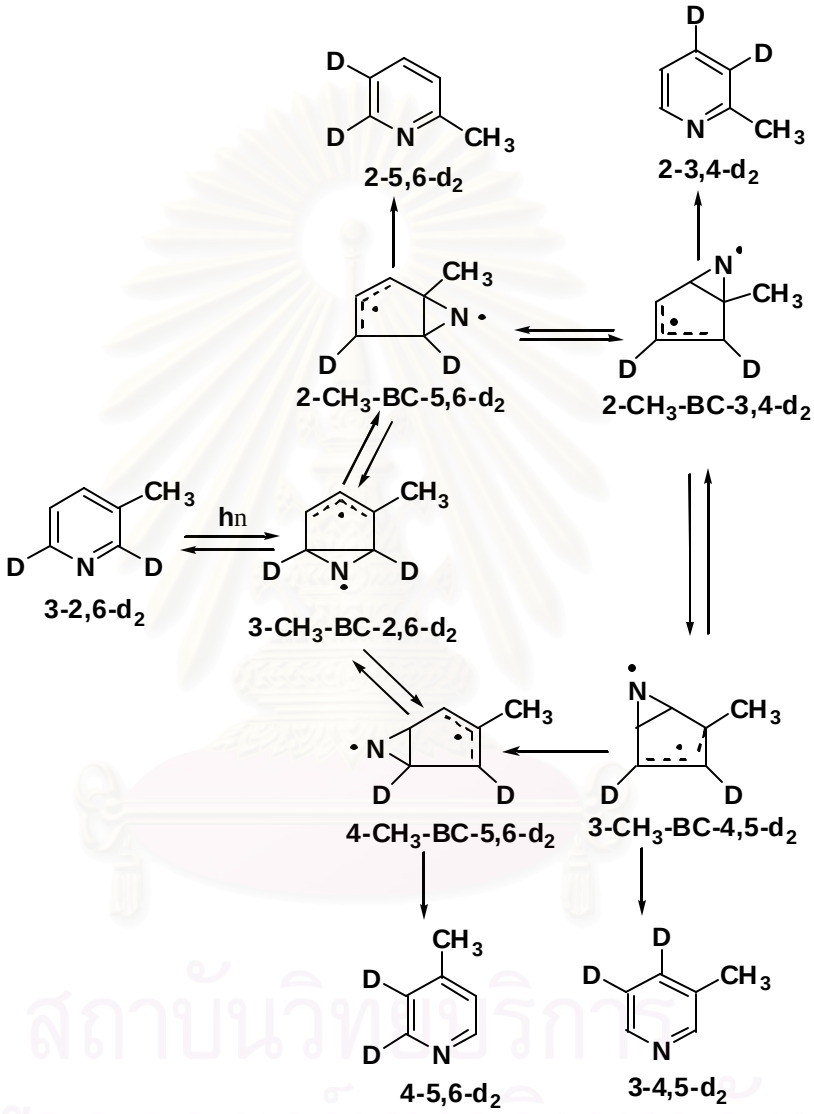


Figure 69d: The mass spectrum at 13 minutes

These products formed by irradiation of 3-methylpyridine-2,6-d_2 are those predicted by the electrocyclic ring closure – heteroatom migration mechanism previously suggested for these reactions. As shown in Scheme 22, detection of all four products shows that nitrogen migration occurs around all five sides of the cyclopentenyl ring. As shown in Scheme 22, irradiation of **3-2,6-d_2** results in electrocyclic ring closure and the formation of the preazafulvene species, **3-CH_3-BC-2,6-d_2.** From this species, nitrogen migration can occur in either clockwise or counterclockwise direction. Clockwise migration converts **3-CH_3-BC-2,6-d_2** to **2-CH_3-BC-5,6-d_2**. This species can either rearomatize to form one of the observed products **2-5,6-d_2** or it can undergo a second nitrogen migration to form **2-CH_3-BC-3,4-d_2**. Rearomatization at this point leads to a second observed product **2-3,4-d_2**. Alternatively, **2-CH_3-BC-3,4-d_2** could undergo another nitrogen migration to yield **3-CH_3-BC-4,5-d_2** which could rearomatize to the observed

product, **3-4,5-d_2** or isomerize to **4-CH_3-BC-5,6-d_2**, the precursor of the final product, **4-5,6-d_2**. All of these nitrogen migrations can also occur in the opposite direction as shown in Scheme 22.



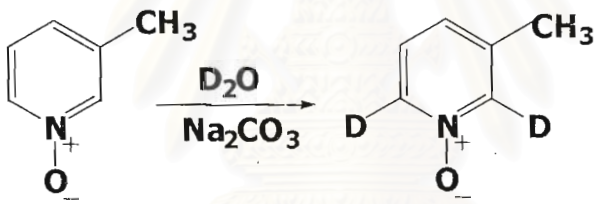
Scheme 22: Proposed mechanism for the formation of phototransposition products from **3-2,6-d_2**

3.5 Photochemistry of 2,4,6-trideuterio-3-methylpyridine

3.5.1 Synthesis of 2,4,6-trideuterio-3-methylpyridine

3.5.1.1 Synthesis of 2,4,6-trideuterio-3-methylpyridine *N*-oxide

3-Methylpyridine *N*-oxide was allowed to react with deuterium oxide in the presence of sodium carbonate in order to exchange the protons at ring positions 2 and 6 for deuterium. Scheme 23 shows synthesis of 2,6-dideuterio-3-methylpyridine *N*-oxide.



Scheme 23: Synthesis of 2,6-dideuterio-3-methylpyridine N-oxide

The ^{1}H-NMR spectrum of the product from this reaction in D_2O solvent is shown in Figure 70. As expected for 2,6-dideuterio-3-methylpyridine the spectrum shows a 3H singlet at δ 2.0 for the methyl protons and two 1H doublets at δ 7.0 (J = 8.08 Hz) and δ 7.1 (J = 8.08 Hz) for the protons at ring positions 5 and 4 respectively. In addition, very small signals can be seen at δ 7.8 and 7.9 for residual unexchanged protons at ring positions 2 and 6.

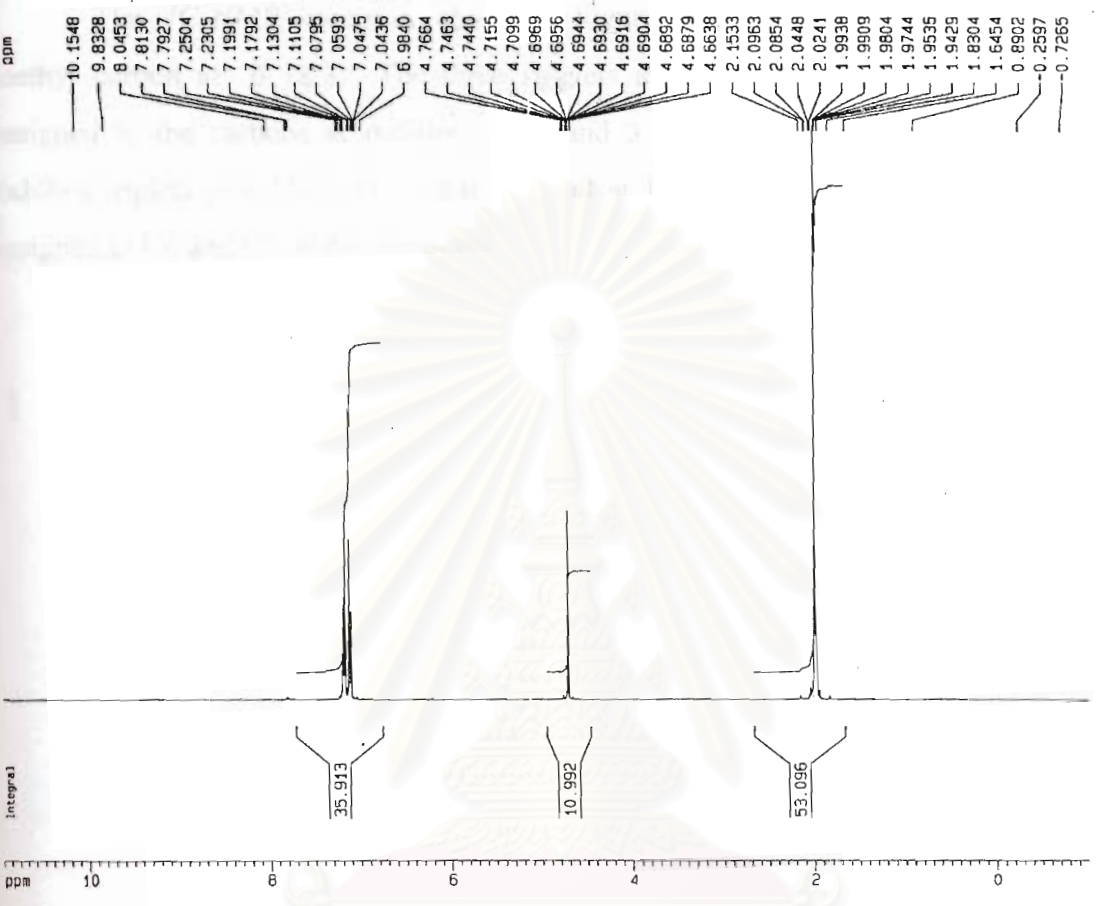


Figure 70: The ^{1}H-NMR spectrum of 2,6-dideuterio-3-methylpyridine N-oxide in D_2O

The ^{13}C-NMR spectrum, shown in Figure 71, exhibits a signal due to the methyl carbon at δ 18.3. The three singlets at δ 123.6, 127.8 and 136.8 were assigned to the carbons at positions 5, 4 and 3 respectively. The spectrum also exhibits triplets at δ 136.5 (J = 28.6 Hz) and at 138.8 (J = 28.3 Hz) which can be assigned to C6 and C2 of the pyridine ring.

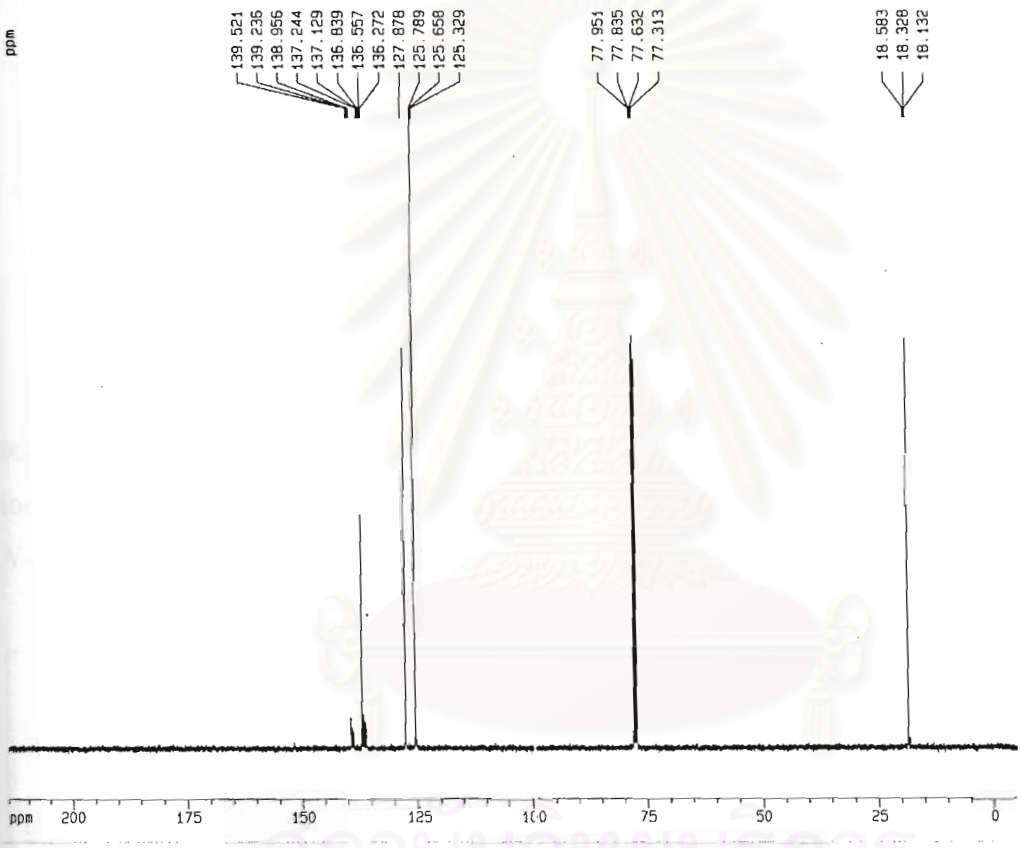
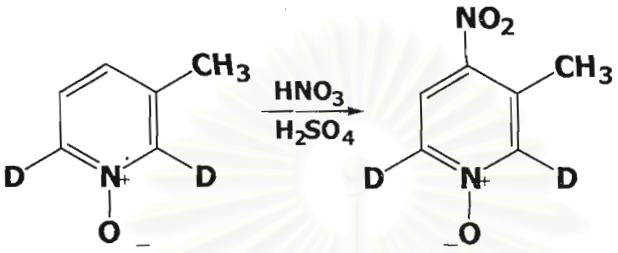


Figure 71: The ^{13}C-NMR spectrum of 2,6-dideuterio-3-methylpyridine *N*-oxide in $CDCl_3$

3.5.1.2 Synthesis of 2,6-dideuterio-4-nitro-3-methylpyridine *N*-oxide

According to the method described by Ochai[7], 3-methylpyridine *N*-oxide-2,6d_2 was heated with concentrated sulphuric acid and concentrated nitric acid at 100°C to give 4-nitro-3-methylpyridine *N*-oxide-2,6d_2 in 52% yield.



Scheme 23: Nitration of pyridine N-oxide

GC analysis (Figure 72a) of this product shows one peak, which eluted at a retention time of 26.5 minutes. The mass spectrum (Figure 72b) exhibits a molecular ion at m/z 158 consistent with the molecular weight of 4-nitro-3-methylpyridine *N*-oxide-2,6-d_2 (MW 156).

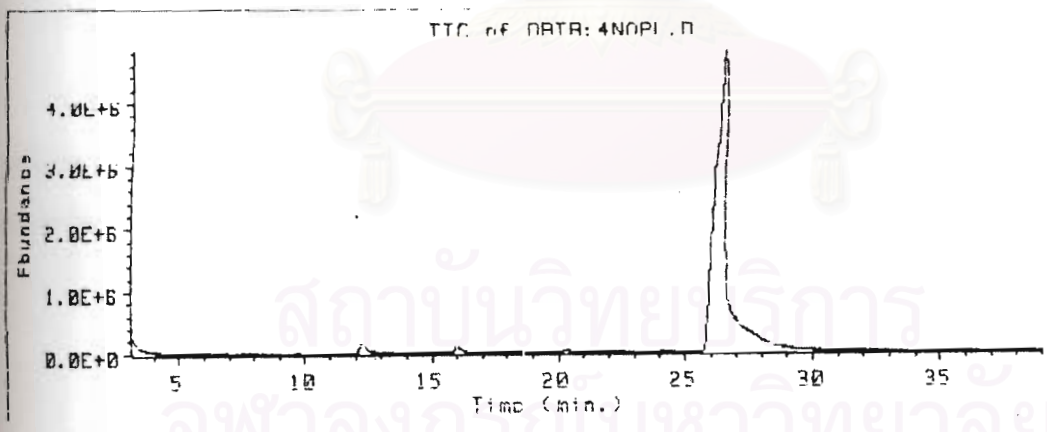


Figure 72a: GC trace of the synthesized 2,6-dideuterio-4-nitro-3-methylpyridine N-oxide

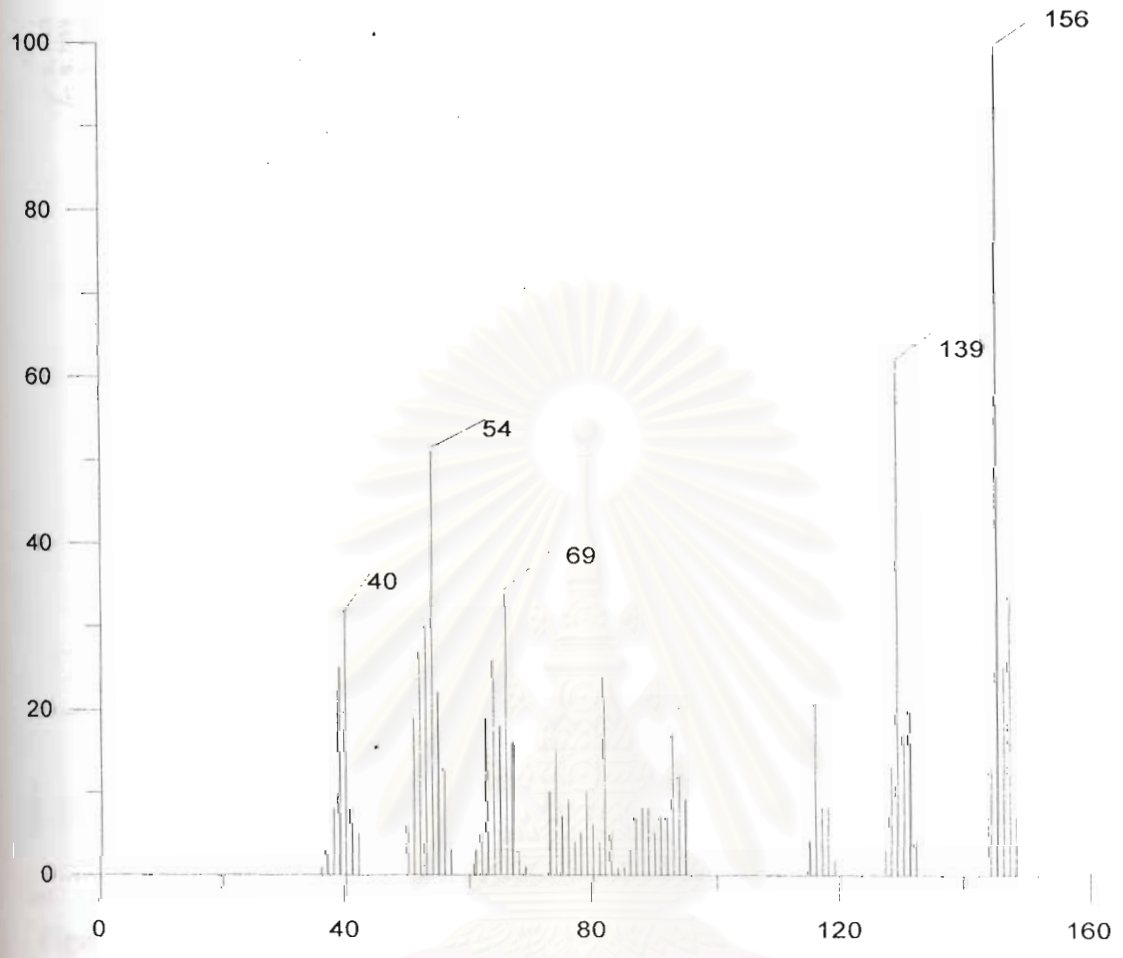


Figure 72b: Mass spectrum of 2,6-dideuterio-4-nitro-3-methylpyridine *N*-oxide

The ^{1}H-NMR spectrum (Figure 73) shows a singlet at δ 2.5 due to the methyl protons. The singlet at δ 7.9 is due to the protons at C-5 proton. The spectrum does not show signals at δ 8.0-8.2 where protons at positions 2 and 6 are known to absorb.

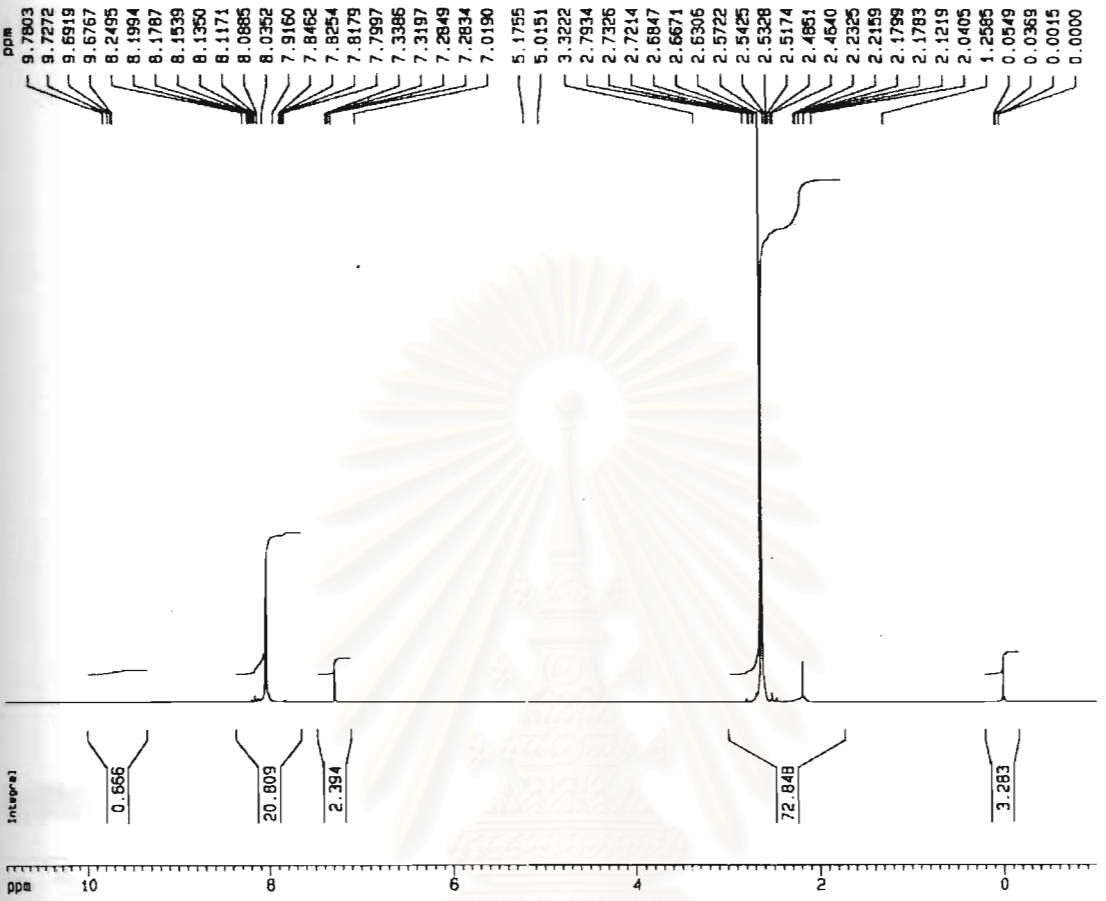


Figure 73: The ^{1}H-NMR spectrum of 6-deuterio-4-nitro-3-methylpyridine *N*-oxide

The ^{13}C-NMR spectrum, shown in Figure 74, exhibits a singlet due to the methyl carbon at δ 18.4. The four singlets at δ 122.2, 133.2, and 141.4 were assigned to the carbons at positions 5, 3, and 4 respectively. In addition, the signals at δ 137.7 and 141.8 appear as triplets (J = 29.9 Hz) which are due to carbons at positions 2 and 6 which are coupling with the attached deuterium atom.

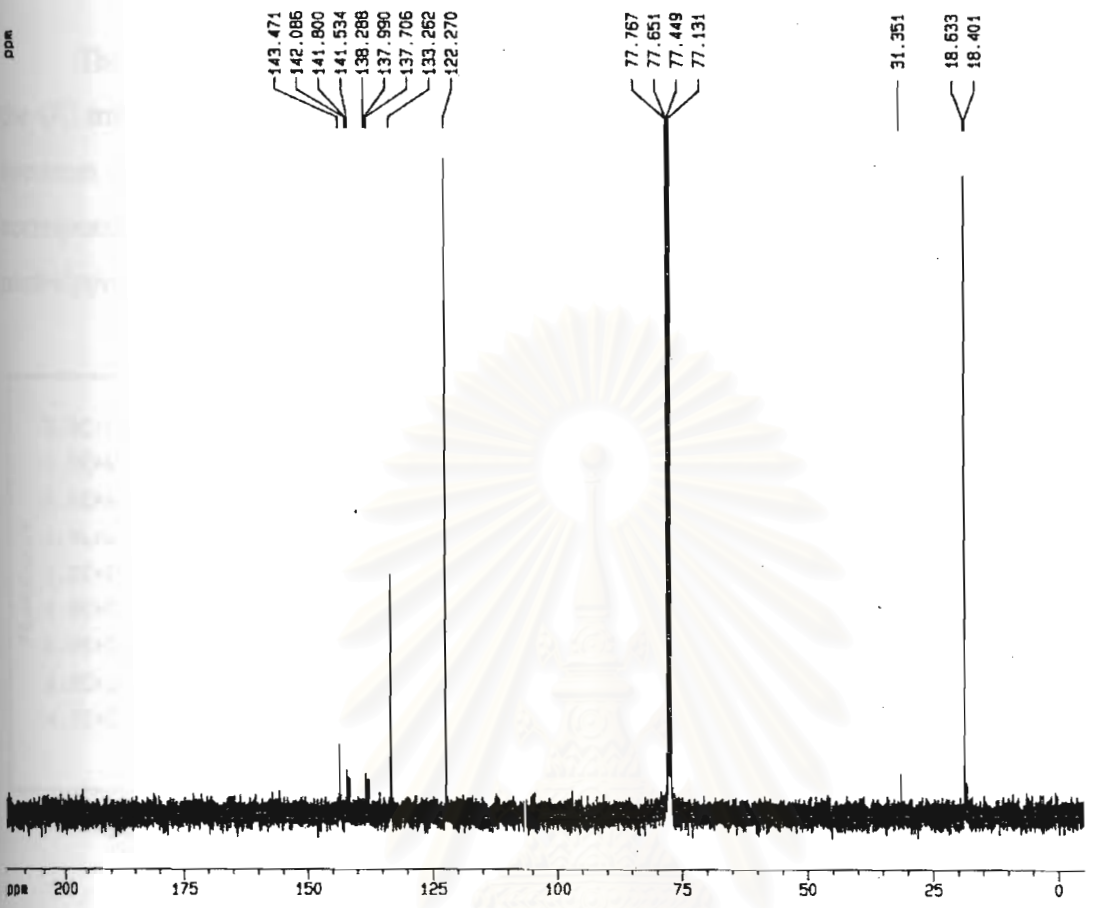
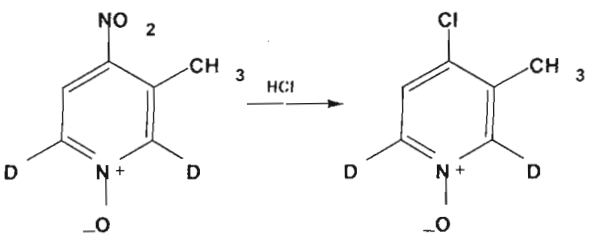


Figure 74: The ^{13}C-NMR spectrum of 6-deuterio-4-nitro-3-methylpyridine *N*-oxide

3.5.1.3 Synthesis of 4-chloro-2,6-dideuterio-3-methylpyridine *N*-oxide

According to the procedure for the conversion of 4-nitro-2-methylpyridine *N*-oxide-6d to 4-chlo-2-methylpyridine *N*-oxide-6d, 4-nitro-3-methylpyridine *N*-oxide-2,6-d_2 was treated with concentrated hydrochloric acid.



