5-Nitropyridine-2-sulfonic acid, a new precursor for 2,5-disubstituted pyridines

Jan M. Bakke[*a], Hanna S. H. Gautun[a], Christian Rømming[b], and Ingrid Sletvold[a]

[a)]Department of Chemistry, The Norwegian University of Science and Technology, Sem Sælands vei 8, NO-7491 Trondheim, Norway; [b)]Department of Chemistry, University of Oslo, PO 1033 Blindern, NO-0315 Oslo, Norway
E-mail: Jan.Bakke@chembio.ntnu.no

(received 25 Jun 01; accepted 18 Oct 01; published on the web 26 Oct 01)

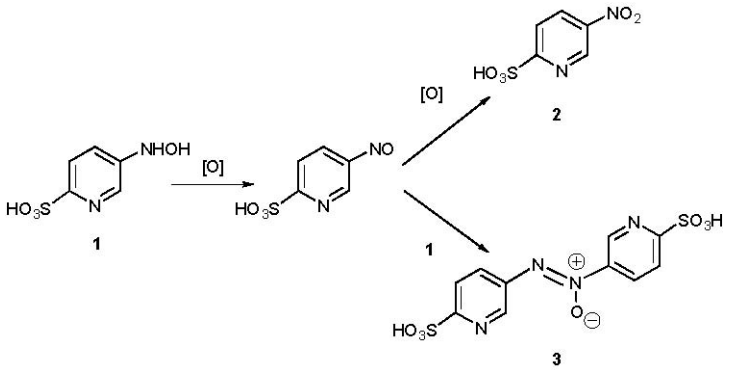
Abstract
Oxidation of 5-hydroxyaminopyridine-2-sulfonic acid (**1**) to 5-nitropyridine-2-sulfonic acid (**2**) may be performed selectively by SPB in acetic acid, bleach in water or potassium permanganate in water, with the last as the preferred one. The structure of **2** was verified by X-ray crystallography. The crude products proved difficult to purify efficiently due to inorganic impurities, but substitution of the sulfonyl group in **2** with methanol yielded 2-methoxy-5-nitropyridine (**6**) in 44, 42 and 57 % overall yield from **1**, respectively from the three methods. The reaction of **1** with SPC afforded 5,5'-azoxypyridine-2,2'-disulfonic acid (**3**) which, upon treatment with methanol gave 5,5'-azoxypyridine-2,2'-dimethoxypyridine (**5**) in 57 % yield from **1**.

Keywords: 2,5-Disubstituted pyridines, 5-nitropyridine-2-sulfonic acid, oxidation, sodium perborate (SPB), X-ray crystallography

Introduction

We have reported a new method for preparation of β-nitropyridines[1] and are currently investigating their chemistry. As the electron deficient character of the pyridine ring is enhanced by the incorporation of a nitro group in the 3-position, these compounds would be expected to be susceptible to nucleophilic attacks in the positions *ortho* and *para* to the nitro group. The 2,5-substitution pattern of pyridine is the base for many pharmaceuticals and agrochemicals. In general, however, this pattern has been difficult to obtain with a high regioselectivity.[2] We have recently reported nucleophilic substitution reactions on a number of substituted 3-nitropyridines by which hydrogen was substituted by various amino groups.[3] Also, we have published the addition of sodium sulfite to 3-nitropyridine to give 5-hydroxyaminopyridine-2-sulfonic acid **(1)**

as the final product.[4] In continuation with this we wished to investigate the versatility of **1** for preparation of other 2,5-substituted pyridines by substituting the sulfonic acid with other nucleophiles. In order to improve the nucleofuge character of the sulfonic acid it was desirable to oxidize the hydroxylamino group of **1** to the corresponding 5-nitropyridine-2-sulfonic acid **(2).** By this it would also be possible by standard transformations of the nitro group to introduce a variety of substituents into the 5-position of the pyridine ring. Only one brief reference to compound 2 was found in the litterature. In an attempt to convert 2-thiol-5-nitropyridine to 2-amino-5-nitropyridine with ammoniacal potassium permanganate minor amounts of potassium-5-nitropyridine-2-sulfonate were obtained. No yields or analytical data were reported.[5]
The litterature offers numerous reagents for oxidations of amines, hydroxylamines and nitroso compounds to the corresponding nitro compounds. Unfortunatly, such oxidations are often complicated by condensation between unreacted hydroxylamine and the *in situ* formed nitroso compound, to form an azoxy product[6] as illustrated for **1** in Scheme 1.



Scheme 1 Oxidation of 5-hydroxyaminopyridine-2-sulfonic acid **(1).**

In order to favour the formation of **2**, a strong oxidant and a low concentration of the hydroxylamine **1** would be necessary. We have investigated the oxidation of **1** with a number of oxidizing agents and under a variety of conditions. The results are given here.

Results and Discussion

In a preliminary experiment the hydroxylamine **1** was treated with 65 % nitric acid. The reaction was run at 50 °C in order to achieve a complete convertion of **1** to **2**. However, under these conditions the sulfonyl group of **2** was readily substituted with water and 2-hydroxy-5-nitropyridine **(4)** was obtained as the final product. Although this was not the desired result, it indicated that the sulfonyl group of **1** would be a good leaving group, confirming our predictions above. Hydrolysis of 2-chloro-5-nitropyridine has been proposed by Reinheimer *et al.*[7] to be an acid catalysed nucleophilic aromatic substitution. In view of this we tried to