Scheme 24: The synthesis of 4-chloro-3-methylpyridine *N*-oxide-2,6-d_2

The product from this reaction was analyzed by GC. As shown in Figure 75a the GC trace shows a single peak with a retention time of 19.7 minutes. The mass spectrum of this peak (Figure 75b) exhibited a molecular ion at m/z 145 which corresponds to the molecular weight of the desired product, 4-chloro-3-methylpyridine *N*-oxide-2,6-d_2.

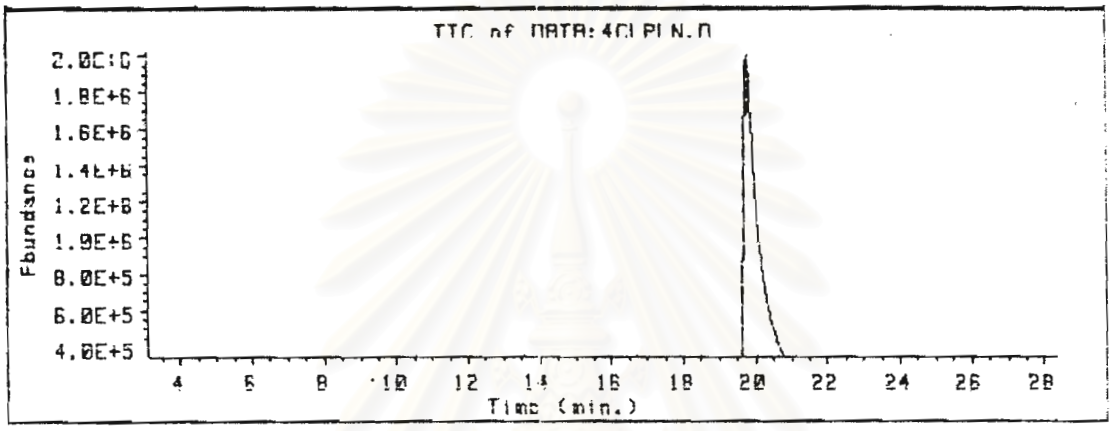


Figure 75a: GC trace of 4-chloro-3-methylpyridine *N*-oxide-2,6-d_2

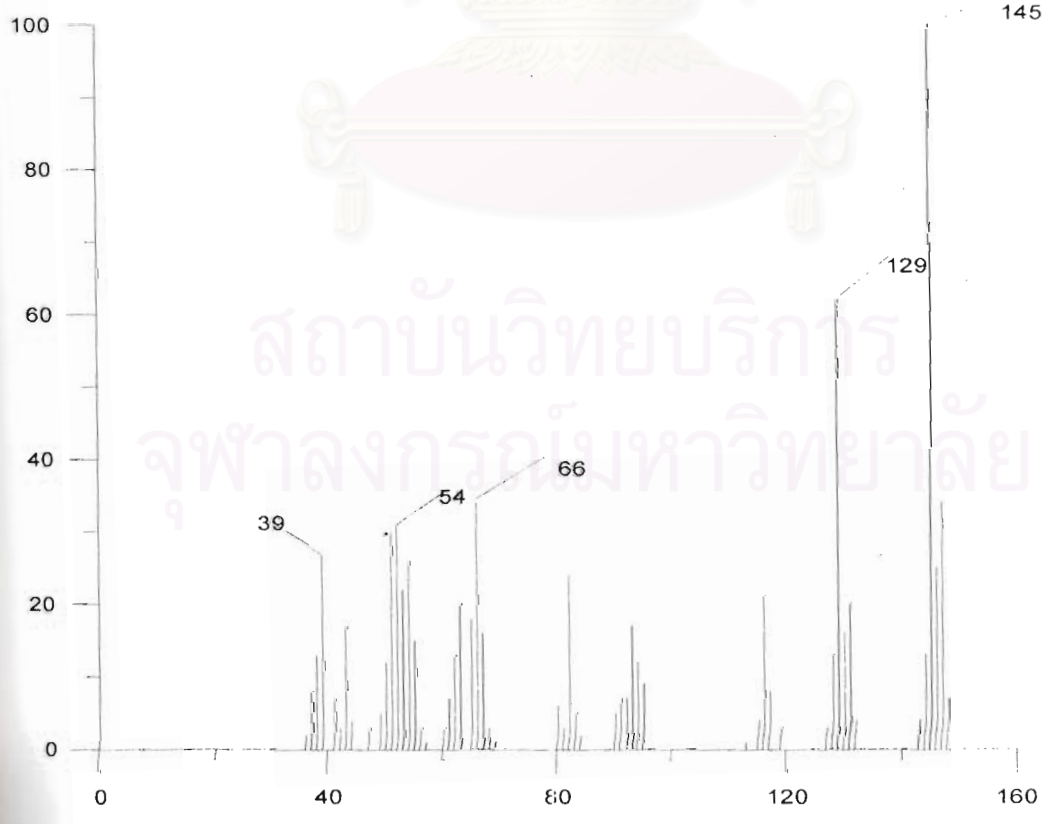


Figure 75b: Mass spectrum of 4-chloro-3-methylpyridine *N*-oxide-2,6-d_2

The ^{1}H-NMR spectrum of this product (Figure 76) shows a singlet at δ 7.1 which is due to the proton at position 5, a very small doublet at 7.9 due to the residual proton at position 6, and a singlet of low intensity at δ 8.0 due to residual proton at position 2. The spectrum also shows a 3H singlet at δ 2.1 due to the protons of methyl group.

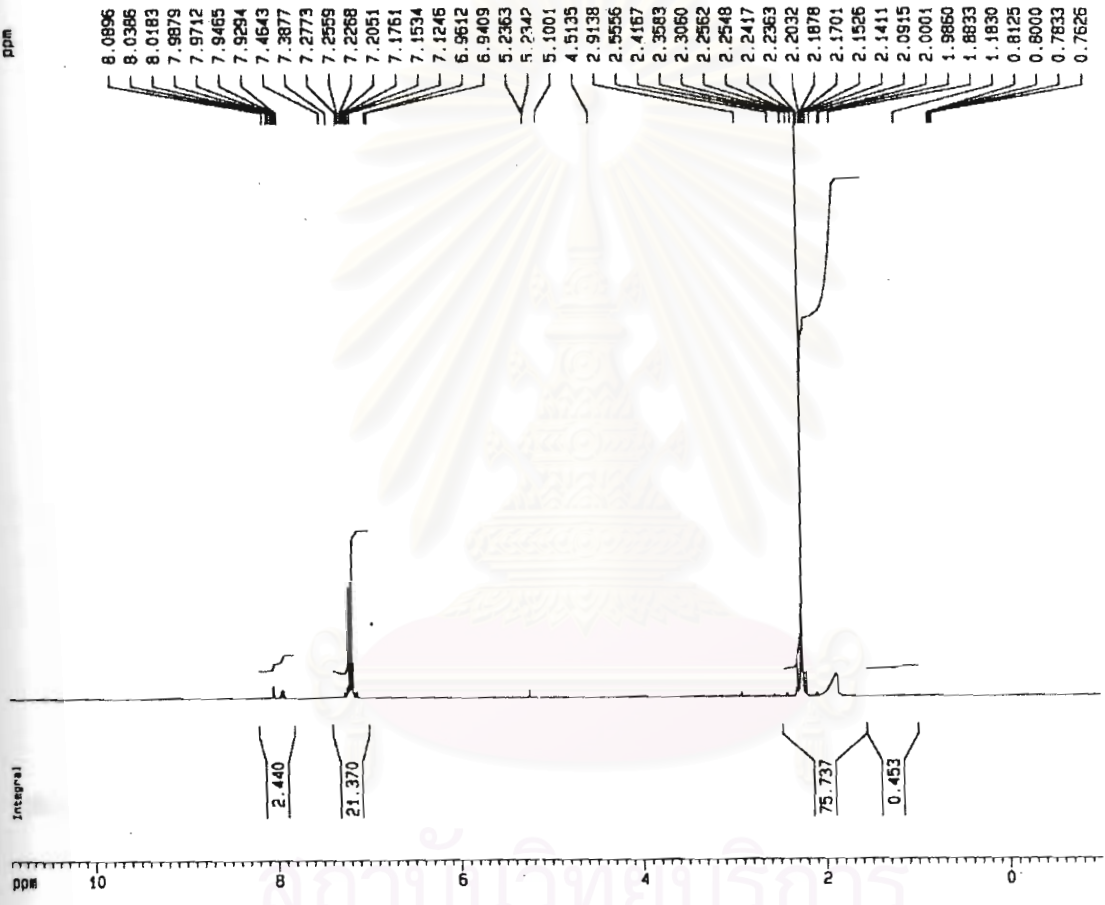


Figure 76: The ^{1}H-NMR spectrum of 4-chloro-2-methylpyridine *N*-oxide-2,6-d_2

The ^{13}C-NMR spectrum (Figure 77) reveals a singlet at δ 16.8 due to the carbon of the methyl group while the signals due to the C3, C4 and C5 ring carbons appear as singlets at δ 132.3, 144.4 and 124.1, respectively. The signals due to the C2 and C6 ring carbons appear downfield as triplets at δ 148.2 (J = 28.1 Hz) and 151.4 (J = 28.5 Hz) due to their coupling with the attached deuterium atoms.

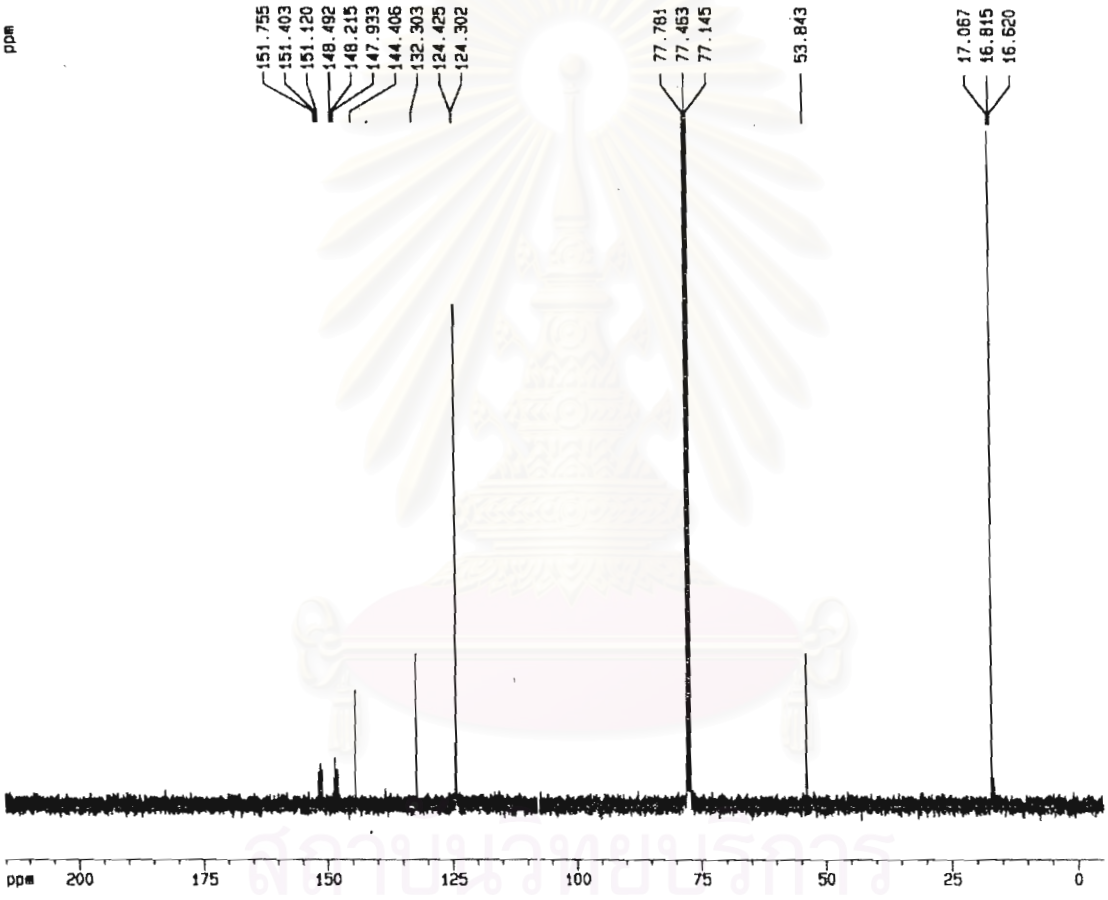
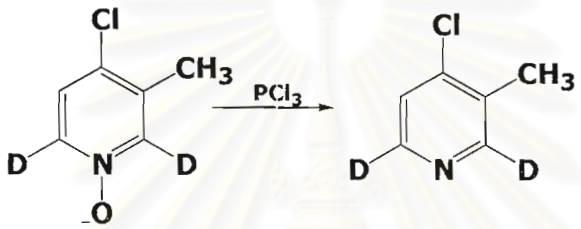


Figure 77: The ^{13}C-NMR spectrum of 4-chloro-3-methylpyridine *N*-oxide-2,6-d_2

3.5.1.4 Synthesis of 4-chloro-2,6-dideuterio-3-methylpyridine

Pyridine *N*-oxide can be reduced to pyridine by reaction with phosphorous trichloride. Using this procedure described by Ochiai(7), 2,6-dideuterio-4-chloro-3-methylpyridine *N*-oxide was treated with phosphorous trichloride in refluxing dichloromethane to give 4-chloro-2,6-dideuterio-3-methylpyridine as a yellow liquid.



Scheme 25: Synthesis of 4-chloro-2,6-dideuterio-3-methylpyridine

GC analysis of this product (Figure 78a) showed only one peak which eluted at a retention of 8.4 minutes. The mass spectrum (Figure 79b) exhibits a molecular ion at m/z 129 consistent with molecular weight of 4-chloro-3-methylpyridine-2,6-d_2. The mass spectrum also exhibits a base peak at m/z 94 which indicates that 4-chloro-3-methylpyridine undergoes elimination of a chlorine atom.

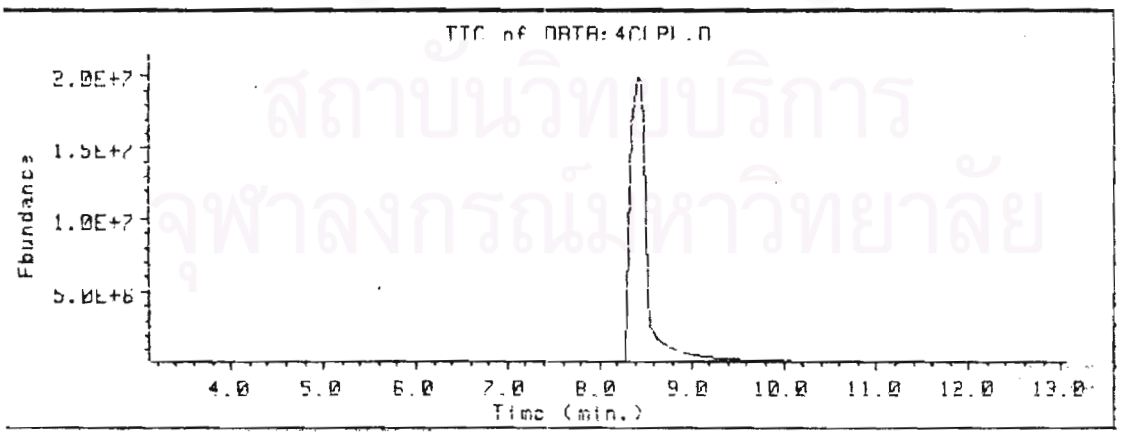


Figure 78a: GC trace of 4-chloro-3-methylpyridine-2,6-d_2

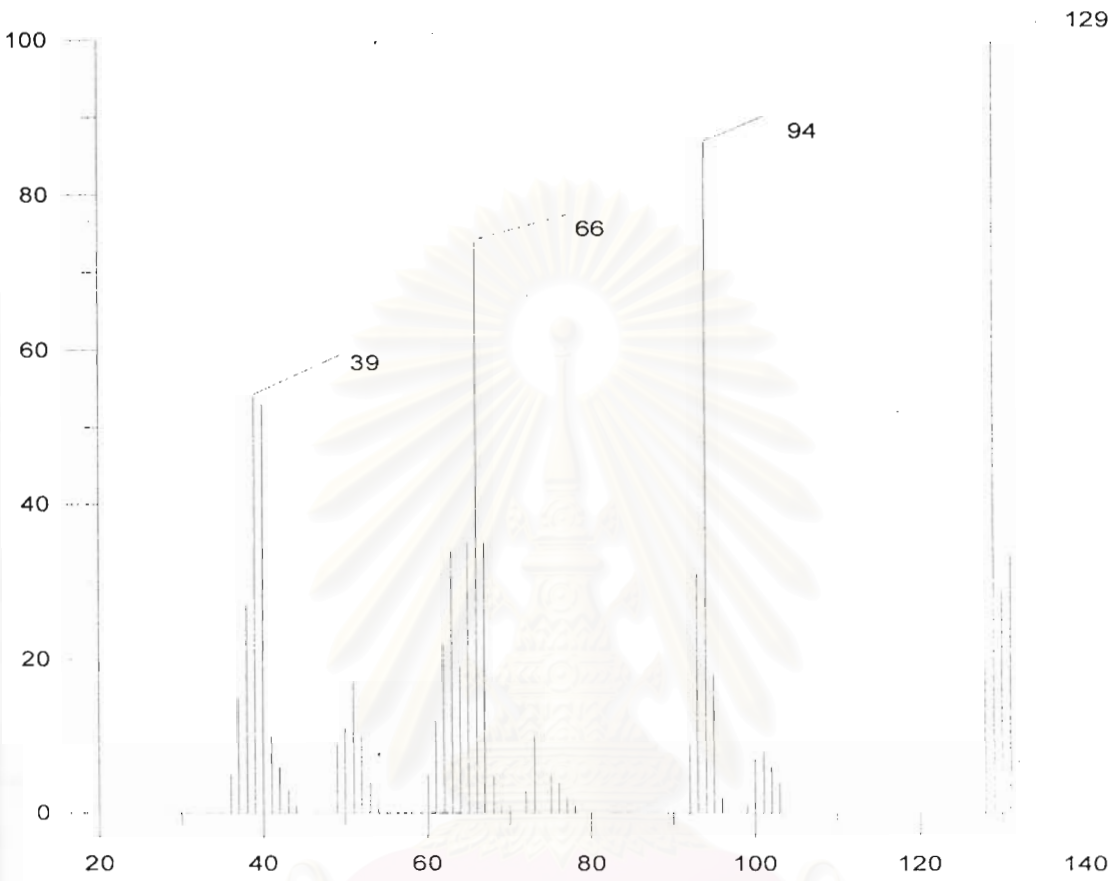


Figure 78b: The mass spectrum of 4-chloro-2,6-dideuterio-3-methylpyridine

The ^{1}H-NMR spectrum of this liquid (Figure 79) shows a singlet at δ 2.5 due to the methyl protons. The singlet at δ 7.2 is due to the proton at position 5. In addition, the spectrum also exhibits a doublet of low intensity at δ 8.3 and a singlet at δ 8.4 which are due to residual protons at positions 2 and 6.

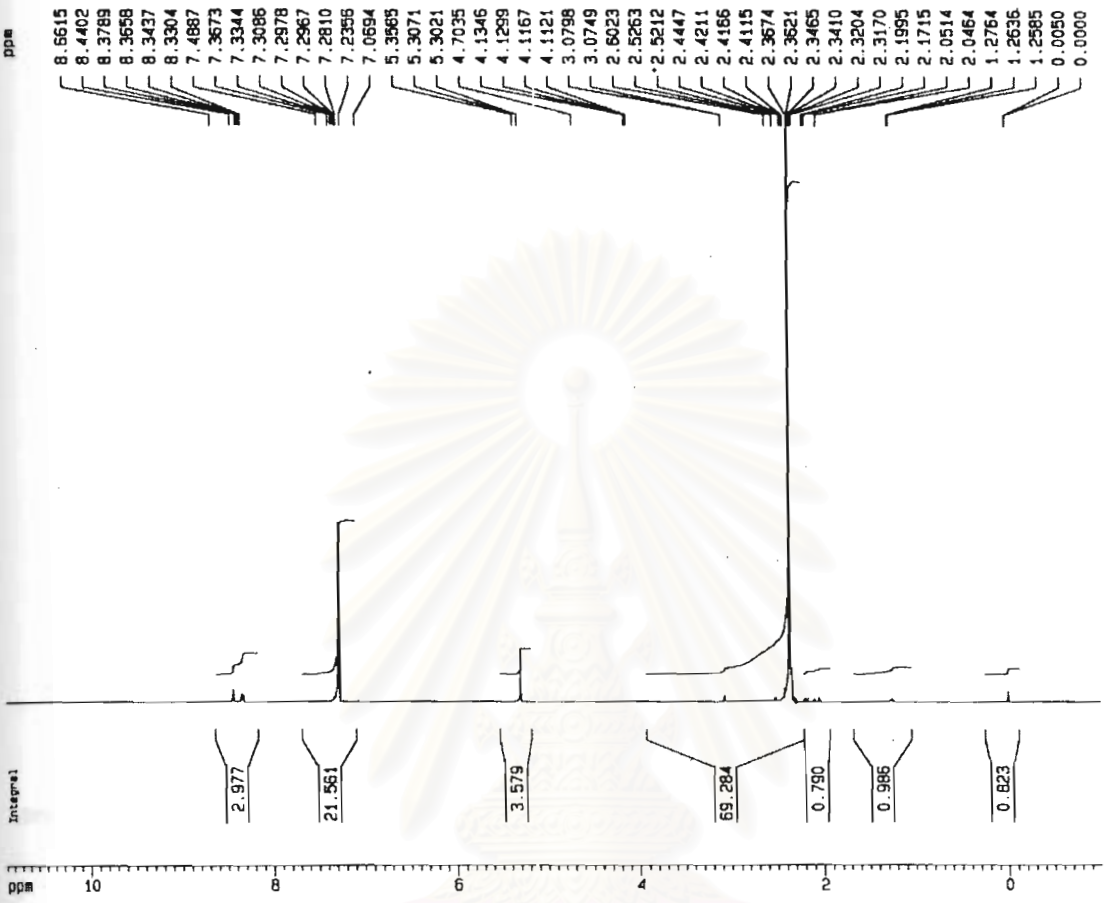


Figure 79: The ^{1}H-NMR spectrum of 4-chloro-2,6-dideuterio-3-methylpyridine

The ^{13}C-NMR spectrum of this liquid (Figure 80) also show signals consistent with the structure of 4-chloro-2,6-dideuterio-3-methylpyridine. The signal at δ 16.8 was assigned to the carbon of the methyl group. The three signals at δ 124.3, δ 132.3 and δ 144.4 were assigned to the carbons at ring positions 5, 3 and 4 respectively. The spectrum also shows two triplets at δ 148.2 (J = 27.1 Hz) and 151.4 (J = 26.6 Hz) as due to the C2 and C6 carbons coupling with the attached deuterium atoms.

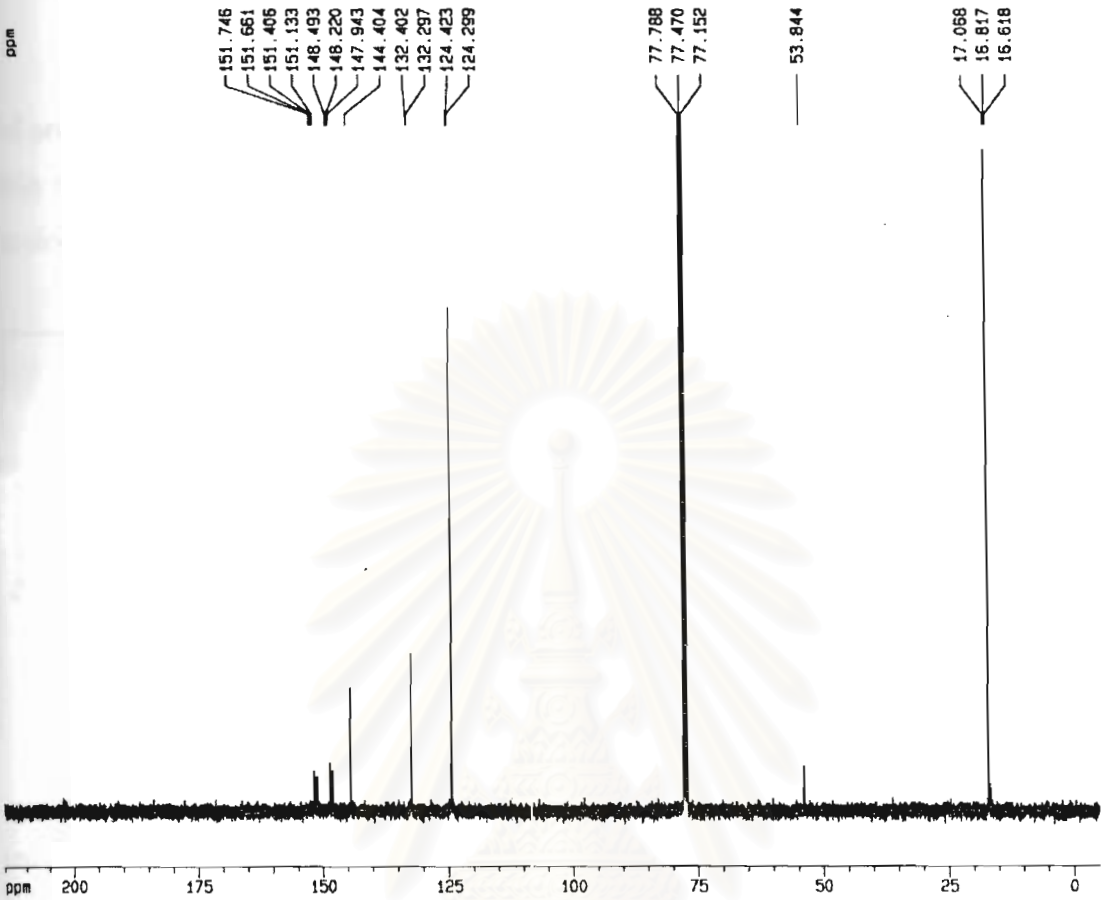
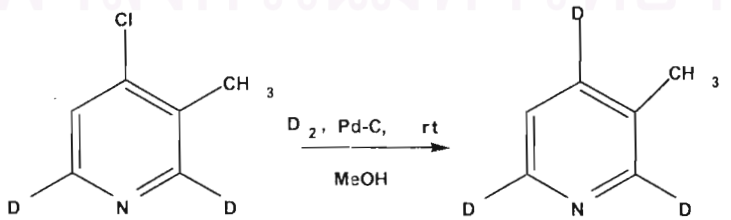


Figure 80: The ^{13}C-NMR spectrum of 4-chloro-3-methylpyridine-2,6-d_2

3.5.1.5 Synthesis of 2,4,6-trideuterio-3-methylpyridine

Dehalohydrogenolysis of 4-chloro-2,6-dideuterio-3-methylpyridine to 2,4,6-trideuterio-3-methylpyridine should be possible by treating the reactant with D_2 in the presence of a Pd on C catalyst as shown in Scheme 26.



Scheme 26 : The synthesis of 2,4,6-dideuterio-3-methylpyridine

GC analysis of the product from this reaction (Figure 81a) shows the presence of only one peak which eluted at a retention of 12.5 minutes. The mass spectrum of this material (Figure 81b) exhibited a molecular ion at m/z 96 consistent with the molecular weight of 2,4,6-trideuterio-3-methylpyridine.

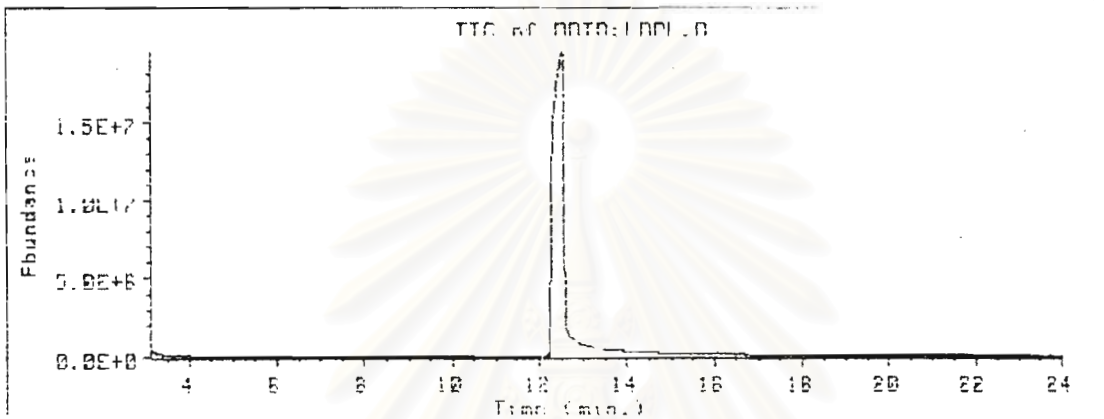


Figure 81a: GC trace of 2,4,6-trideuterio-2-methylpyridine before irradiation

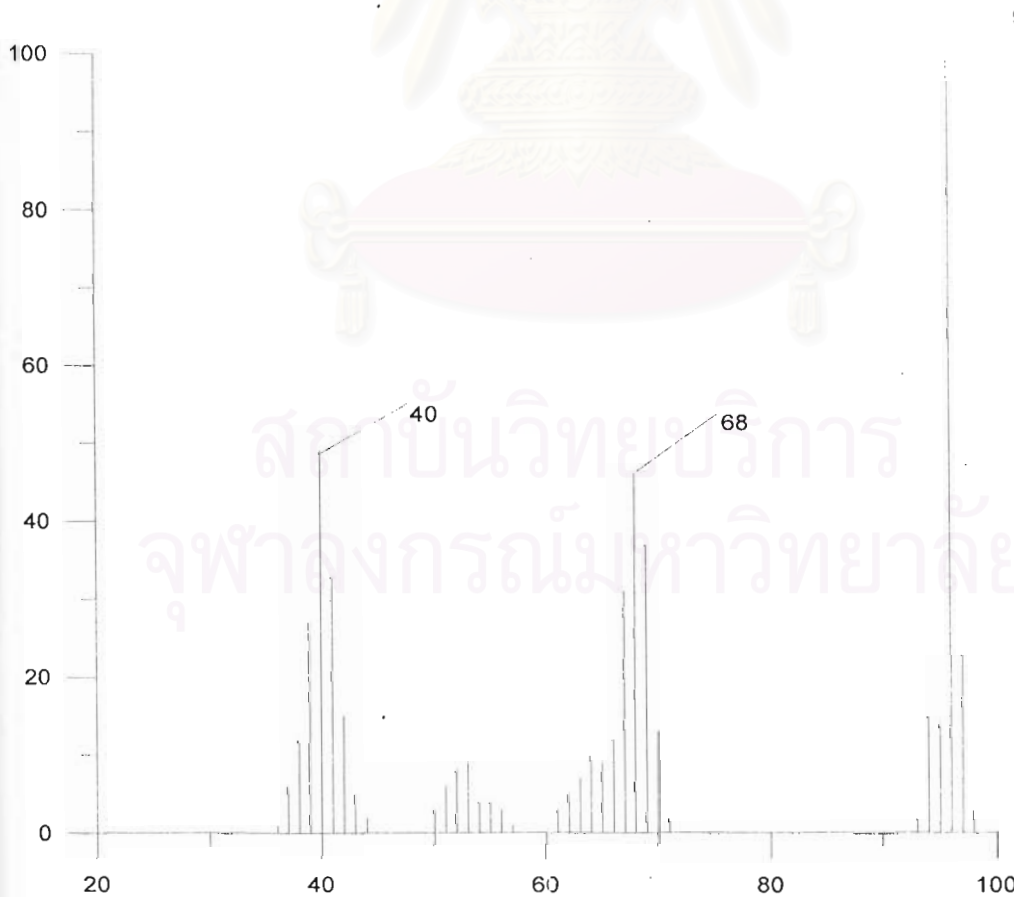


Figure 81b: The mass spectrum of 2,4,6-trideuterio-3-methylpyridine

The ^{1}H-NMR spectrum (Figure 82) shows a singlet at δ 2.4 due to the methyl proton. The singlet at δ 7.1 is due to proton at ring positions 5. In addition, the spectrum also exhibits two doublets and one singlet of low intensity at δ 7.4, 8.35 and 8.39, which are due to residual protons at ring positions 4, 6, and 2 respectively.

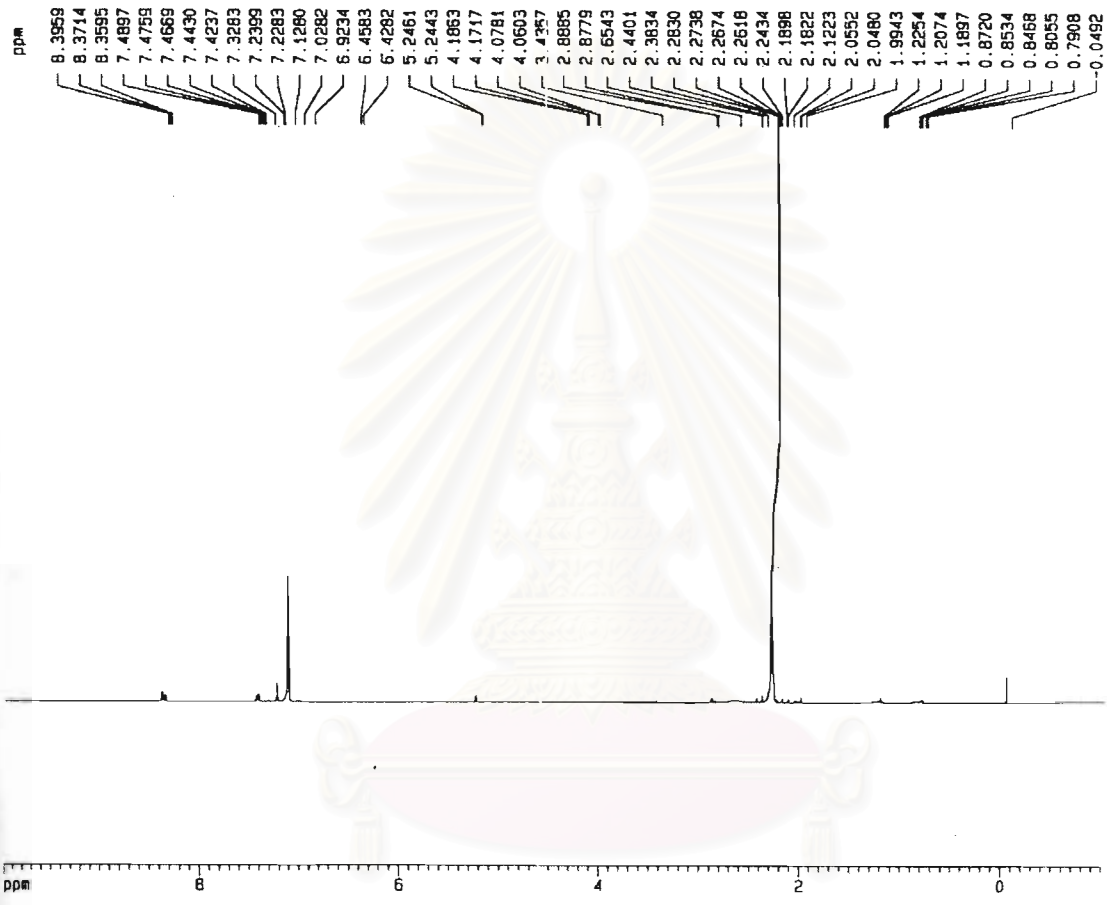


Figure 82: *The ^{1}H-NMR of 2,4,6-trideuterio-3-methylpyridine*

The ^{13}C-NMR spectrum (Figure 83) exhibits a signal for a quaternary carbon at δ 136.7 and was therefore assigned to the C3 carbon of the pyridine ring. The spectrum also exhibits triplets at δ136.7 (J = 24.3 Hz), 146.9 (J = 27.3 Hz) and at δ 150.3 (J = 26.7 Hz) which can be assigned to C4, C6, and C2 of the pyridine ring. Since these signals appear as triplets, this confirms that these carbon atoms are bonded to deuterium. The singlet at δ 123.5 can be assigned to C5.

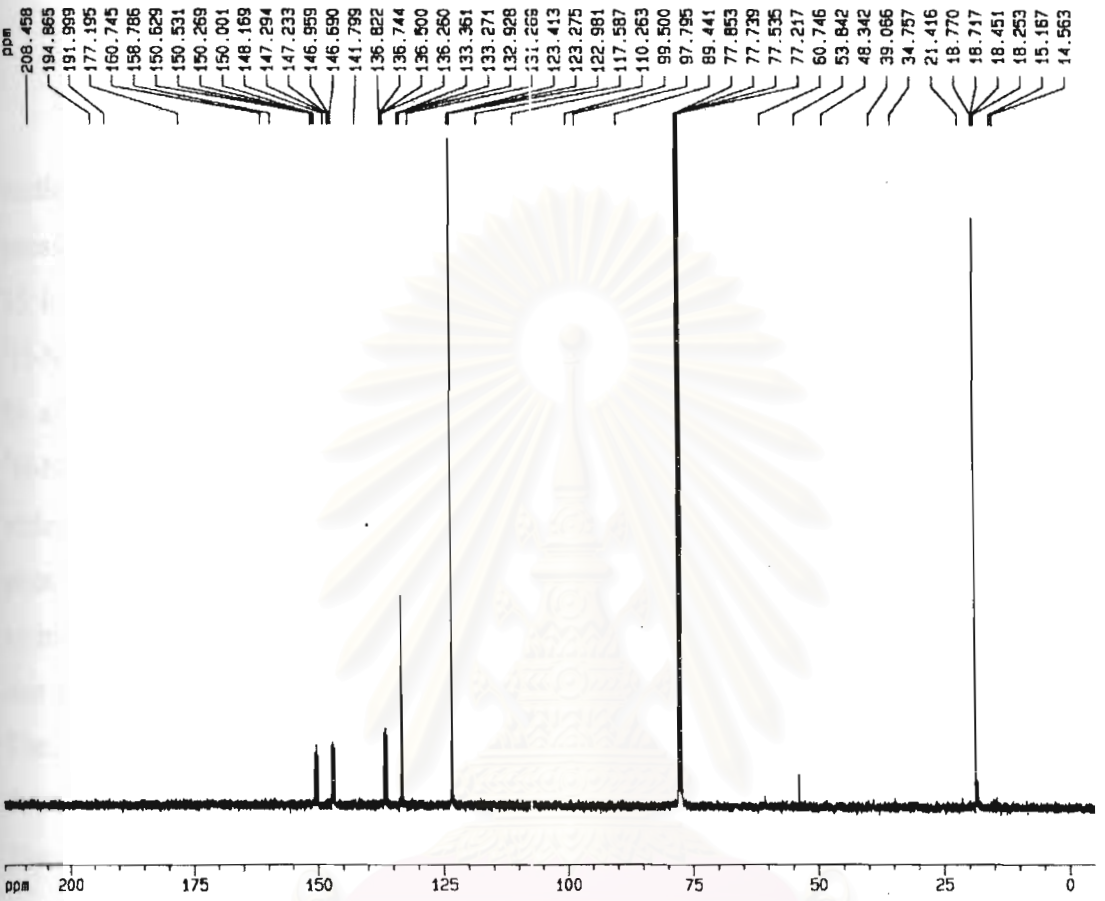
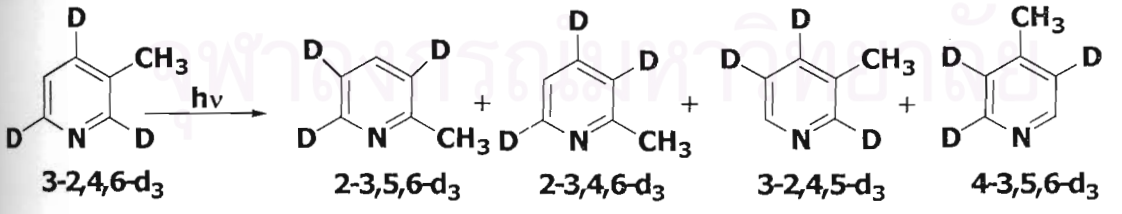


Figure 83: The ^{13}C-NMR spectrum of 2,4,6-trideuterio-3-methylpyridine

3.5.2 Vapor phase photochemistry of 2,4,6-trideuterio-3-methylpyridine

In the initial photochemical experiment, a sample of 2,4,6-trideuterio-3-methylpyridine was allowed to vaporize into the 3L quartz flask at 25°C to a final pressure of 4.0 Torr. This was then irradiated in the Rayonet reactor at 254 nm using 15 low pressure mercury arc lamps for 24 hours. Figure 84 shows a portion of the ^{1}H-NMR spectrum from 6-10 ppm in $CDCl_3$ of the reactant a) before irradiation and b) after irradiation of the sample at 254 nm for 24 hours. After irradiation, the ^{1}H-NMR spectrum shows signals at δ 7.1 due to the H5 protons of unreacted 2,4,6-trideuterio-3-methylpyridine and four new singlets due to the formation of photoproducts. Since each methylpyridine photoproduct will bear three deuterium atoms and one proton bonded to ring positions, the formation of four singlets means that four different methylpyridine-d_3 isomers have been formed in this photoreaction. These new singlets can be assigned by comparison with the known chemical shift for the ring protons in 2-, 3-, and 4-methylpyridine as discussed in section **2** of this thesis. Thus, as shown on figure b, the singlet at δ 7.58 can be assigned to H4 of 2-methyl-pyridine-3,5,6-d_3; the singlet at δ 7.10 can be assigned to H5 of 2-methylpyridine-3,4,6-d_3; the singlet at δ 8.43 can be assigned to H6 of 3-methylpyridine-2,4,5-d_3; and the singlet at δ 8.46 can be assigned to H6 of 4-methylpyridine-2,3,5-d_3. The overall phototransposition reaction is thus shown in the equation below.



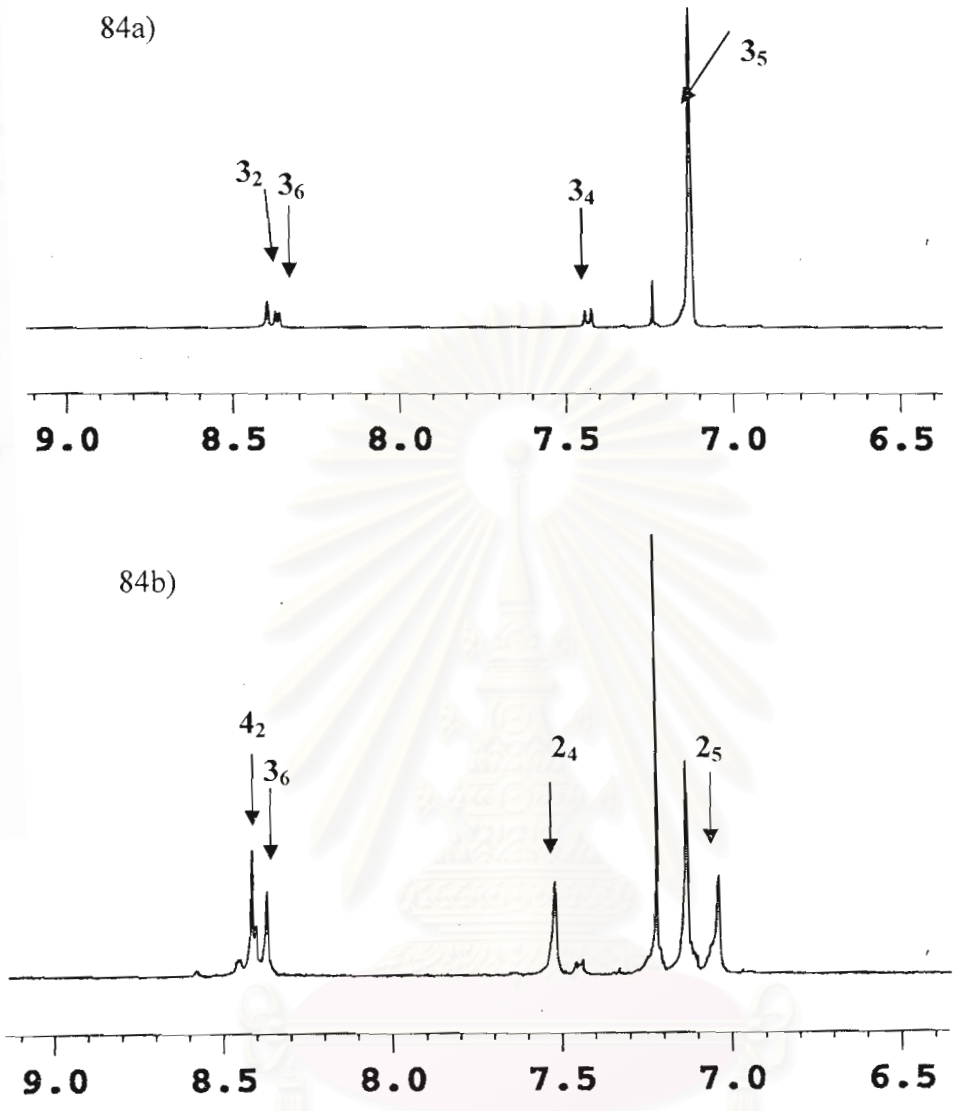


Figure 84: (a) ^{1}H-NMR spectrum of 2,4,6-trideuterio-3-methylpyridine before irradiation
(b) ^{1}H-NMR spectrum of 2,4,6-trideuterio-3-methylpyridine after irradiation for 24 hours in $CDCl_3$

Gas chromatographic analysis of the product mixture (Figure 85a) showed one peak at 9.0 minutes retention time due to a mixture of 2-methylpyridine-3,5,6-d_3, 2-methylpyridine-3,4,6-d_3 and 2-methylpyridine-4,5-d_2 and a second much lager peak at 12.3 minutes due to unreacted 3-methylpyridine-2,4,6-d_3 and photoproducts 3-methylpyridine-2,4,5-d_3 and 4-methylpyridine-3,5,6-d_3. The mass spectrum exhibits peaks at m/z 96 as shown in Figure 85b and 85c.

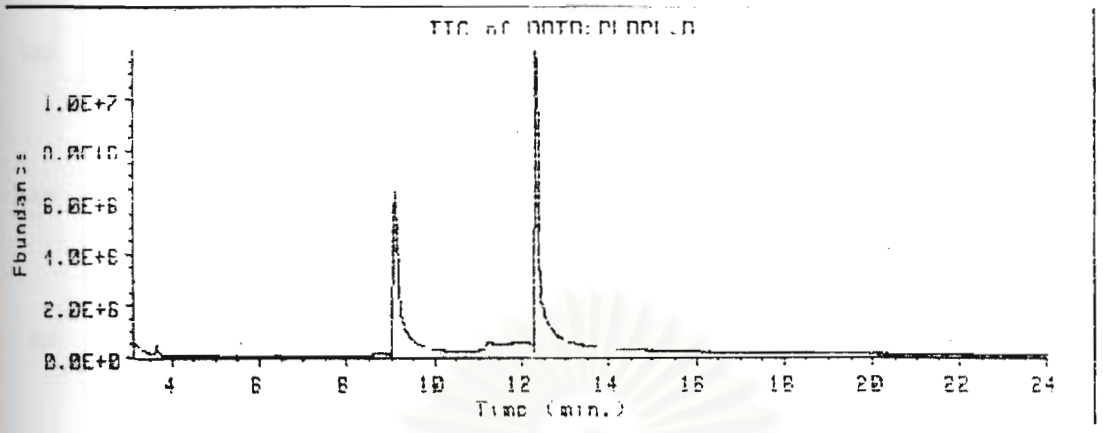


Figure 85a: The GC-MS analysis of 2,4,6-trideuterio-3-methylpyridine after irradiation for 24 hour

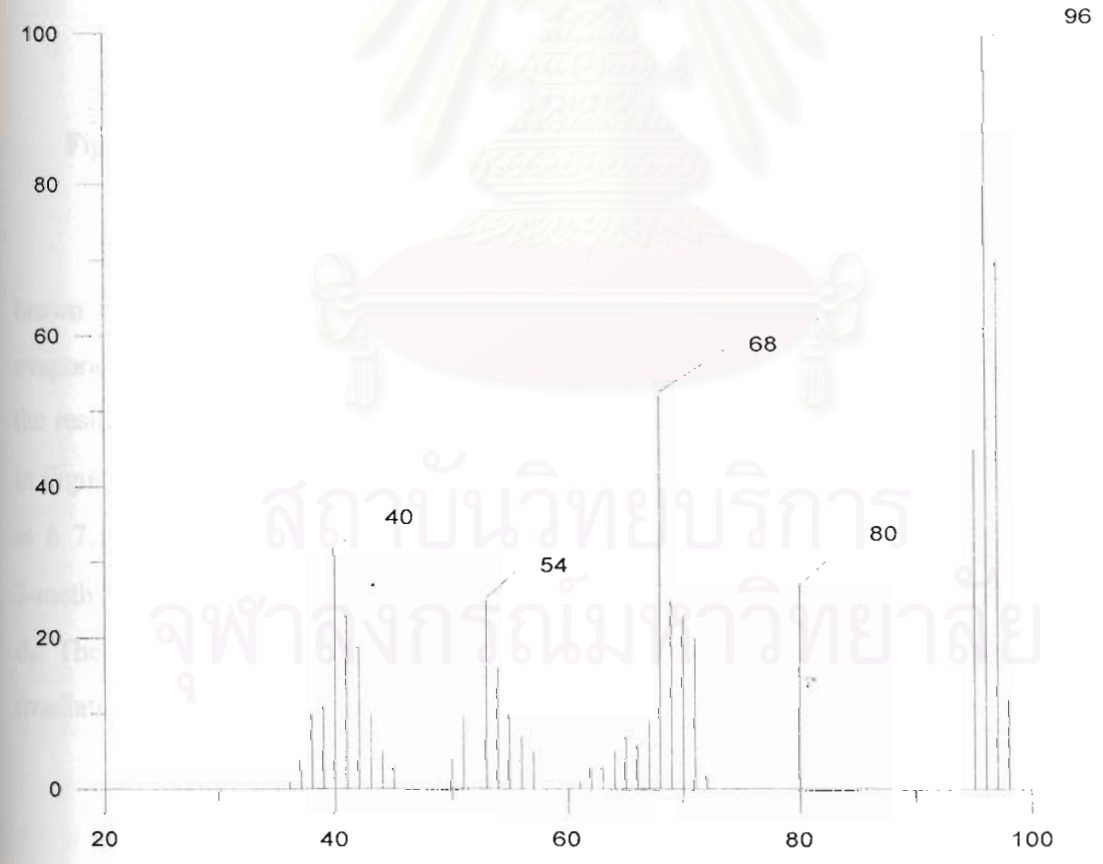


Figure 85b: The mass spectrum at 9.0 minutes after irradiation for 24 hours

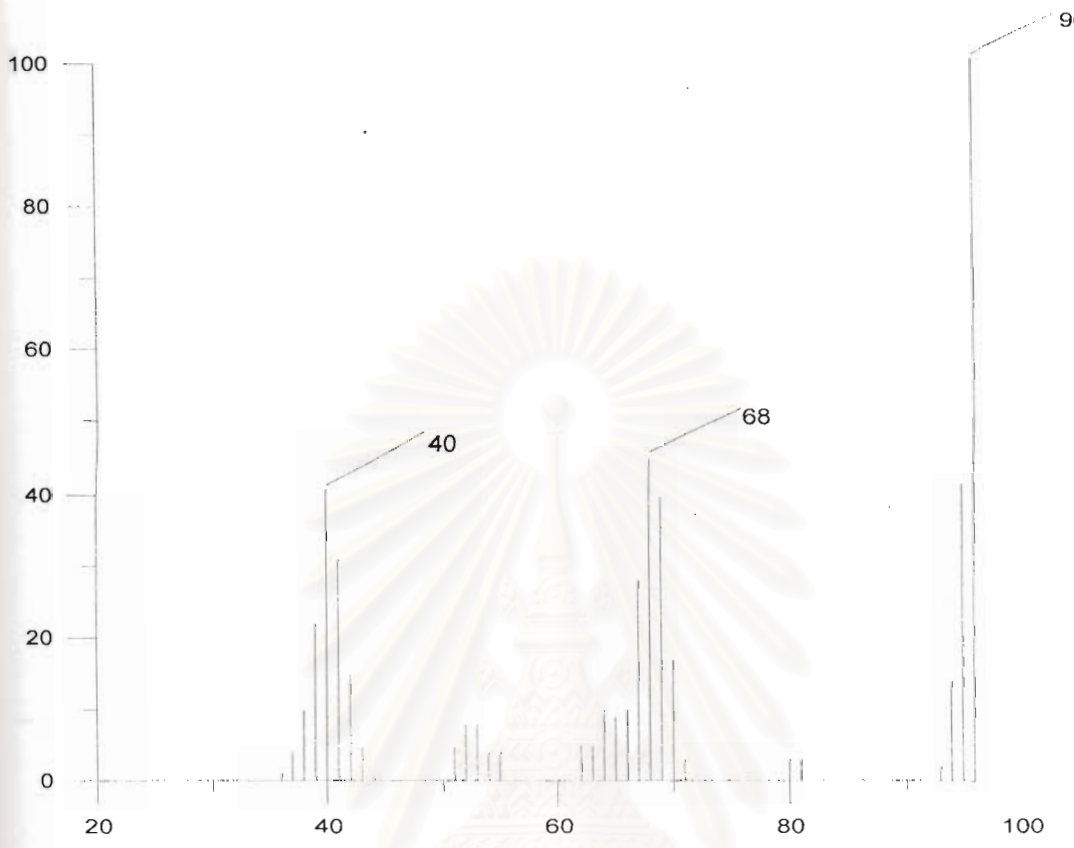


Figure 85c: The mass spectrum at 12.3 minutes after irradiation for 24 hours

After irradiation, the walls of the reaction flask were again coated with a brown film. This material was washed with acetone and the acetone extract was evaporated to dryness. The residue was recovered to give (0.012 g) yield then the residue analyzed by ^{1}H-NMR in $CDCl_3$. The ^{1}H-NMR spectrum which is shown in Figure 86 exhibits signal at δ 7.58 (s, H_4) due to 2-methylpyridine-3,5,6-d_2; signal at δ 7.1 (s, H_5) due to 2-methylpyridine-3,4,6-d_3; signal at δ 8.43 (s, H_6) due to 3-methylpyridine-2,4,5-d_3; and signal at δ 8.46 (s, H_2) due to 4-methylpyridine-3,5,6-d_3. These are the same products that were observed in the condensed vapor after irradiation

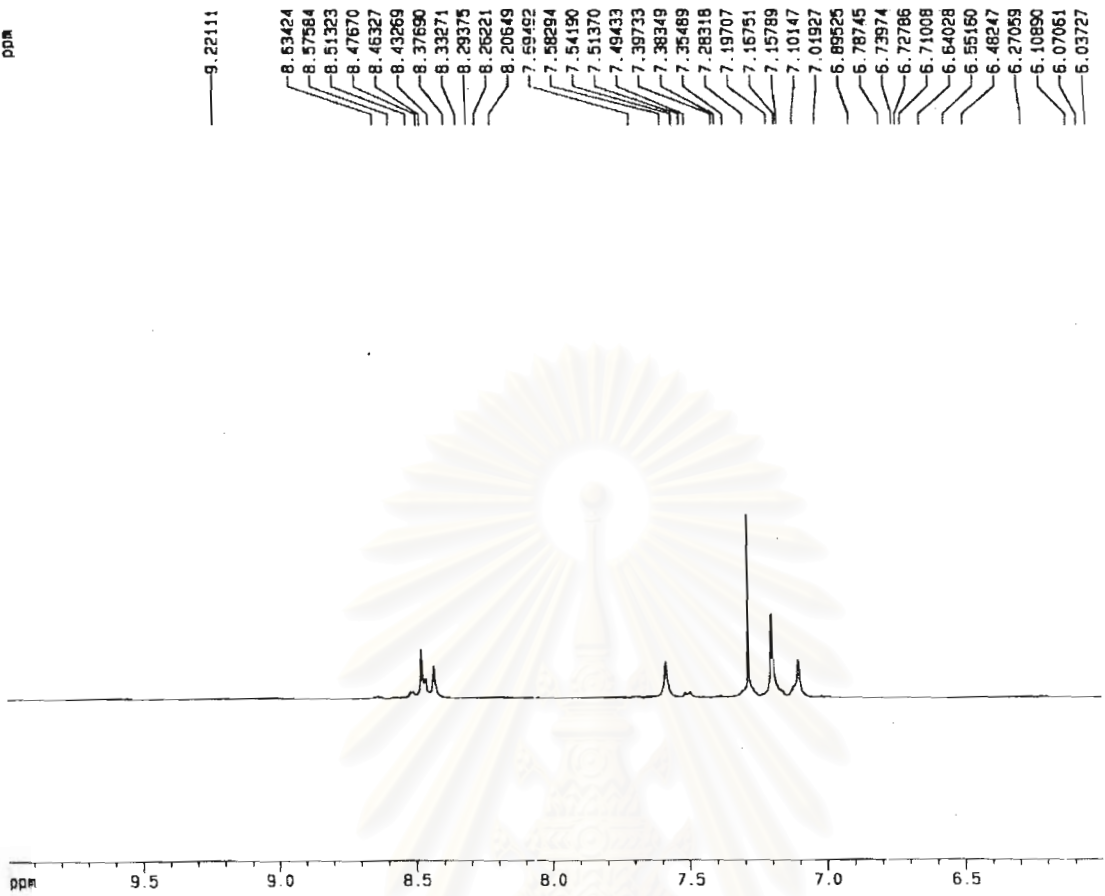
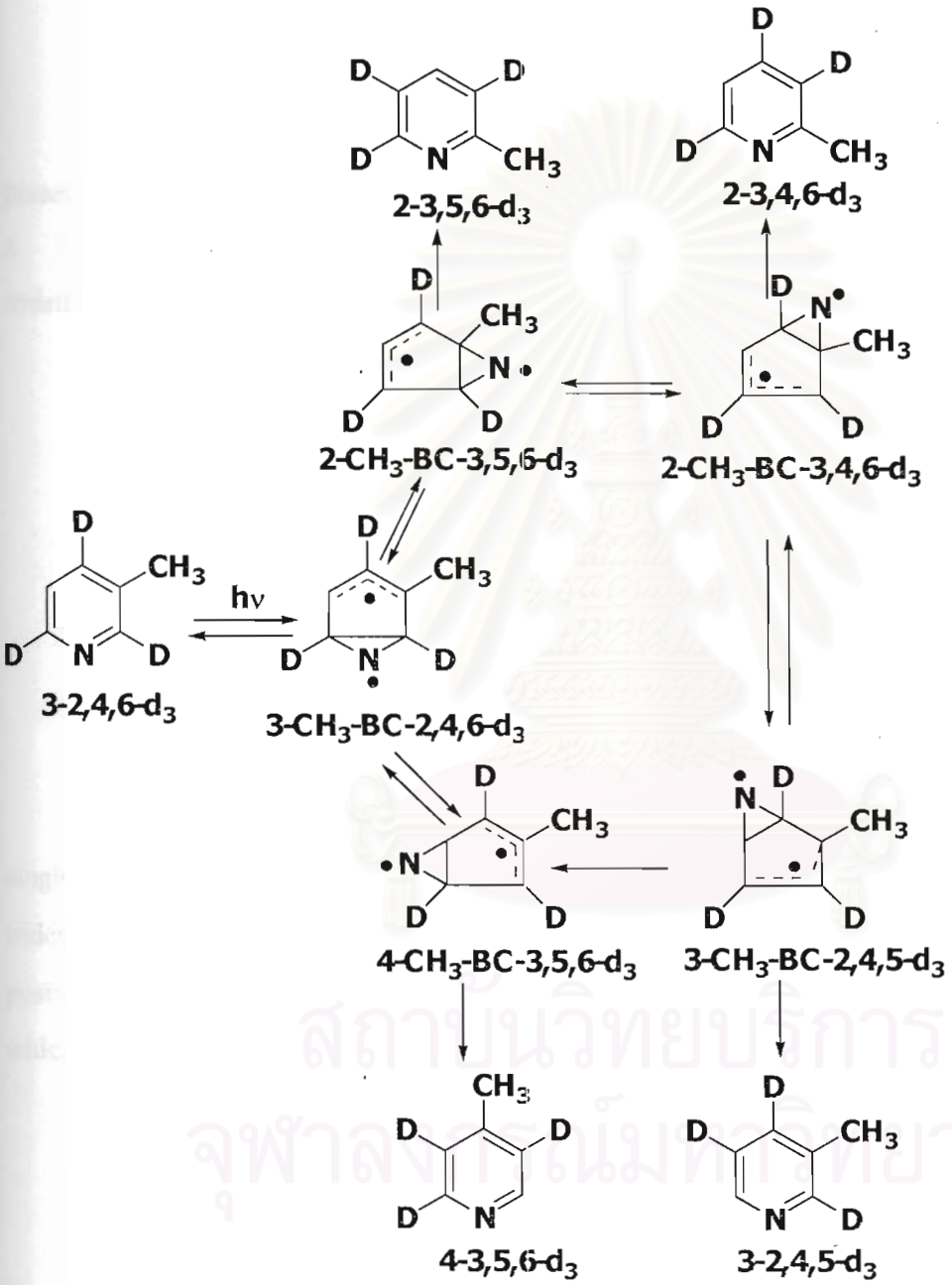


Figure 86: The ^{1}H-NMR of brown film

These products formed by irradiation of 3-methylpyridine-2,4,6-d_3 are those predicted by the electrocyclic ring closure – heteroatom migration mechanism previously suggested for these reactions. As shown in Scheme 27, detection of all four products shows that nitrogen migration occurs around all five sides of the cyclopentenyl ring. As shown in Scheme 27, irradiation of **3-2,4,6-d_3** results in electrocyclic ring closure and the formation of the preazafulvene species, **3-CH_3-BC-2,4,6-d_3.** From this species, nitrogen migration can occur in either clockwise or counterclockwise direction. Clockwise migration converts **3-CH_3-BC-2,4,6-d_3** to **2-CH_3-BC-3,5,6-d_3.** This species can either rearomatize to form one of the observed products **2-3,5,6-d_3** or it can undergo a second nitrogen migration to form **2-CH_3-BC-3,4,6-d_3.** Rearomatization at this point leads to a second observed product **2-3,4,6-d_3.** Alternatively, **2-CH_3-BC-3,4,6-d_3** could undergo another nitrogen migration to yield **3-CH_3-BC-2,4,5-d_3** which could

rearomatize to the observed product, **3-2,4,5-d_3** or isomerize to **4-CH_3-BC-3,5,6-d_3**, the precursor of the final product, **4-3,5,6-d_3**. All of these nitrogen migrations can also occur in the opposite direction as shown in Scheme 27.



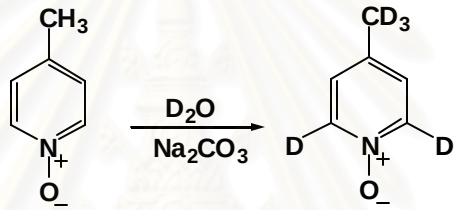
Scheme 27: Proposed mechanism for the formation of phototransposition products **3-2,4,6-d_3**

3.6 Photochemistry of 2,6-dideuterio-4-trideuteriomethylpyridine

3.6.1 Synthesis of 2,6-dideuterio-4-trideuterio methylpyridine

3.6.1.1 Synthesis of 2,6-dideuterio-4-trideuteriomethylpyridine *N*-oxide

4-Methylpyridine *N*-oxide was allowed to react with deuterium oxide in the presence of sodium carbonate in order to exchange the protons at ring positions 2 and 6 for deuterium. Scheme 28 shows synthesis of 2,6-dideuterio-4-trideuteriomethylpyridine.



Scheme 28: Synthesis of 2,6-dideuterio-4-trideuteriomethylpyridine *N*-oxide

The ^{1}H-NMR spectrum of this compound, as shown in Figure 87, exhibits a singlet of very low intensity at δ 2.1 due to the residual protons of the trideuteriomethyl group. The singlet at δ 7.28 is due to the equivalent protons at ring positions 3 and 5. The spectrum also exhibits a doublet of low intensity at δ 8.0, which is due to residual equivalent protons at ring positions 2 and 6.

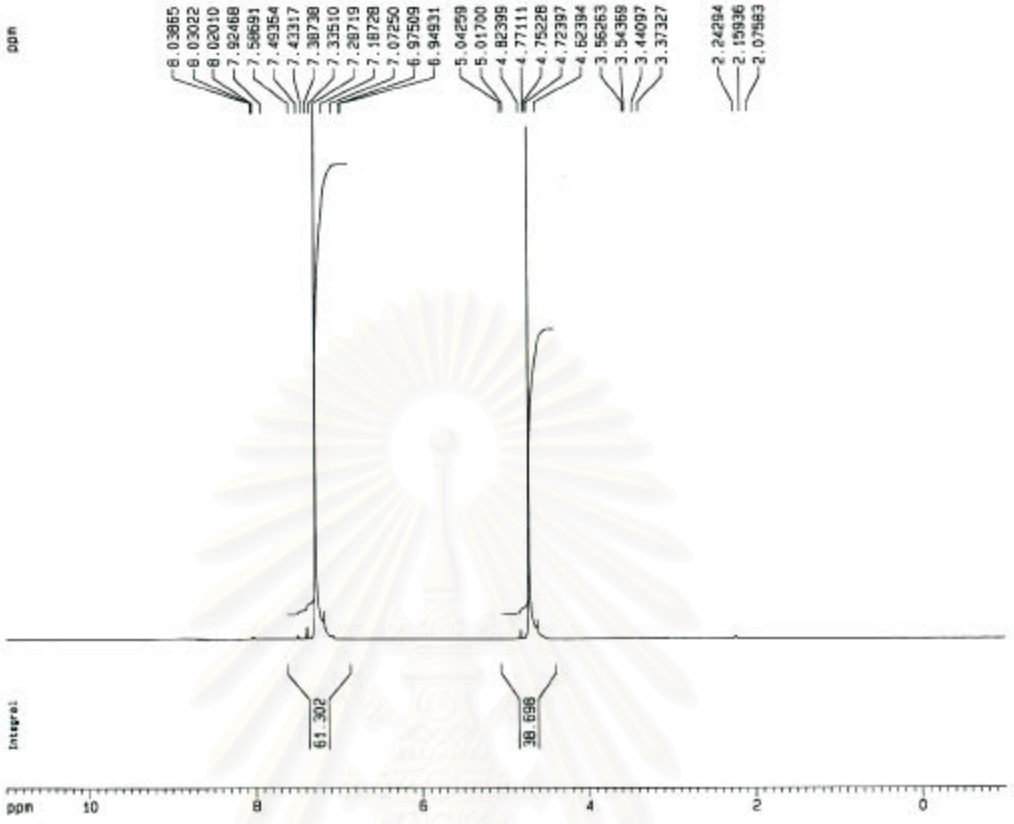


Figure 87: The ^{1}H-NMR spectrum of 2,6-dideuterio-4-trideuteriomethylpyridine *N*-oxide

The ^{13}C-NMR spectrum in deuterium oxide, shown in Figure 88, exhibits a signal for the trideuterio methyl carbon at δ 19.8 as a multiple due to coupling with deuterium atoms. The singlet at δ 128.4 can be assigned the equivalent carbon at positions 3 and 5. The quaternary carbon at δ 146.2 was assigned to C4 carbon of the pyridine ring. The triplet (J = 28.4 Hz) at δ 138.5 is due to carbon at positions 2 and 6 which are coupling with deuterium atoms.

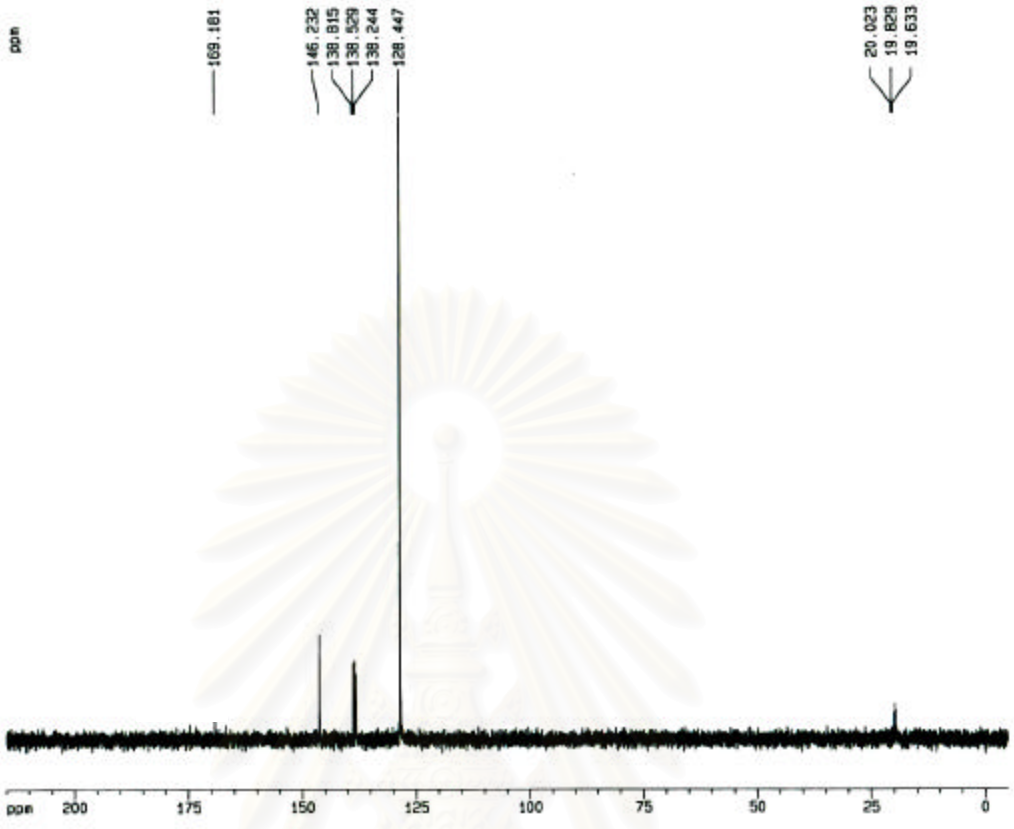


Figure 88: The ^{13}C-NMR spectrum of 2,6-dideuterio-4-trideuteriomethylpyridine *N*-oxide

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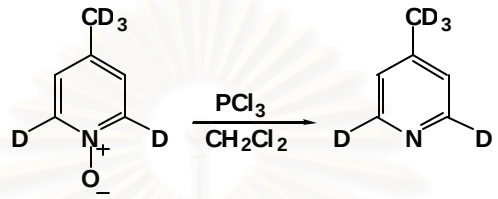
3.6.1.2 Synthesis of 2,6-dideuterio-4-trideuteriomethylpyridine

The reduction of 4-trideuteriomethylpyridine *N*-oxide-2,6-d_2 using phosphorus trichlororide gave 4-trideuteriomethylpyridine-2,6-d_2. Scheme 29 shows the synthesis of 4-methylpyridine-2,6-d.



Scheme 29: Synthesis of 2,6-dideuterio-4-trideuteriomethylpyridine

The colorless liquid product was identified by GC-MS, ^{1}H- and ^{13}C-NMR spectroscopy. The GC analysis of the sample, shown in Figure 89a, shows only one of compound. The mass spectrum of this compound, (Figure 89b), exhibits a molecular ion at m/z 98 correspond to the molecular weight of 4-trideuteriomethylpyridine-2,6d_2.

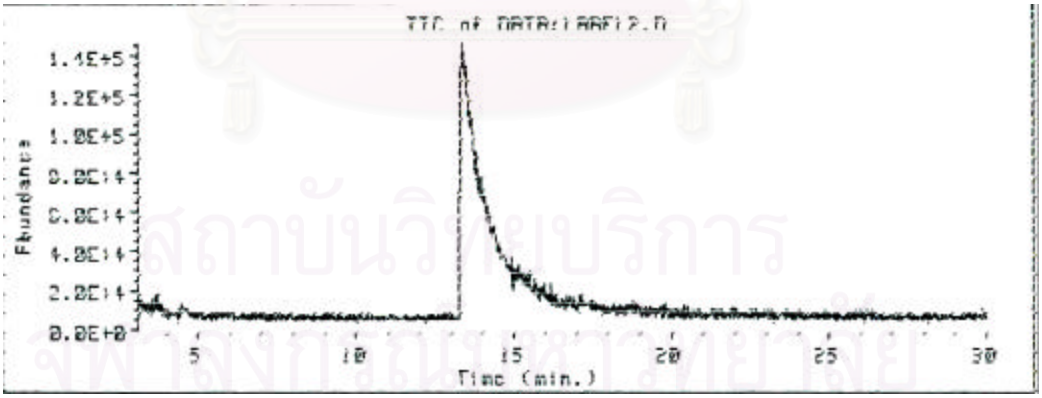


Figure 89a: GC trace of the synthesis of 2,6-dideuterio-4-trideuteriomethylpyridine

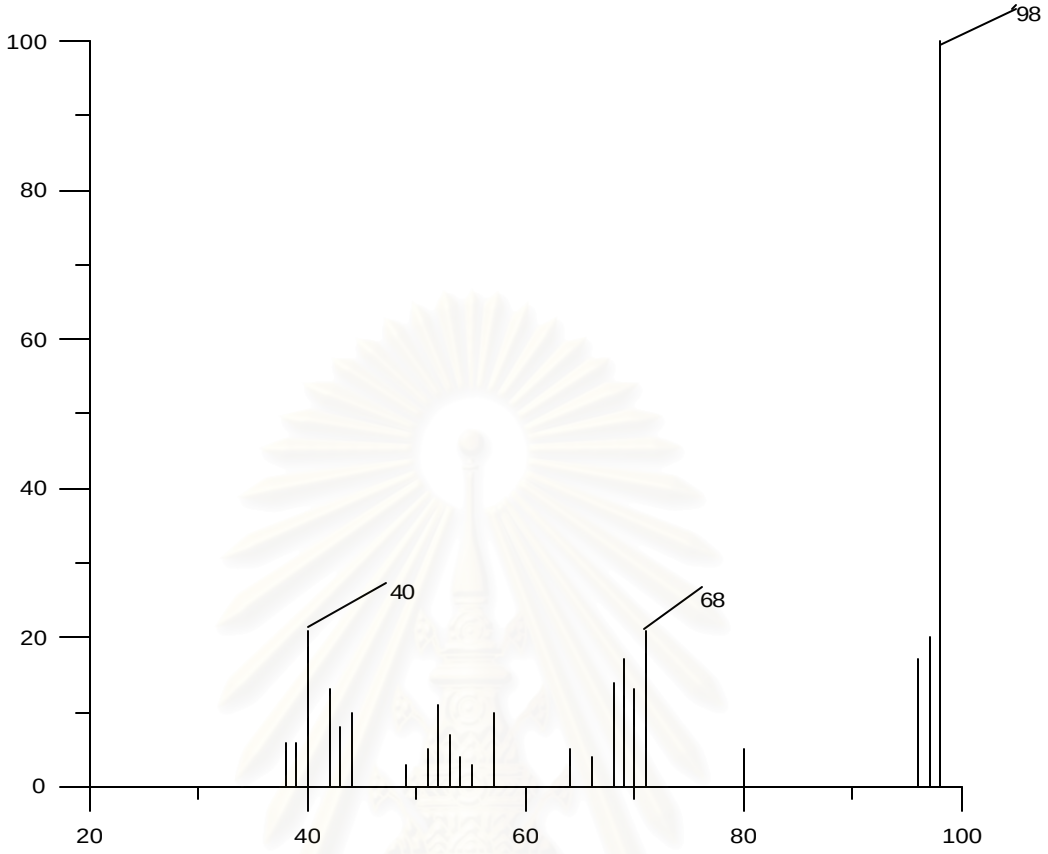


Figure 89 b: The mass spectrum of the peak at 13 min

The ^{1}H-NMR spectrum of this compound, as shown in Figure 90, exhibits a singlet of low intensity at δ 2.2 due to the residual protons of the trideuteriomethyl group. The singlet at δ 7.06 is due to the equivalent protons at ring positions 3 and 5. The spectrum also exhibits a doublet of low intensity at δ 8.4, which is due to residual equivalent protons at ring positions 2 and 6.

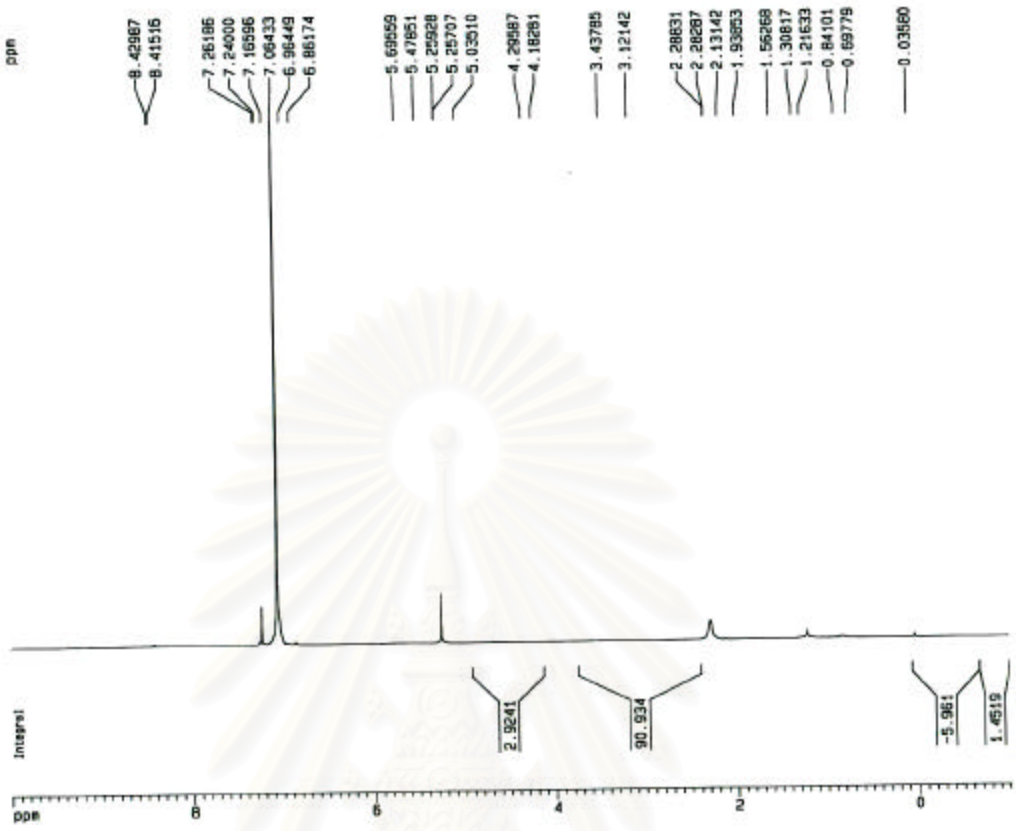


Figure 90: The ^{1}H-NMR spectrum of 2,6-dideuterio-4-trideuteriomethylpyridine

The ^{13}C-NMR spectrum in $CDCL_3$, shown in Figure 91, exhibits a signal due to the trideuterio methyl carbon at δ 20.5 as a multiplet due to coupling with deuterium atoms. The singlet at δ 124.9 can be assigned the equivalent carbons at positions 3 and 5. The quaternary carbon at 147.3 was assigned to the C4 carbon of the pyridine ring. The triplet (J = 28.4 Hz) at δ 149.5 is due to the carbons at positions 2 and 6 which are each coupling with a deuterium atom.

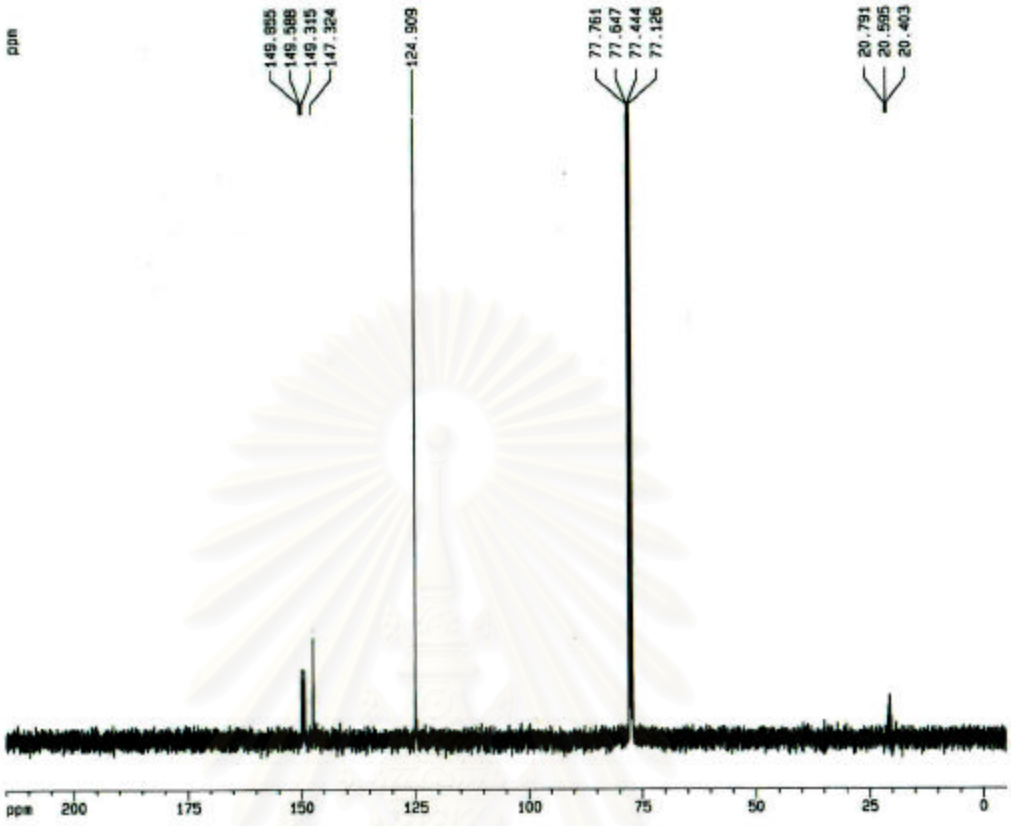
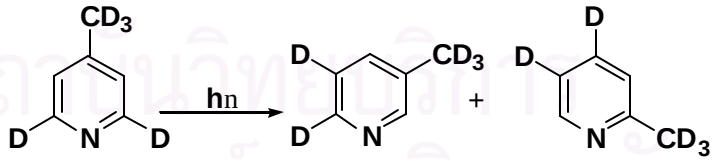


Figure 91: The ^{13}C-NMR spectrum of 2,6-dideuterio-4-trideuterio methylpyridine

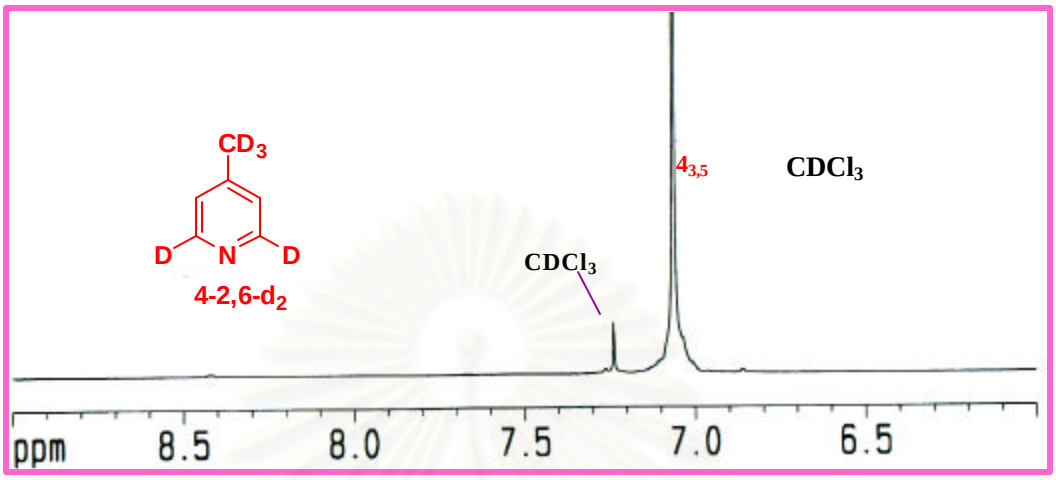
3.6.2 Vapor phase photochemistry of 2,6-dideuterio-4-trideuteriomethylpyridine

In the photochemical experiment, a sample of 2,6-dideuterio-4-trideuteriomethylpyridine was vaporized into the 3L quartz flask at 25°C to a final pressure of 4.0 Torr. This was then irradiated in the Rayonet reactor at 254 nm using 15 low pressure mercury arc lamps for 24 hours. Figure 92 shows a portion of the ^{1}H-NMR spectrum from 6-10 ppm in $CDCl_3$ a) before irradiation and b) after irradiation of the sample at 254 for 24 hours. After irradiation, the ^{1}H-NMR spectrum shows a signal at δ 7.04 due to the equivalent protons H3 and H5 of unreacted 2,6-dideuterio-4-trideuteriomethylpyridine and four new singlets due to the formation of photoproducts. Since each trideuteriomethylpyridine photoproduct will bear two deuterium atoms and two protons bonded to ring positions, the formation of four singlets means that two different trideuteriomethylpyridine isomers have been formed in this photoreaction. These new signals can be assigned by comparison with the known chemical shifts for the ring protons in 2-,3-, and 4-methylpyridine as discussed in section **2** of this thesis. Thus, as shown on figure 33b, the two singlets at δ 7.09 and 8.41 can be assigned to H3 and H6 of 2-trideuteriomethylpyridine-4,5-d_2; the two singlets at δ 8.39 and 7.4 can be assigned to H2 and H4 of 3-trideuterio-methylpyridine-5,6-d_2. The overall phototransposition reaction is thus shown in the equation below.



4-2,6-d_2 **3-5,6-d_2** **2-4,5-d_2**

92a)



92b)

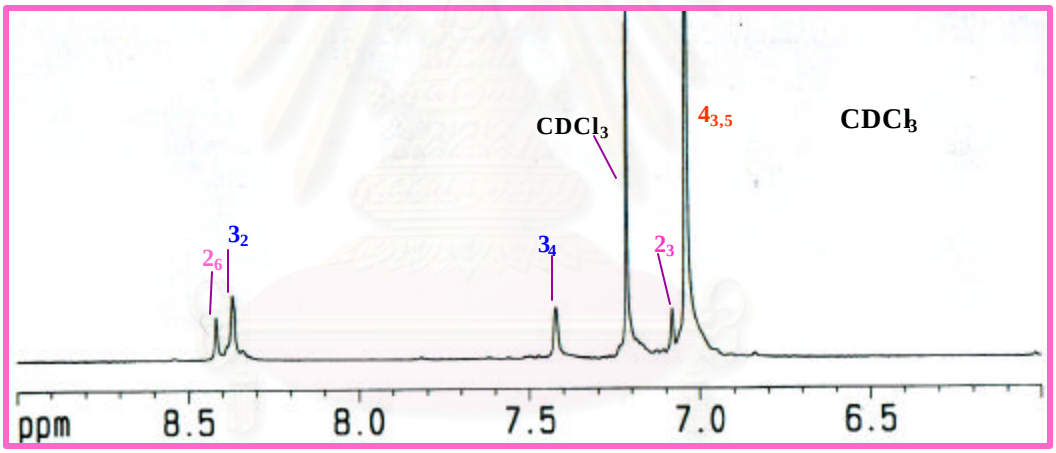


Figure92: a) 4-Trideuteriomethylpyridine-2,6-d_2 before irradiation
b) After irradiation of 4-trideuteriomethylpyridine-2,6-d_2 at 254 nm for 24 hours

The product mixture was also analyzed by GC- mass spectroscopy. Figure 93a shows that the GC trace exhibits a peak at 12.6 minutes which is due to a mixture of 4-trideuteriomethylpyridine-2,6-d_2 and 3-trideuteriomethylpyridine-5,6-d_2. The GC trace also shows a smaller peak at 8.8 minutes due to 2-trideuteriomethylpyridine-4,5-d_2 formed in the reaction. Figure 93b and 93c shows the mass spectrum of the compounds that eluted at 8.8 and 12.6 minutes, respectively.

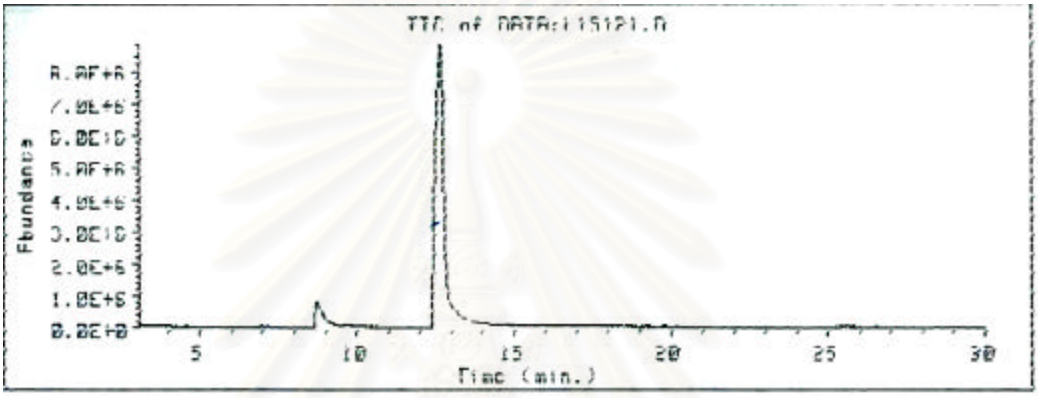


Figure 93a: GC trace of 4-methylpyridine-2,6-d_2 after irradiation for 24 hours

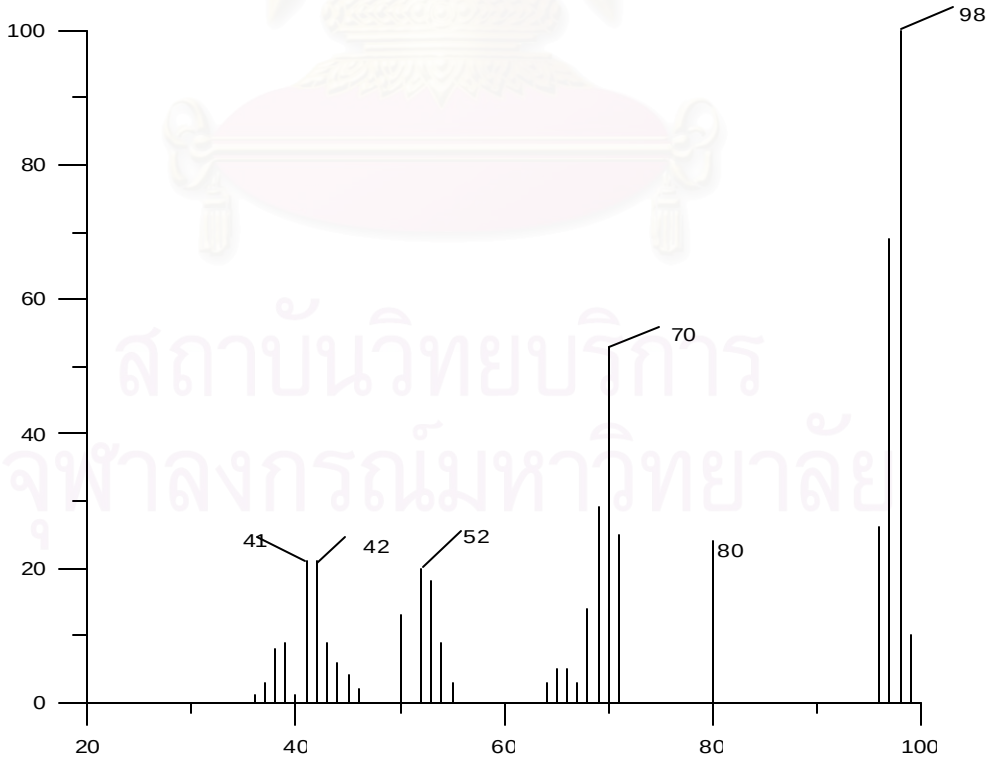


Figure 93b: The mass spectrum at 8.8 minutes after irradiation for 24 hours

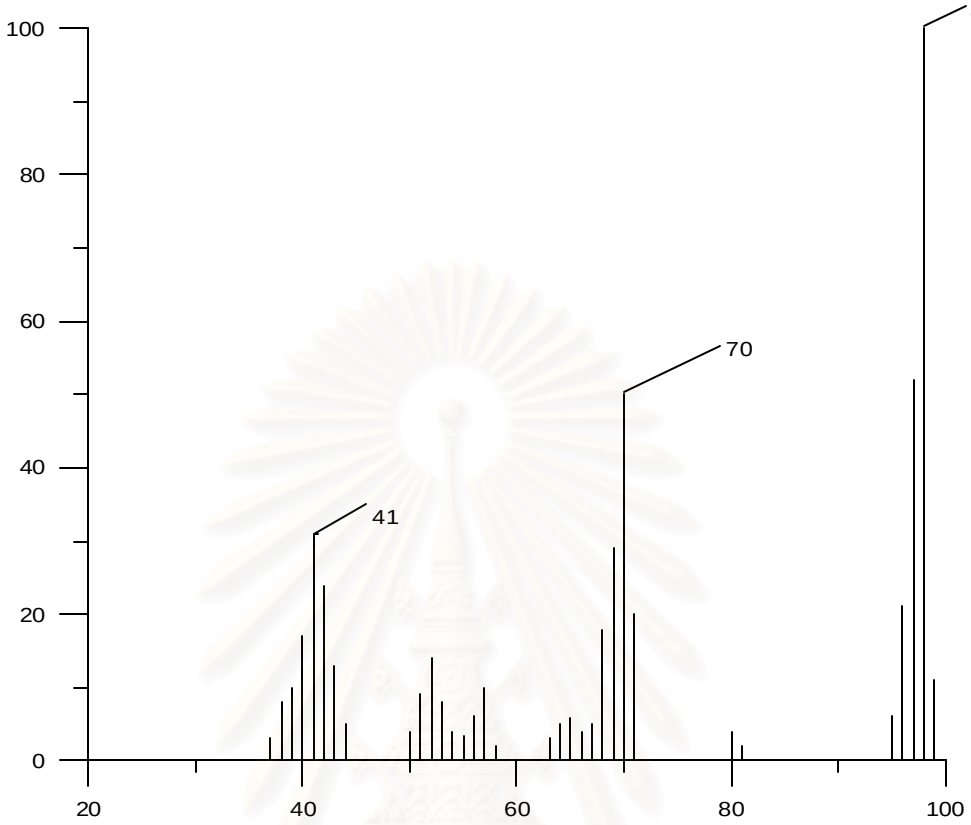


Figure 93c: The mass spectrum at 12 minutes after irradiation for 24 hours

After irradiation, the walls of the reaction flask were again coated with a film. This material was washed with acetone and the acetone extract was evaporated to dryness and the residue analyzed by ^{1}H-NMR in $CDCl_3$. The ^{1}H-NMR spectrum which is shown in Figure 94 exhibits signals at δ 7.09 (s, H_3) and 8.41 (s, H_6) due to 2-trideuteriomethylpyridine-3,5-d_2; signals at δ 8.39 (s, H_4) and 7.4 (s, H_2). These are the same products that were observed in the condensed vapor after irradiation.

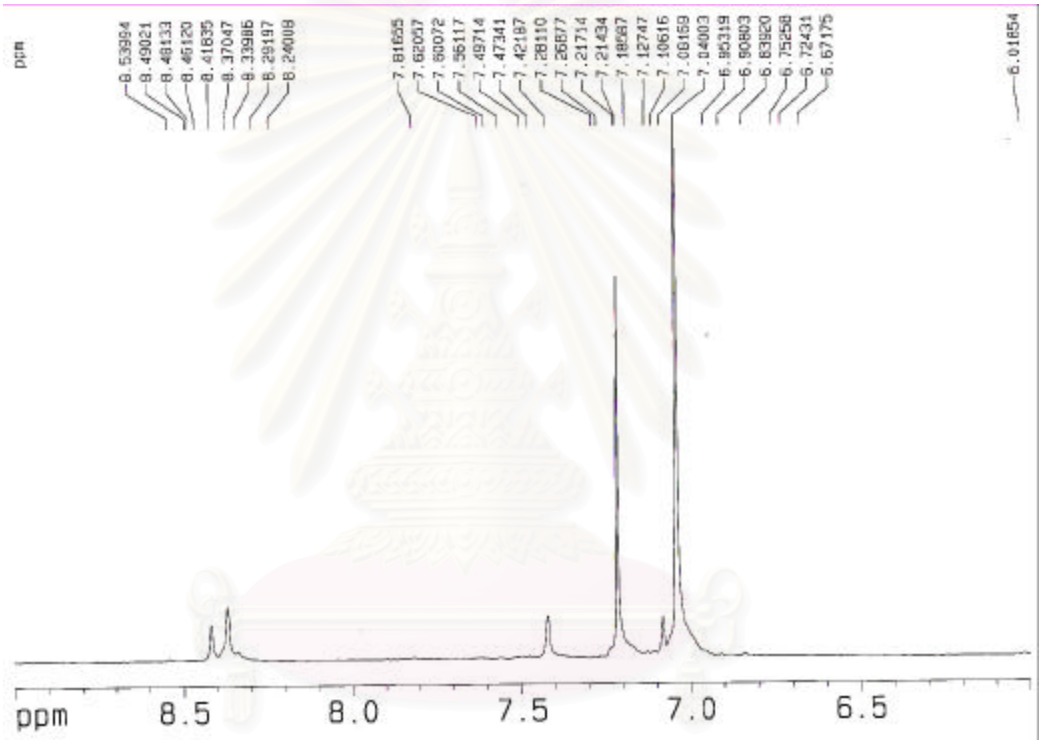


Figure 94: The ^{1}H-NMR of the brown polymer

The brown polymer was analyzed also by GC-MS. GC trace (Figure 95a) indicated the three peaks which eluted at retention of 8.8, 10 and 12 minutes. The mass spectrum at 8.8 minutes (Figure 95b) exhibits a molecular ion at m/z 98 consistent with molecular weigh of 2-methylpyridine-4,5-d_2 (MW. 98).

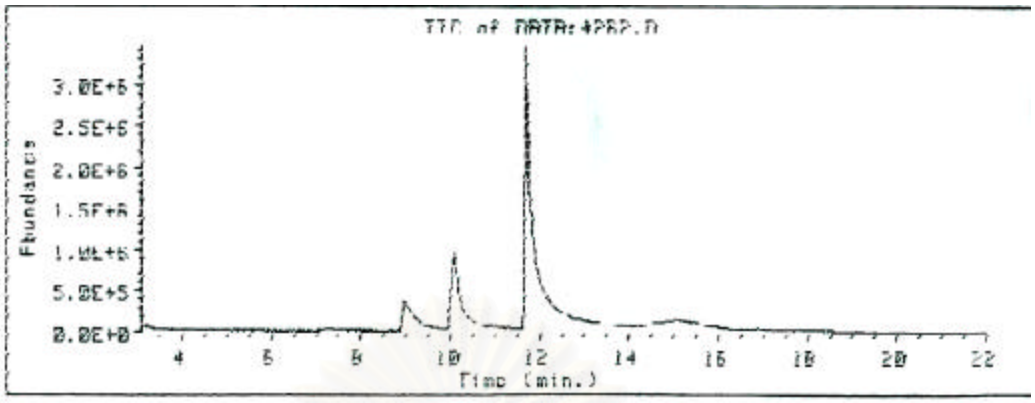


Figure 95a: GC trace of the brown polymer

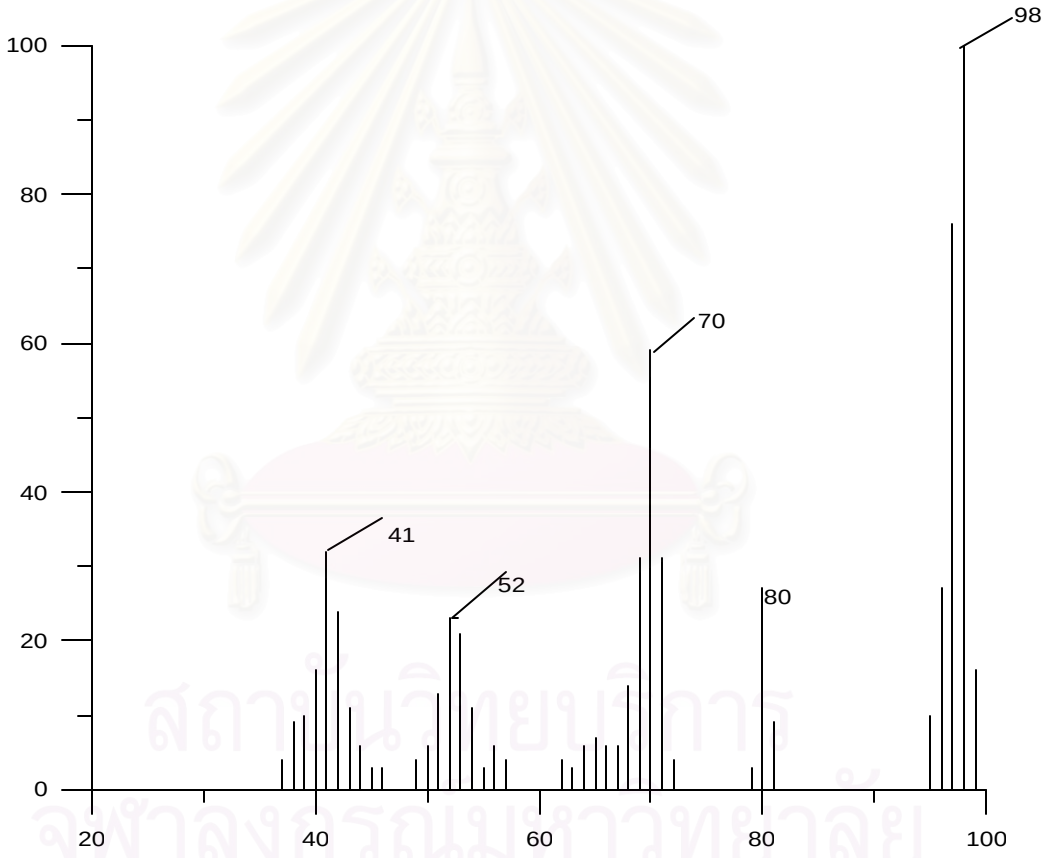


Figure 95b: The mass spectrum at 8 minutes of the brown polymer

The mass spectrum at 10 minutes (Figure 95c) shows a molecular ion at m/z 101 is due to unknown.

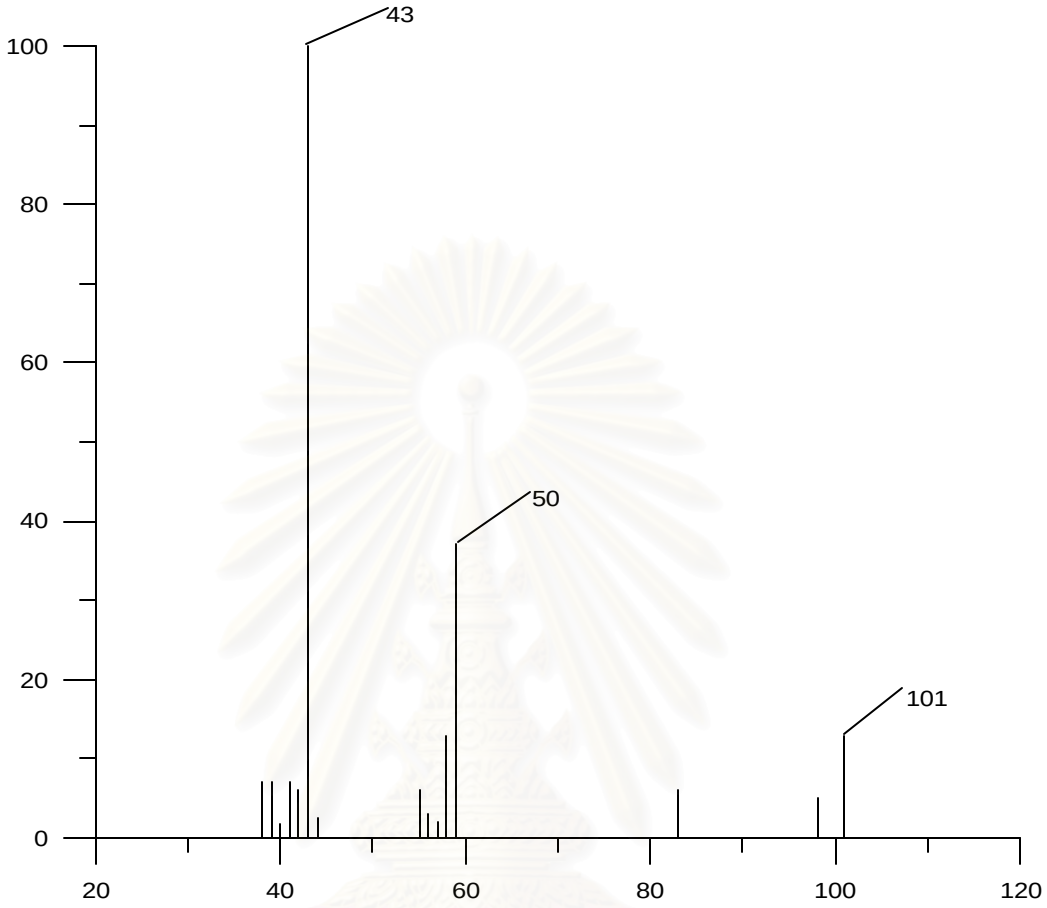


Figure 95c: The mass spectrum at 10 minutes of brown polymer

The mass spectrum exhibits peaks at m/z 98 eluted at 12 minutes as shown in Figure 95d, which consistent with the molecular weight of 3-methylpyridine-5,6-d_2 and 4-methylpyridine-2,6-d_2.

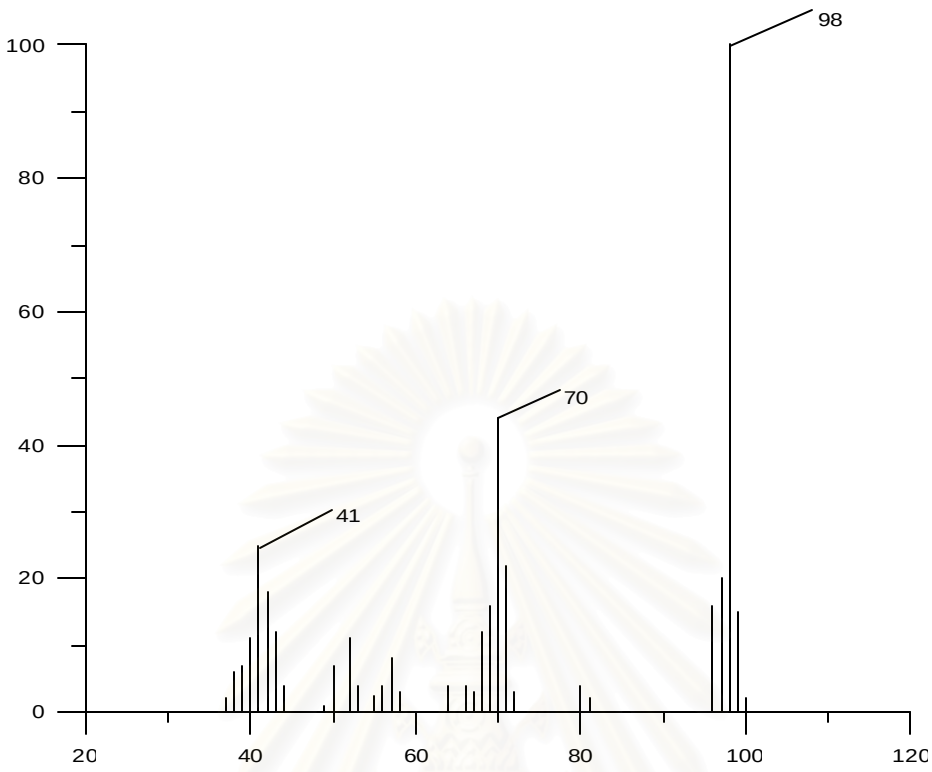
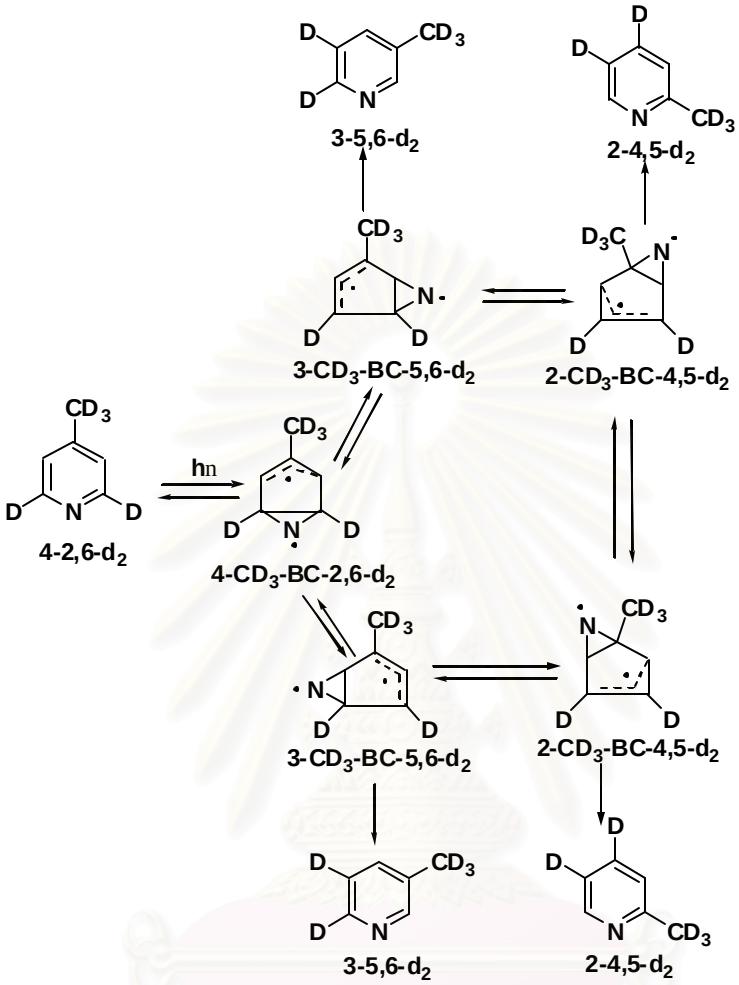


Figure 95 d: The mass spectrum at 12 minutes of the brown polymer

These products formed by irradiation of 4-trideuteriomethylpyridine-2,6-d_2 are those predicted by the electrocyclic ring closure – heteroatom migration mechanism previously suggested for these reactions. As shown in scheme 30, electrocyclic ring closure results in the formation of **4-CD_3-BC-2,6-d_2**. Because of the symmetry of the reactant, one or two nitrogen migrations in either a clockwise or a counterclockwise direction leads to the same two bicyclic intermediates and, after rearomatization, to the same two photoproducts, **3-4,6-d_2** and **2-4,5-d_2**. Thus, the products observed could have been formed by nitrogen migration around two or all five sides of the cyclopentenyl ring. These two possibilities cannot be distinguished because of the symmetry of the reactant.

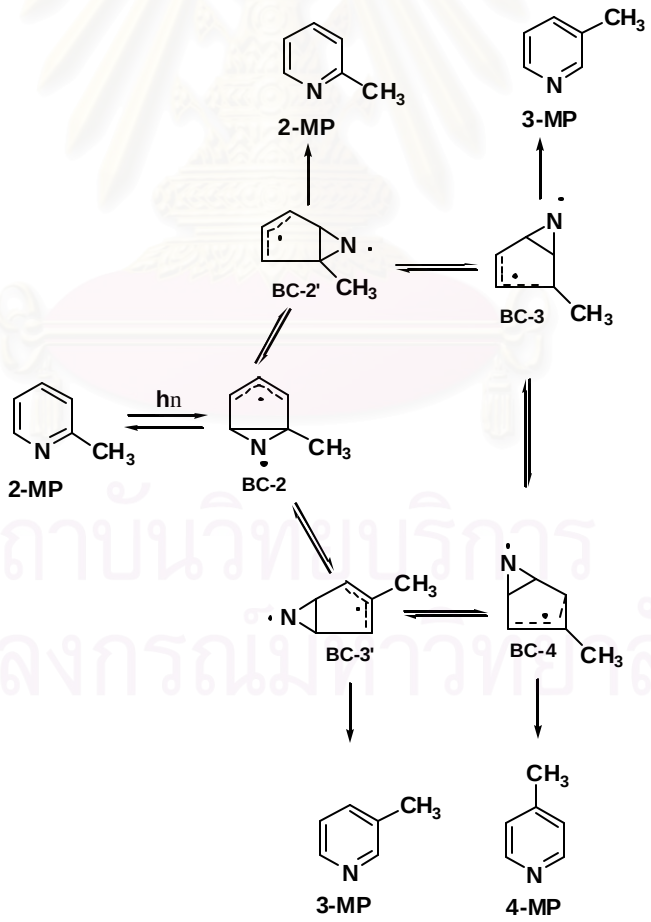


Scheme 30: Proposed mechanism for the formation of phototransposition products **4-2,6-d_2**

CHAPTER 4

CONCLUSION

The vapor phase photochemistry of methylpyridines had previously been studied but results from number of researchers were not consistent to each others. In the course of re-investigation on the photochemistry of methylpyridines presented in this thesis, the results have shown that irradiation of any one of the methylpyridine isomers, 2-, 3- or 4-methylpyridine, in the vapor phase at 254 nm results in the formation of the other two isomers and in the trace quantities formation of pyridine and some dimethylpyridines. The observed isomerizations are consistent with a mechanism involving 2,6-bonding, nitrogen migration and re-aromatization, as shown in Scheme 1.



Scheme 1 : Photo-interconvertion of methylpyridines

The photochemistry of deuterium labeled methylpyridines has also been studied in this thesis. The results reveal that the products observed after vapor phase photolysis of 2-methylpyridine-4,6-d_2, 3-methylpyridine-2,6-d_2, 4-methylypyridine-2,6-d_2, and 3-methylpyridine-2,4,6-d_3 are also consistent with a mechanism involving 2,6-bonding followed by nitrogen migration around all five sides of the cyclopentenyl ring and re-aromatization. No product that arise from an intermediate which corresponds to a dewar or azaprismane structure was observed, in both unlabeled and deuterium labeled experiments. Therefore, these results confirm that upon irradiation of methylpyridines in vapor phase, they undergo electrocyclic ring closure (2,6-bonding) to the formation of preazafulvene-type intermediates, nitrogen migrations can occur around all five sides of the cyclopentenyl ring, re-aromatization of each preazafulvene intermediate will result in the formation of the observed transposition products.

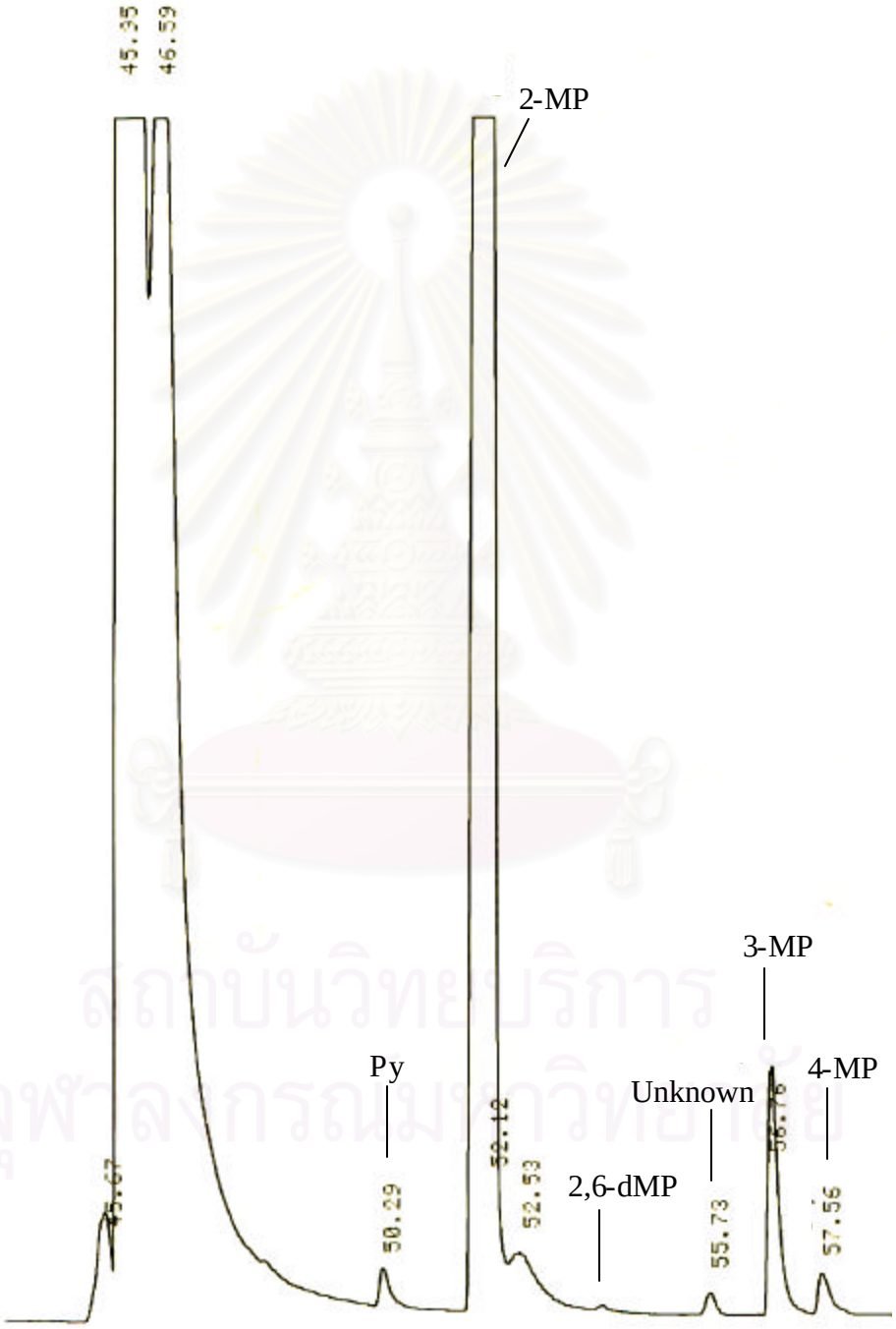
REFERENCES

1. Caplain, S. and Lablache-Combier, A. "Gas-Phase Photochemistry of Picolines and Lutidine" *J. Chem. Soc. Chem. Commun.* (1970):1247.
2. Roebke, W. "Gas-phase Photolysis of 2-picoline" *J. Phys. Chem*. 74(1970):4198-4203.
3. Pascual, O. S.; Tuazon, L. O. "Photolysis of 2- and 4-picolines" *Chem. Abs.* 66(1967):115125b.
4. Pavlik, J. W.; Kebede, N. "Vapor-Phase Photochemistry of Dimethylpyridines" *J. Am. Chem. Soc.* 121(1999):5666.
5. Cao, Z.; Zhang, Q. "Theoretical characterization of photoisomerization channels of dimethylpyridines on the Singlet and Triplet Potential Energy Surfaces" *Chem. Eur. J.* 7(2001):1927.
6. Lalinsky, B.; Cuper, C. "Base-Catalyzed Deuterium Exchange in Pyridine *N*-oxides" *J. Org. Chem.* 35(1970):1175.
7. Ochiai, E. "Recent Japanese Work on the Chemistry of Pyridine 1-Oxide and Related Compound" *J. Org. Chem.* 18(1953):534.
8. Barnes, J. H.; Hartley, F. R.; Jones C. "The Preparation of 4- and 6-Chloro-2-Chloromethylpyridine" *Tetrahedron.* 38(1982):3277.
9. Azzam, R.; Borggraeve, W.; Compernolle, F. and Hoornaert G. "New Routes for the Synthesis of 3- and 5-Substituted 2(1H)-Pyrazinones" *Tet Lett.* 45(2004):1885.

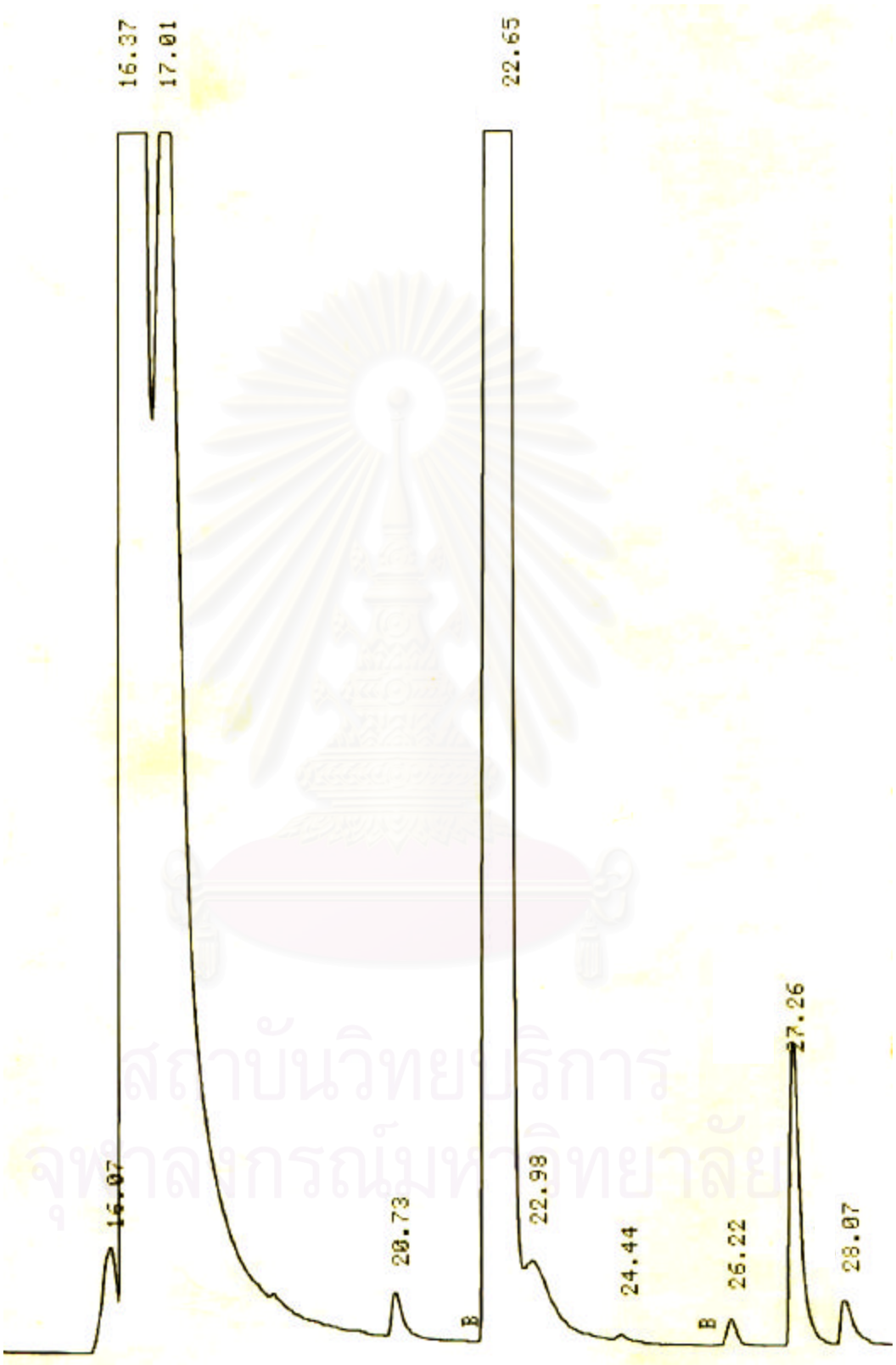
APPENDICES

Analysis of 2-methylpyridine photoreaction

GLC (PE8500)



Irradiation of 2-MP at 254 nm for 24 hours

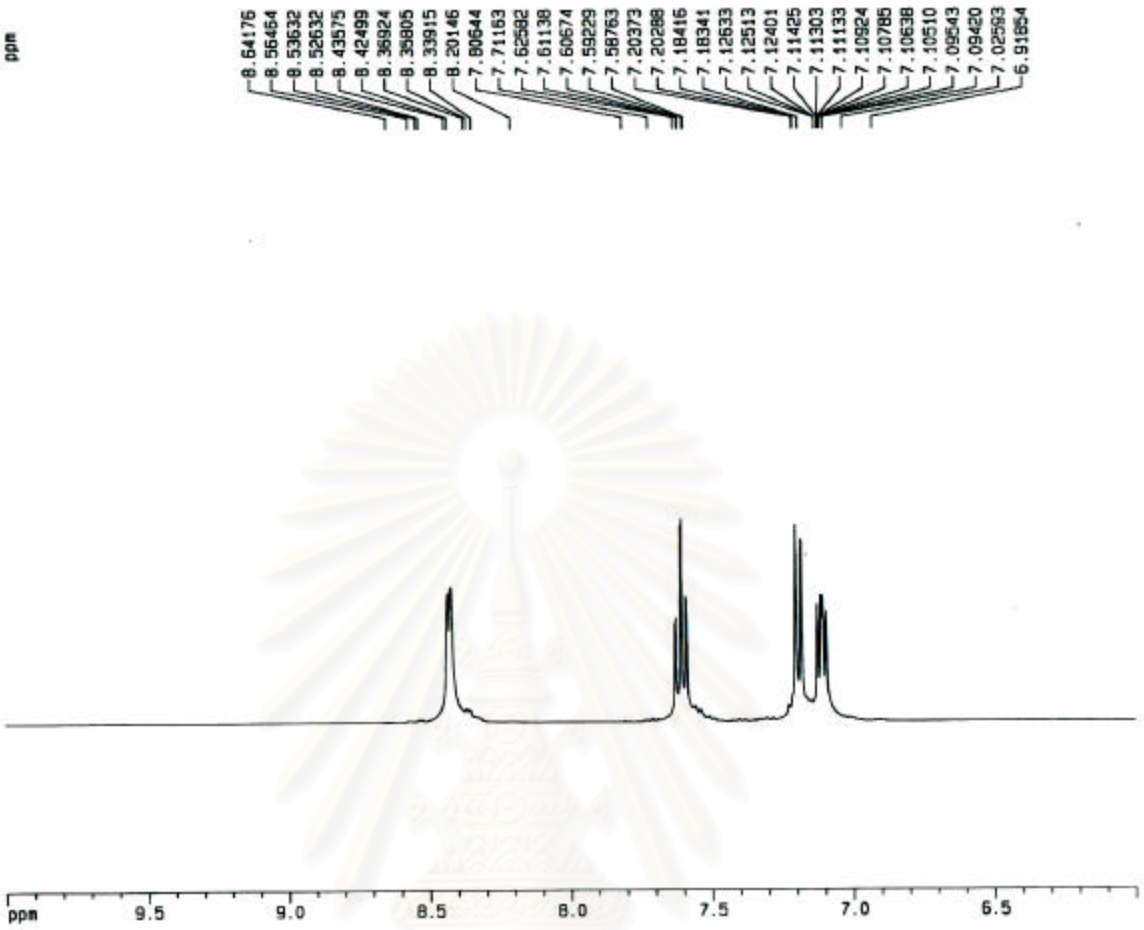


Irradiation of 2-MP at 254 nm for 48 hours

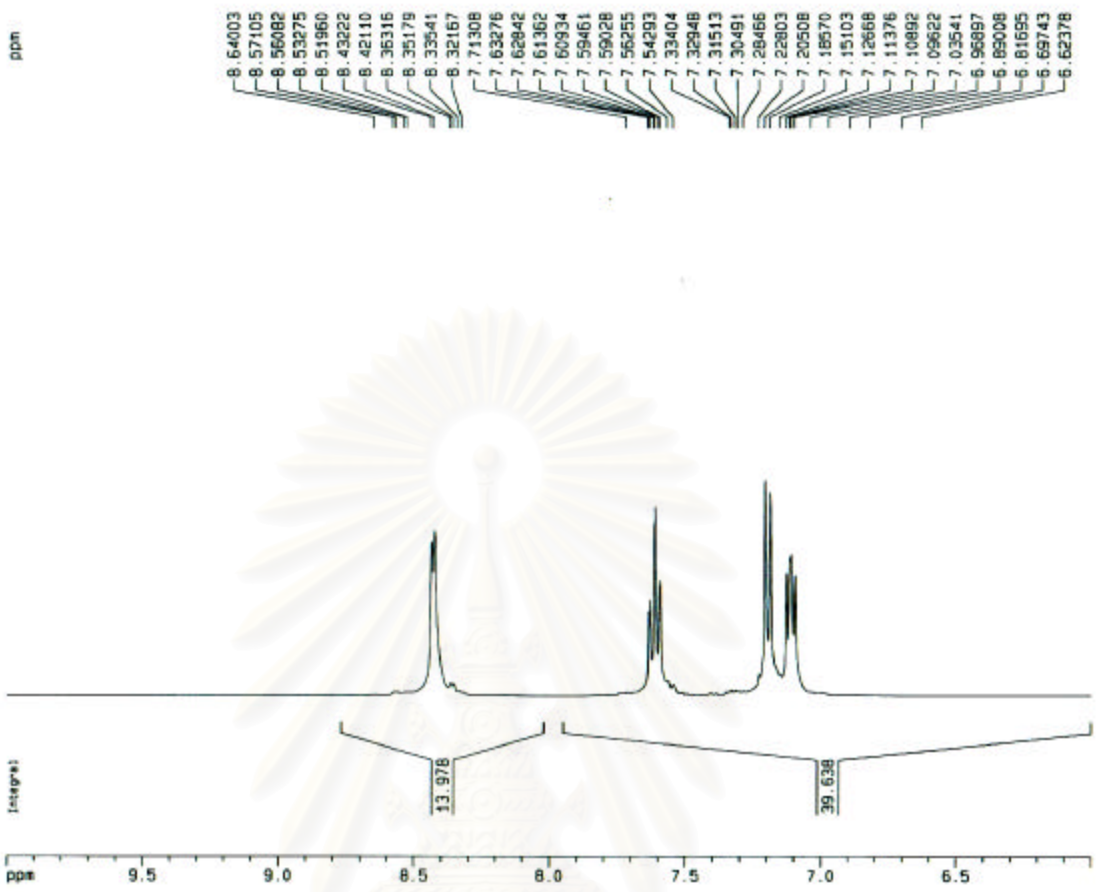
Irradiation of 2-MP at 254 nm for 72 hours

Irradiation of 2-MP at 254 nm for 96 hours

^{1}H-NMR



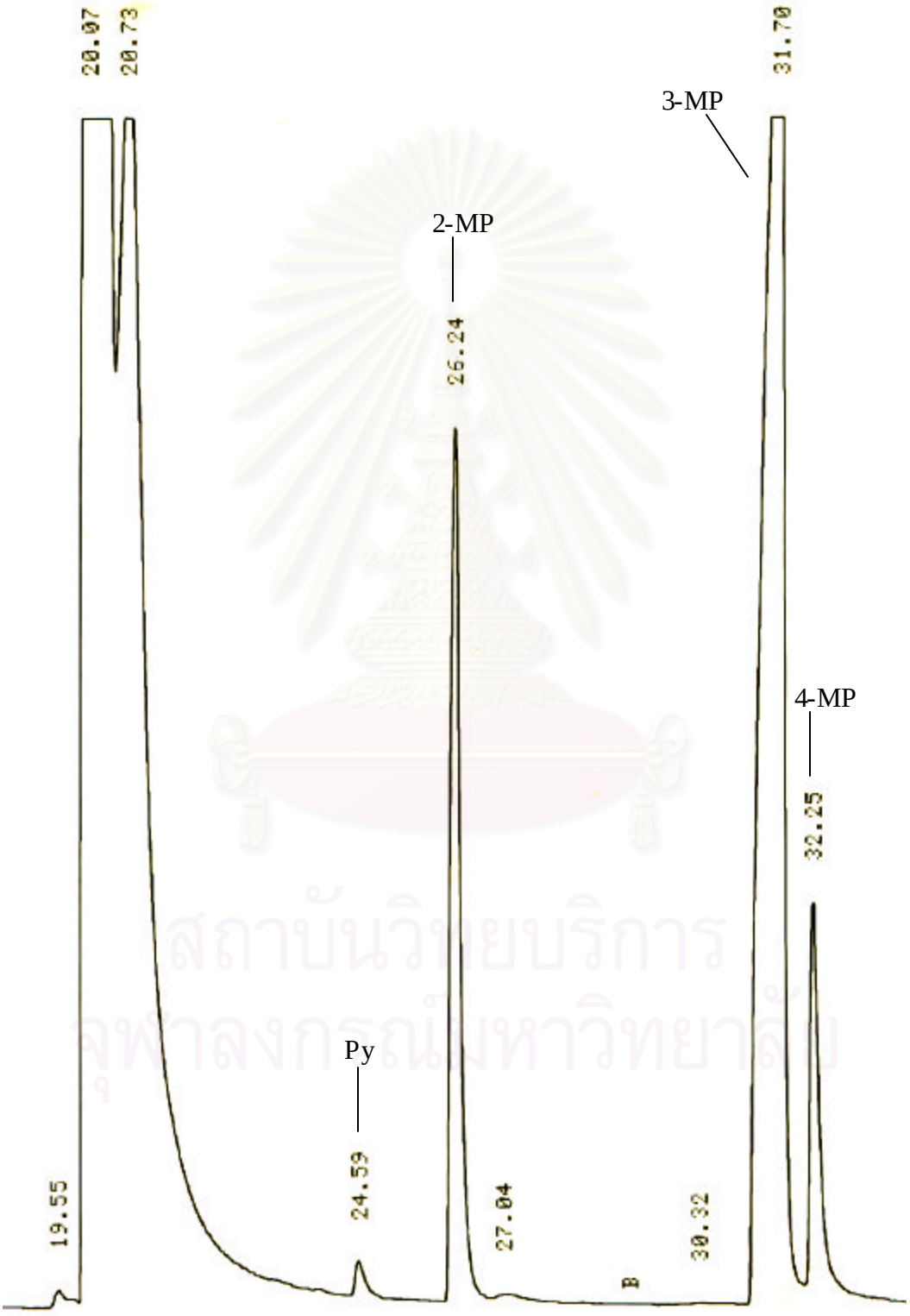
Irradiation of 2-MP at 254 nm for 48 hours



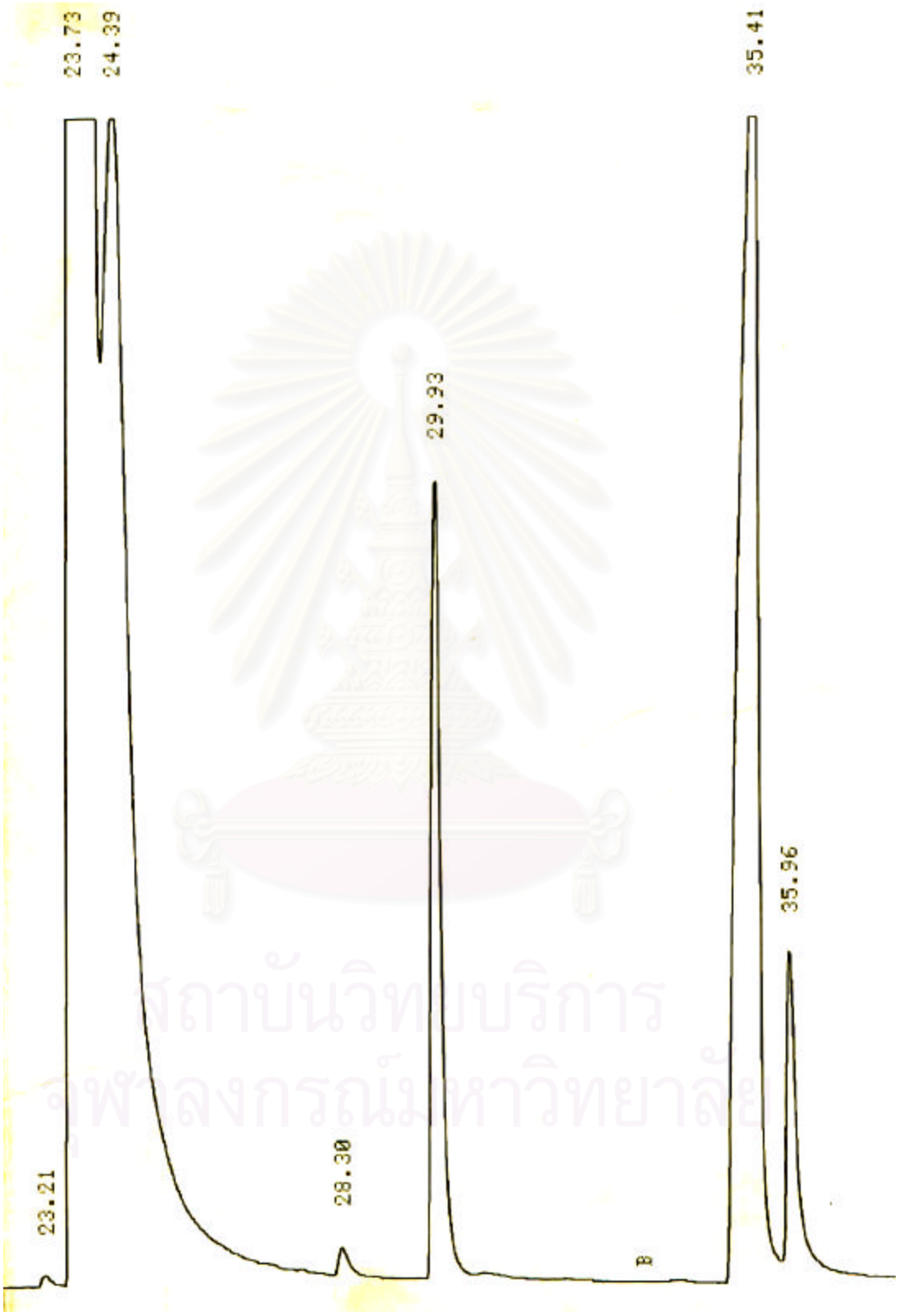
Irradiation of 2-MP at 254 nm for 72 hours

Analysis of 3-methylpyridine photoreaction

GLC (PE8500)

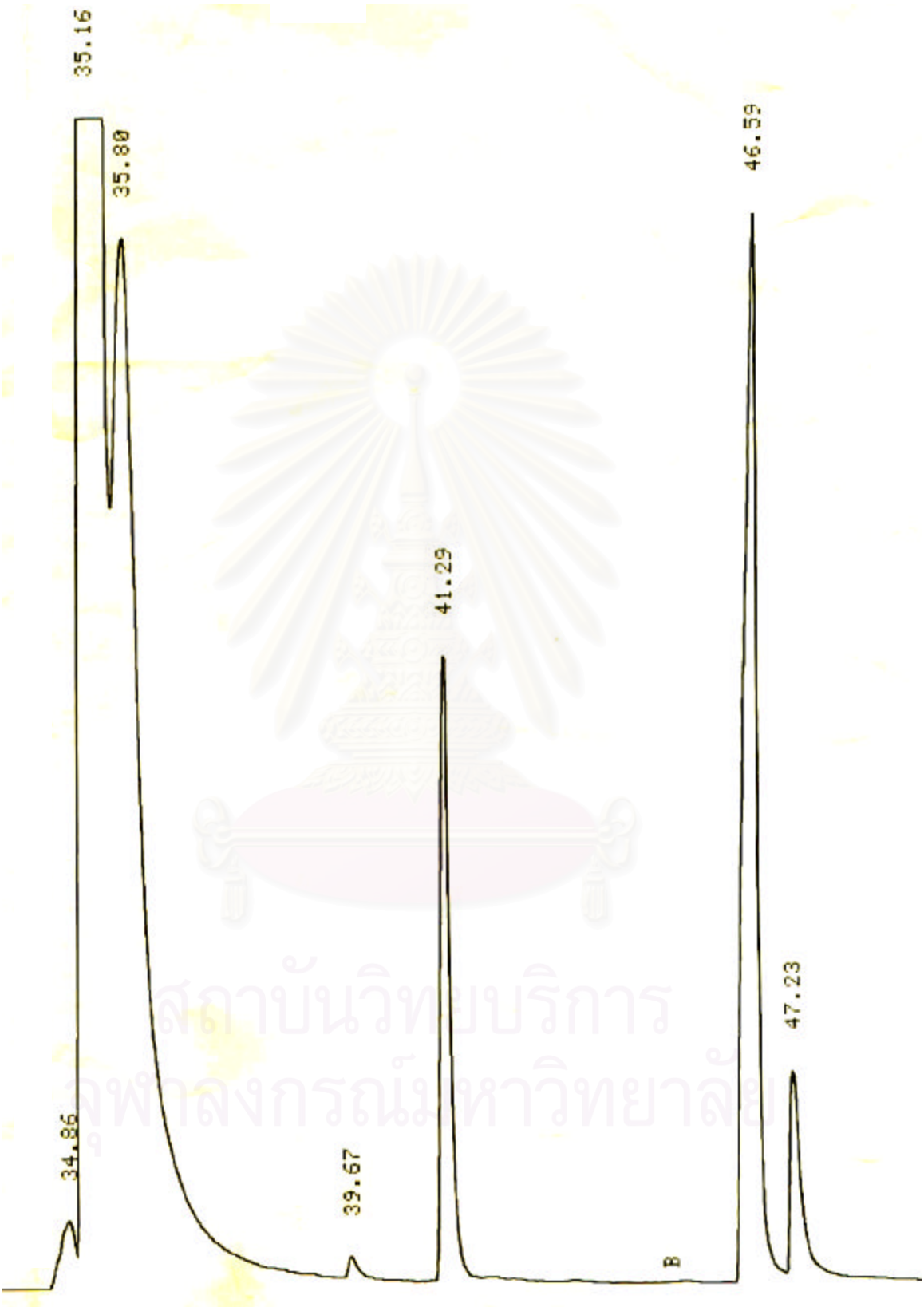


Irradiation of 3-MP at 254 nm for 24 hours



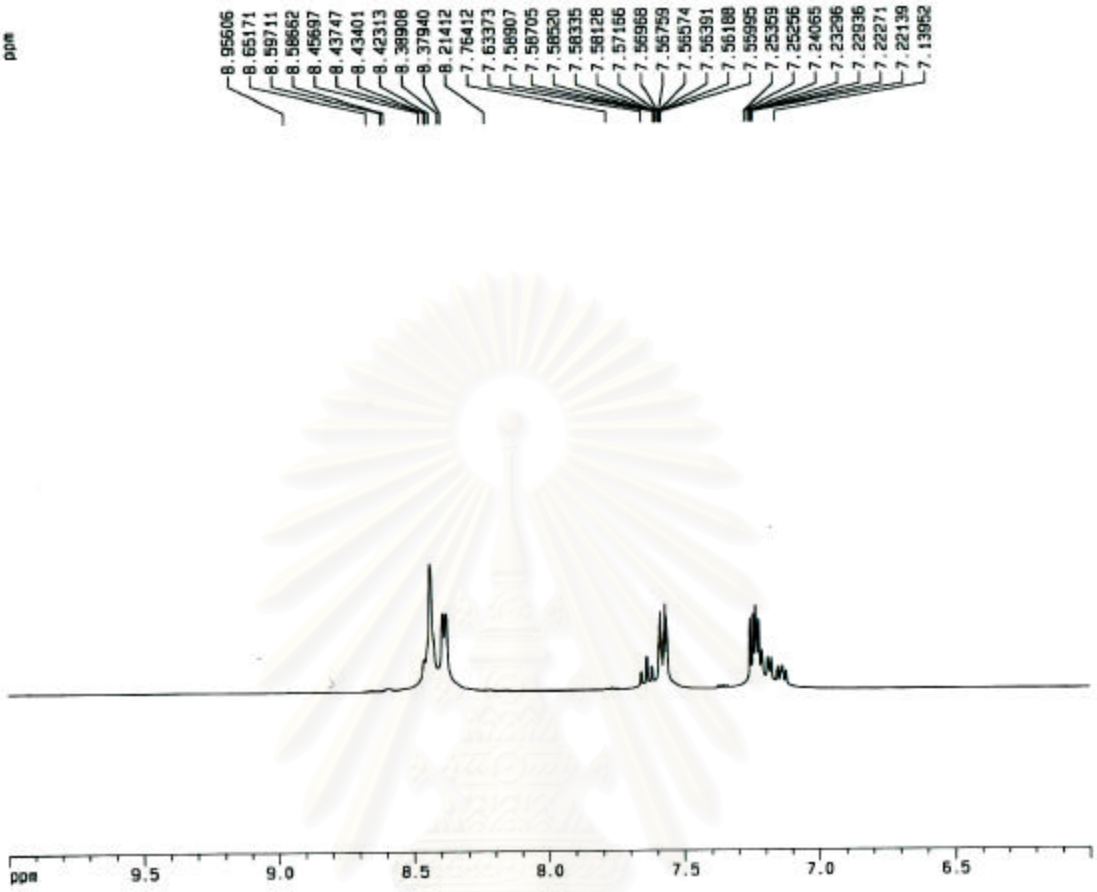
Irradiation of 3-MP at 254 nm for 48 hours

Irradiation of 3-MP at 254 nm for 72 hours

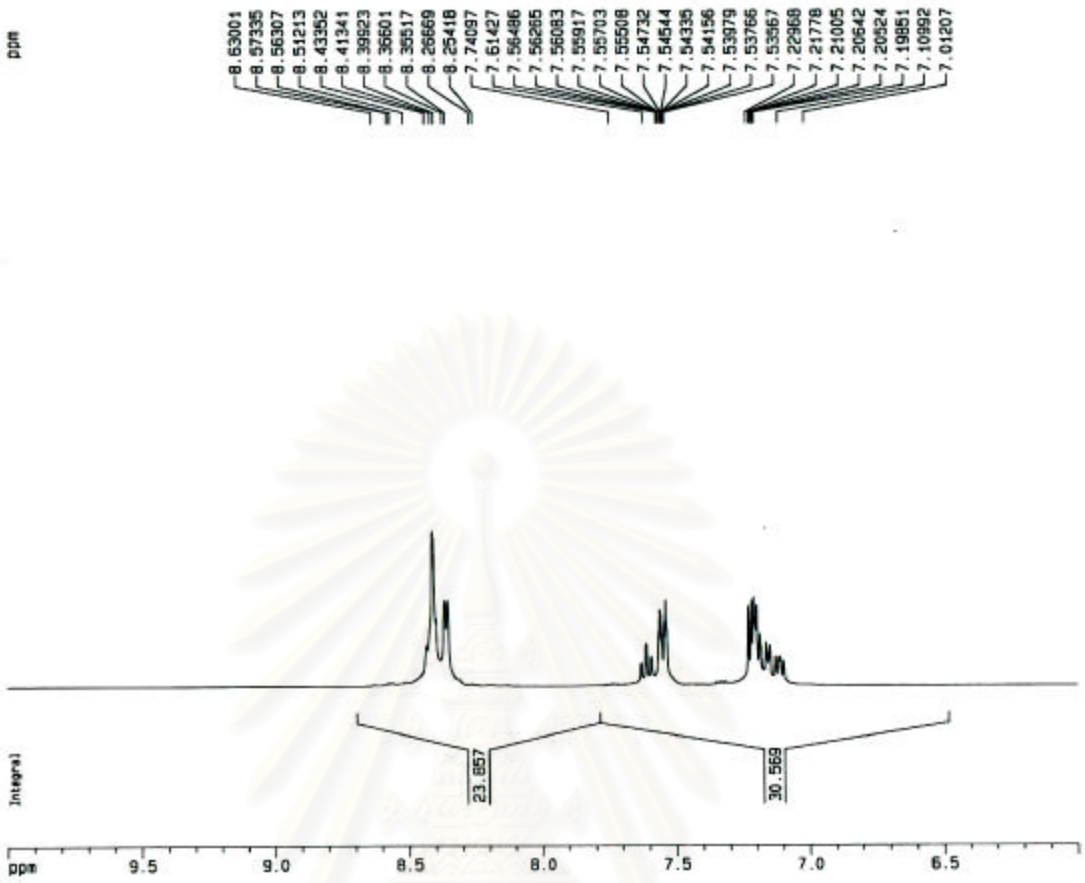


Irradiation of 3-MP at 254 nm for 98 hours

^{1}H-NMR



Irradiation of 3-MP at 254 nm for 48 hours



Irradiation of 3-MP at 254 nm for 72 hours

Analysis of 4-methylpyridine photoreaction

GLC (PE8500)

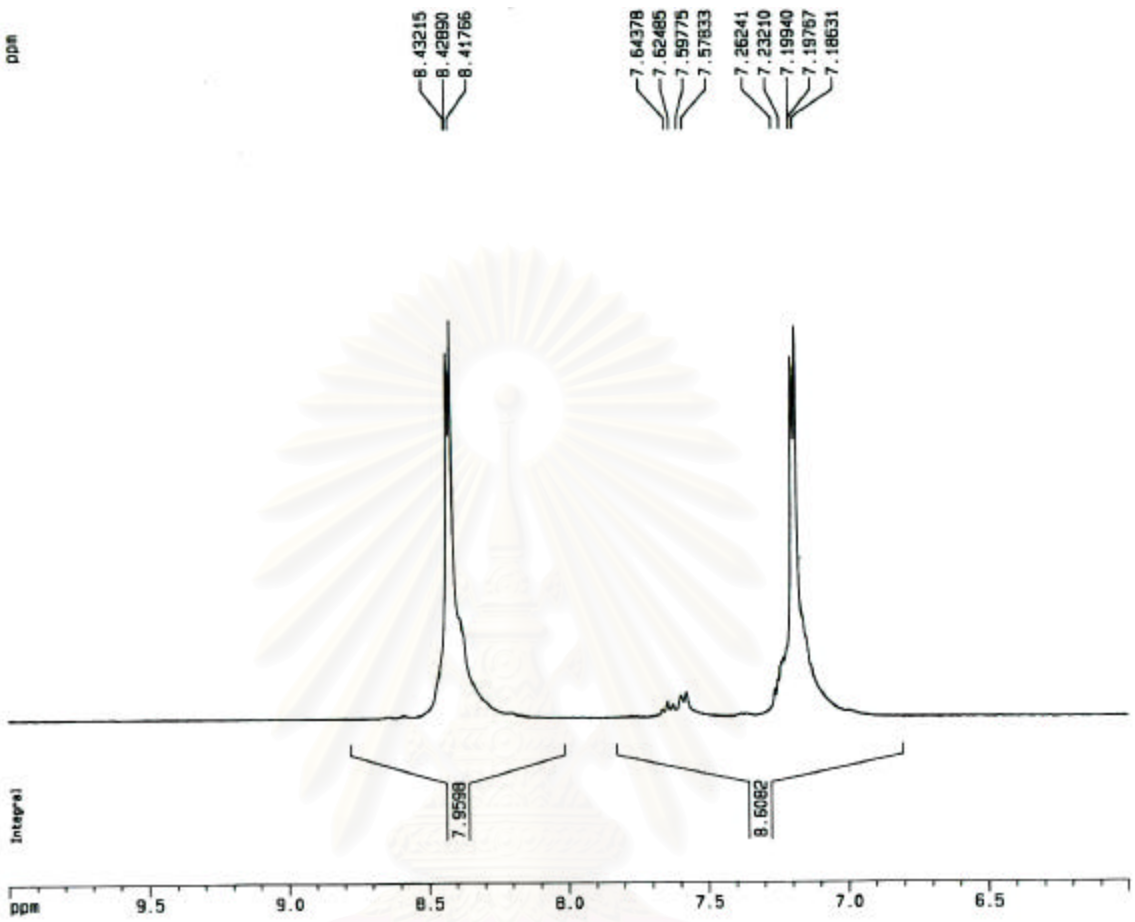
Irradiation of 4-MP at 254 nm for 24 hours

Irradiation of 4-MP at 254 nm for 48 hours

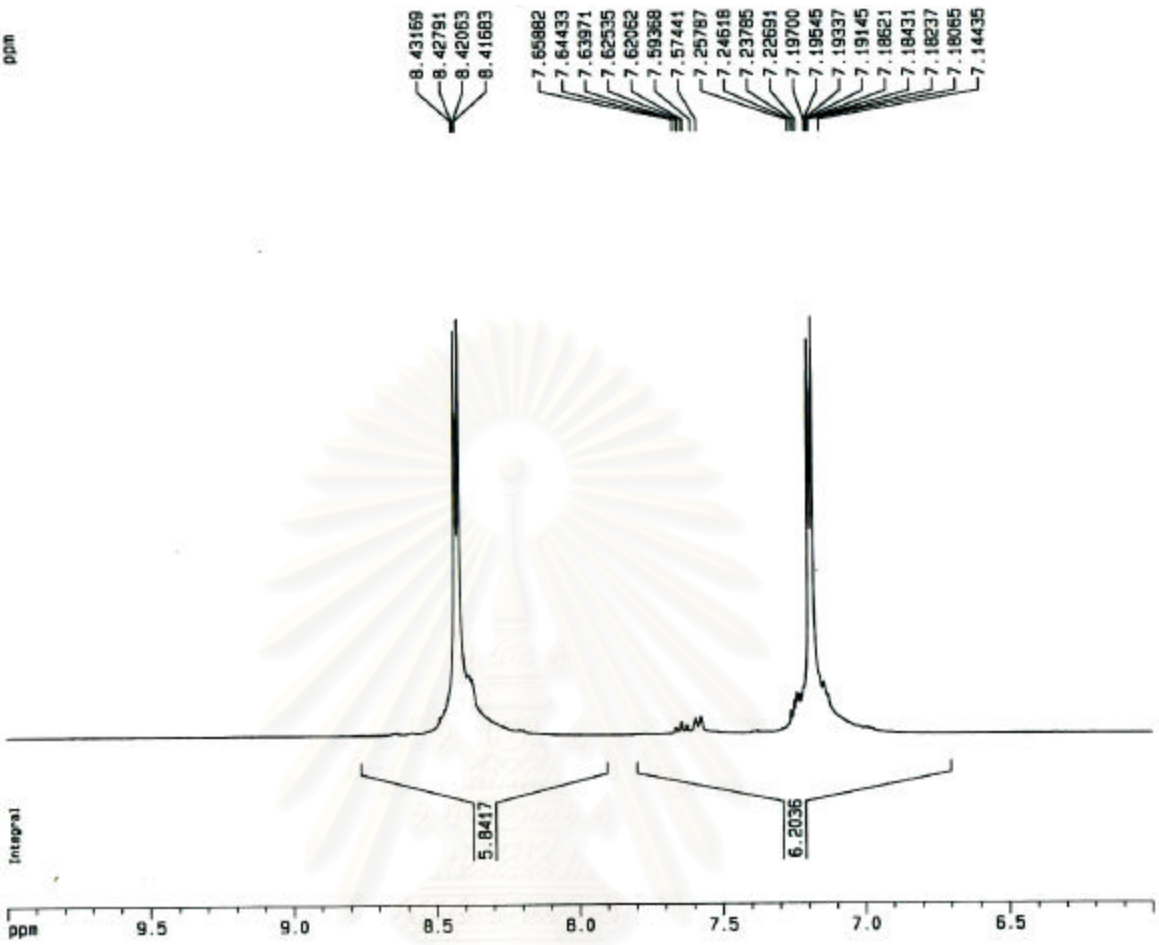
Irradiation of 4-MP at 254 nm for 72 hours

Irradiation of 4-MP at 254 nm for 96 hours

^{1}H-NMR



Irradiation of 4-MP at 254 nm for 48 hours



Irradiation of 4-MP at 254 nm for 72

Quantitative analysis of methylpyridine photoreactions

Photolysis of 2-methylpyridine

Time (hrs)	2-MP			3-MP			4-MP		
	RT (min)	GC Area	% cons	RT (min)	GC Area	% yield	RT (min)	GC Area	% yield
24	7	57.5	6	12	2.43	61	13	0.5	10
48	7	43.4	3	12	2.32	-	13	0.5	-
72	7	27.5	28.7	12	1.4	11	13	0.32	2
96	7	49	9	12	2.13	41	13	0.61	10

Photolysis of 3-methylpyridine

Time (hrs)	3-MP			2-MP			4-MP		
	RT (min)	GC Area	% cons	RT (min)	GC Area	% yield	RT (min)	GC Area	% yield
24	12	22.3	31	7	6.57	73	13	3.23	27
48	12	19.66	35	7	6.77	73	13	3.2	25
72	12	14.25	47	7	6.77	61	13	2.65	18
96	12	11.45	44	7	4.95	62	13	2.12	23

Photolysis of 4-methylpyridine

Time (hrs)	4-MP			2-MP			3-MP		
	RT (min)	GC Area	% cons	RT (min)	GC Area	% yield	RT (min)	GC Area	% yield
24	13	10.67	72	7	1	5	12	1.3	6
48	13	19.26	53	7	2.2	16	12	2.9	19
72	13	10.31	65	7	1.3	9	12	1.7	10
96	13	17.22	58	7	2.51	14	12	3.15	16

GC-Area = Average area of 3 injections

% yields are obtained by using calibration curves

Quantitative analysis of vapor phase photolysis of 2-methylpyridine

24 Hours irradiation

1. Calculation consumption of 2-methylpyridine after 24 hours irradiation

y = 125.07x

y = peak area of 2-picoline = 57.5

57.5 = 125.07x

x = 0.46 M; mol = (0.46*2)/1000 = 9.2×10^{-4} mol

weight of crude reaction from trapping = 0.091g

g/MW = 0.091/93 = 9.78×10^{-4} mol

(9.2×10^{-4} / 9.78×10^{-4}) x100 = 94 % rest

100- 94 % rest = **6 % consumption**

2. Calculation formation of 3-methylpyridine after 24 hours irradiation

y = 136.78x

y = peak area of 3-picoline = 2.43

2.43 = 136.78x

x = 0.018 M; mol = (0.018*2)/1000 = 3.6×10^{-5} mol

mole consume of 2-picoline = (9.78×10^{-4})* 6/100 = 5.87×10^{-5} mol

% formation of 3-picoline = (3.6×10^{-5} /5.87×10^{-5})*100 = **61.3 %**

3. Calculation formation of 4-methylpyridine after 24 hours irradiation

y = 166.58x

y = peak area of 4-picoline = 0.5

0.5 = 166.58x

x = 0.003 M; mol = (0.003*2)/1000 = 6×10^{-6} mol

mole consume of 2-picoline = $(9.78x10^{-4})$* 6/100 = $5.87x10^{-5}$ mol

% formation of 4-picoline = $(6\times10^{-6}/5.87x10^{-5})$*100 = **10.2 %**

48 Hours irradiation

1. Calculation consumption of 2-methylpyridine after 48 hours irradiation

y = 125.07x

y = peak area of 2-picoline = 43.4

43.4 = 125.07x

x = 0.35 M; mol = (0.35*2)/1000 = 7.0×10^{-4} mol

weight of crude reaction from trapping = 0.067g

g/MW = 0.067/93 = $7.2x10^{-4}$ mol

$(9.2\times10^{-4} / 9.78 x10^{-4})$ x100 = 97 % rest

100- 94 % rest = **3 % consumption**

2. Calculation formation of 3-methylpyridine after 48 hours irradiation

y = 136.78x

y = peak area of 3-picoline = 2.32

2.32 = 136.78x

x = 0.017 M; mol = (0.017*2)/1000 = 3.4×10^{-5} mol

mole consume of 2-picoline = $(7.2\text{x}10^{-4})$* 3/100 = $2.16\text{x}10^{-5}$ mol

% formation of 3-picoline = $(3.4\times10^{-5}/2.16\text{x}10^{-5})$*100 = **157**

3. Calculation formation of 4-methylpyridine after 48 hours irradiation

y = 166.58x

y = peak area of 4-picoline = 0.5

0.5 = 166.58x

x = 0.003 M; mol = (0.003*2)/1000 = 6×10^{-6} mol

mole consume of 2-picoline = $(7.2\text{x}10^{-4})$* 3/100 = $2.16\text{x}10^{-5}$ mol

% formation of 4-picoline = $(6\times10^{-6}/2.16\text{x}10^{-5})$*100 = **27.7 %**

72 Hours irradiation

1. Calculation consumption of 2-methylpyridine after 72 hours irradiation

y = 125.07x

y = peak area of 2-picoline = 27.5

27.5 = 125.07x

x = 0.23 M; mol = (0.23*2)/1000 = 4.6×10^{-4} mol

weight of crude reaction from trapping = 0.06g

g/MW = 0.06/93 = $6.45\text{x}10^{-4}$ mol

$(4.6\times10^{-4} / 6.45 \times10^{-4}) \times100 = 71.3$ % rest

100- 71.3 % rest = **28.7 % consumption**

2. Calculation formation of 3-methylpyridine after 72 hours irradiation

y = 136.78x

y = peak area of 3-picoline = 1.4

1.4 = 136.78x

x = 0.01 M; mol = (0.01*2)/1000 = 2×10^{-5} mol

mole consume of 2-picoline = (6.45×10^{-4})* 28.7/100 = 1.85×10^{-4} mol

% formation of 3-picoline = $(2\times10^{-5} /1.85\times10^{-4})$*100 = **11 %**

3. Calculation formation of 4-methylpyridine after 24 hours irradiation

y = 166.58x

y = peak area of 4-picoline = 0.32

0.32 = 166.58x

x = 0.002 M; mol = (0.002*2)/1000 = 4×10^{-6} mol

mole consume of 2-picoline = (6.45×10^{-4})* 28.7/100 = 1.85×10^{-4} mol

% formation of 4-picoline = $(4\times10^{-6}/1.85\times10^{-4})$*100 = **2 %**

96 Hours irradiation

1. Calculation consumption of 2-methylpyridine after 96 hours irradiation

y = 125.07x

y = peak area of 2-picoline = 49

49 = 125.07x

x = 0.39 M; mol = (0.39*2)/1000 = 7.8×10^{-4} mol

weight of crude reaction from trapping = 0.08 g

g/MW = 0.081/93 = $8.6\text{x}10^{-4}$ mol

(7.8×10^{-4} / $8.6\ \text{x}10^{-4}$) x100 = 91 % rest

100- 91 % rest = **9 % consumption**

2. Calculation formation of 3-methylpyridine after 96 hours irradiation

y = 136.78x

y = peak area of 3-picoline = 2.13

2.13 = 136.78x

x = 0.016 M; mol = (0.016*2)/1000 = 3.2×10^{-5} mol

mole consume of 2-picoline = ($8.6\text{x}10^{-4}$)* 9/100 = $7.74\text{x}10^{-5}$ mol

% formation of 3-picoline = (3.2×10^{-5} /$7.74\text{x}10^{-5}$)*100 = **41 %**

3. Calculation formation of 4-methylpyridine after 96 hours irradiation

y = 166.58x

y = peak area of 4-picoline = 0.61

0.61 = 166.58x

x = 0.0037 M; mol = (0.0037*2)/1000 = 7.4×10^{-6} mol

mole consume of 2-picoline = $(8.6\text{x}10^{-4})$* 9/100 = $7.74\text{x}10^{-5}$ mol

% formation of 4-picoline = $(7.4\times10^{-6}/7.74\text{x}10^{-5})$*100 = **10 %**

Quantitative analysis of vapor phase photolysis of 3-methylpyridine

24 Hours irradiation

1. Calculation consumption of 3-methylpyridine after 24 hours irradiation

y = 136.78x

y = peak area of 3-picoline = 22.3

22.3 = 136.78x

x = 0.16 M; mol = (0.16*2)/1000 = 3.2×10^{-4} mol

weight of crude reaction from trapping = 0.043g

g/MW = 0.039/93 = $4.62\text{x}10^{-4}$ mol

$(3.2\times10^{-4} / 4.62\ \text{x}10^{-4})$ x100 = 69.3 % rest

100- 69.3 % rest = **30.7 % consumption**

2. Calculation formation of 2- methylpyridine after 24 hours irradiation

y = 125.07x

y = peak area of 2-picoline = 6.57

6.57 = 125.07x

x = 0.052 M; mol = (0.052*2)/1000 = 1.04×10^{-4} mol

mole consume of 3-picoline = $(4.62\text{x}10^{-4})$* 30.7/100 = $1.42\text{x}10^{-4}$ mol

% formation of 2-picoline = $(1.04\times10^{-4}/1.42\times10^{-4})$*100 = **73.2 %**

3. Calculation formation of 4- methylpyridine after 24 hours irradiation

y = 166.58x

y = peak area of 4-picoline = 3.23

3.23 = 166.58x

x = 0.019 M; mol = (0.019*2)/1000 = 3.8×10^{-5} mol

mole consume of 3-picoline = $(4.62\text{x}10^{-4})$* 30.7/100 = $1.42\text{x}10^{-4}$ mol

% formation of 4-picoline = $(3.8\times10^{-5}/1.42\times10^{-4})$*100 = **26.8 %**

48 Hours irradiation

1. Calculation consumption of 3-methylpyridine after 48 hours irradiation

y = 136.78x

y = peak area of 3-picoline = 19.66

19.66 = 136.78x

x = 0.14 M; mol = (0.14*2)/1000 = 2.8×10^{-4} mol

weight of crude reaction from trapping = 0.04 g

g/MW = 0.04/93 = 4.3×10^{-4} mol

$(2.8 \times 10^{-4} / 4.3 \times 10^{-4}) \times 100$ = 65.1 % rest

100- 65.1 % rest = **34.9 % consumption**

2. Calculation formation of 2-methylpyridine after 48 hours irradiation

y = 125.07x

y = peak area of 2-picoline = 6.77

6.77 = 125.07x

x = 0.054 M; mol = $(0.054*2)/1000 = 1.1 \times 10^{-4}$ mol

mole consume of 3-picoline = $(4.3 \times 10^{-4})* 34.9/100 = 1.5 \times 10^{-4}$ mol

% formation of 2-picoline = $(1.1 \times 10^{-4}/1.5 \times 10^{-4})*100$ = **73.3 %**

3. Calculation formation of 4-methylpyridine after 48 hours irradiation

y = 166.58x

y = peak area of 4-picoline = 3.2

3.2 = 166.58x

x = 0.019 M; mol = $(0.019*2)/1000 = 3.8 \times 10^{-5}$ mol

mole consume of 3-picoline = $(4.3 \times 10^{-4})* 34.9/100 = 1.5 \times 10^{-4}$ mol

% formation of 2-picoline = $(3.8 \times 10^{-5}/1.5 \times 10^{-4})*100$ = **25.3 %**

72 Hours irradiation

1. Calculation consumption of 3-methylpyridine after 72 hours irradiation

y = 136.78x

y = peak area of 3-picoline = 14.25

14.25 = 136.78x

x = 0.1 M; mol = (0.1*2)/1000 = 2×10^{-4} mol

weight of crude reaction from trapping = 0.035 g

g/MW = 0.035/93 = $3.76\text{x}10^{-4}$ mol

(2×10^{-4} / $3.76\ \text{x}10^{-4}$) x100 = 53.2 % rest

100- 53.2 % rest = **46.8 % consumption**

2. Calculation formation of 2-methylpyridine after 72 hours irradiation

y = 125.07x

y = peak area of 2-picoline = 6.77

6.77 = 125.07x

x = 0.054 M; mol = (0.054*2)/1000 = 1.1×10^{-4} mol

mole consume of 3-picoline = ($3.76\text{x}10^{-4}$)* 46.8/100 = $1.8\text{x}10^{-4}$ mol

% formation of 2-picoline = ($1.1\times10^{-4}/1.8\times10^{-4}$)*100 = **61.1 %**

3. Calculation formation of 4-methylpyridine after 72 hours irradiation

y = 166.58x

y = peak area of 4-picoline = 2.65

2.65 = 166.58x

x = 0.016 M; mol = (0.016*2)/1000 = 3.2×10^{-5} mol

mole consume of 3-picoline = ($3.76\text{x}10^{-4}$)* 46.8/100 = $1.8\text{x}10^{-4}$ mol

% formation of 4-picoline = ($3.2\times10^{-5}/1.8\times10^{-4}$)*100 = **17.8 %**

96 Hours irradiation

1. Calculation consumption of 3-methylpyridine after 96 hours irradiation

y = 136.78x

y = peak area of 3-picoline = 11.45

11.45 = 136.78x

x = 0.084 M; mol = (0.084*2)/1000 = 1.7×10^{-4} mol

weight of crude reaction from trapping = 0.028 g

g/MW = 0.028/93 = $3.01\text{x}10^{-4}$ mol

(1.7×10^{-4} / $3.01\ \text{x}10^{-4}$) x100 = 56.5% rest

100- 56.5 % rest = **43.5 % consumption**

2. Calculation formation of 2-methylpyridine after 96 hours irradiation

y = 125.07x

y = peak area of 2-picoline = 4.95

1 = 125.07x

x = 0.04 M; mol = (0.04*2)/1000 = 8×10^{-5} mol

mole consume of 3-picoline = ($3.01\text{x}10^{-4}$)* 43.5/100 = $1.3\text{x}10^{-4}$ mol

% formation of 2-picoline = ($8\times10^{-5}/1.3\times10^{-4}$)*100 = **61.5 %**

3. Calculation formation of 4-methylpyridine after 96 hours irradiation

y = 166.58x

y = peak area of 4-picoline = 2.12

2.12 = 136.78x

x = 0.015 M; mol = (0.015*2)/1000 = 3×10^{-5} mol

mole consume of 3-picoline = ($3.01x10^{-4}$)* 43.5/100 = $1.3x10^{-4}$ mol

% formation of 4-picoline = ($3\times10^{-5}/1.3\times10^{-4}$)*100 = **23.1 %**

Quantitative analysis of vapor phase photolysis of 4-methylpyridine

24 Hours irradiation

1. Calculation consumption of 4-methylpyridine after 24 hours irradiation

y = 166.58x

y = peak area of 4-picoline = 10.67

10.67 = 166.58x

x = 0.064 M; mol = (0.063*2)/1000 = 1.3×10^{-4} mol

weight of crude reaction from trapping = 0.043 g

g/MW = 0.043/93 = $4.6x10^{-4}$ mol

(1.3×10^{-4} / 4.6 $x10^{-4}$) x100 = 28.3 % rest

100- 28.3 % rest = **71.7 % consumption**

2. Calculation formation of 2-methylpyridine after 24 hours irradiation

y = 125.07x

y = peak area of 2-picoline = 1

1 = 125.07x

x = 0.008 M; mol = (0.008*2)/1000 = 1.6×10^{-5} mol

mole consume of 4-picoline = ($4.6x10^{-4}$)* 71.7/100 = $3.3x10^{-4}$ mol

% formation of 2-picoline = (1.6×10^{-5}/3.3×10^{-4})*100 = **4.8 %**

3. Calculation formation of 3-methylpyridine after 24 hours irradiation

y = 136.78x

y = peak area of 3-picoline = 1.3

1.3 = 136.78x

x = 0.0095 M; mol = (0.0095*2)/1000 = 1.9×10^{-5} mol

mole consume of 4-picoline = (4.6×10^{-4})* 71.7/100 = 3.3×10^{-4} mol

% formation of 3-picoline = (1.9×10^{-5}/3.3×10^{-4})*100 = **5.7 %**

48 Hours irradiation

1. Calculation consumption of 4-methylpyridine after 48 hours irradiation

y = 166.58x

y = peak area of 4-picoline = 19.26

19.26 = 166.58x

x = 0.11 M; mol = (0.11*2)/1000 = 2.2×10^{-4} mol

weight of crude reaction from trapping = 0.044 g

g/MW = 0.043/93 = 4.7×10^{-4} mol

(2.2×10^{-4} / 4.7×10^{-4}) x100 = 46.8 % rest

100- 46.8 % rest = **53.2 % consumption**

2. Calculation formation of 2-methylpyridine after 48 hours irradiation

y = 125.07x

y = peak area of 2-picoline = 2.2

2.2 = 125.07x

x = 0.017 M; mol = (0.017*2)/1000 = 3.5×10^{-5} mol

mole consume of 4-picoline = $(4.7\text{x}10^{-4})$* 46.8/100 = $2.2\text{x}10^{-4}$ mol

% formation of 2-picoline = $(3.5\times10^{-5}/2.2\times10^{-4})$*100 = **15.9 %**

3. Calculation formation of 3-methylpyridine after 48 hours irradiation

y = 136.78x

y = peak area of 3-picoline = 2.9

2.9 = 136.78x

x = 0.021 M; mol = (0.021*2)/1000 = 4.2×10^{-5} mol

mole consume of 4-picoline = $(4.7\text{x}10^{-4})$* 46.8/100 = $2.2\text{x}10^{-4}$ mol

% formation of 3-picoline = $(4.2\times10^{-5}/2.2\times10^{-4})$*100 = **19 %**

72 Hours irradiation

1. Calculation consumption of 4-methylpyridine after 72 hours irradiation

y = 166.58x

y = peak area of 4-picoline = 10.31

10.31 = 166.58x

x = 0.062 M; mol = (0.062*2)/1000 = 1.2×10^{-4} mol

weight of crude reaction from trapping = 0.032 g

g/MW = 0.032/93 = $3.4\text{x}10^{-4}$ mol

$(1.2\times10^{-4} / 3.4 \times10^{-4}) \times100 = 35.3$ % rest

100- 35.3 % rest = **64.7 % consumption**

2. Calculation formation of 2-methylpyridine after 72 hours irradiation

y = 125.07x

y = peak area of 2-picoline = 1.3

1.3 = 125.07x

x = 0.0104 M; mol = (0.0104*2)/1000 = 2×10^{-5} mol

mole consume of 4-picoline = (3.4×10^{-4})* 64.7/100 = 2.2×10^{-4} mol

% formation of 2-picoline = $(2\times10^{-5}/2.2\times10^{-4})$*100 = **9.1 %**

3. Calculation formation of 3-methylpyridine after 72 hours irradiation

y = 136.78x

y = peak area of 3-picoline = 1.7

1.7 = 136.78x

x = 0.012 M; mol = (0.012*2)/1000 = 2.4×10^{-5} mol

mole consume of 4-picoline = (3.4×10^{-4})* 64.7/100 = 2.2×10^{-4} mol

% formation of 3-picoline = $(2.4\times10^{-5}/2.2\times10^{-4})$*100 = **10.1 %**

96 Hours irradiation

1. Calculation consumption of 4-methylpyridine after 96 hours irradiation

y = 166.58x

y = peak area of 4-picoline = 17.72

17.72 = 166.58x

x = 0.106 M; mol = (0.106*2)/1000 = 2.1×10^{-4} mol

weight of crude reaction from trapping = 0.047 g

g/MW = 0.047/93 = $5x10^{-4}$ mol

(2.1×10^{-4} / 5.0 $x10^{-4}$) x100 = 42 % rest

100- 42 % rest = **58 % consumption**

2. Calculation formation of 2-methylpyridine after 96 hours irradiation

y = 125.07x

y = peak area of 2-picoline = 2.51

2.51 = 125.07x

x = 0.02 M; mol = (0.02*2)/1000 = 4×10^{-5} mol

mole consume of 4-picoline = ($5.0x10^{-4}$)* 58/100 = $2.9x10^{-4}$ mol

% formation of 2-picoline = (4.0×10^{-5}/2.9×10^{-4})*100 = **13.8 %**

3. **Calculation formation of 3-methylpyridine after 96 hours irradiation**

y = 136.78x

y = peak area of 3-picoline = 3.15

3.15 = 136.78x

x = 0.023 M; mol = (0.023*2)/1000 = 4.6×10^{-5} mol

mole consume of 4-picoline = $(5.0\text{x}10^{-4})$* 58/100 = $2.9\text{x}10^{-4}$ mol

% formation of 3-picoline = $(4.6\times10^{-5}/2.9\times10^{-4})$*100 = **15.8 %**

BIBIOGRAPHY

Miss Tharinee Vongnakorn was born on May 2, 1978 at Trat province. She obtained Bachelor of Science,department of chemistry, Ramkhamheang Universitry in 2000. She was admitted to the Master degree program, Organic chemistry at Chulalongkorn Universitry in 2003. While she was studying,she received the teaching assistant scholarship from faculty of Science, WPI University.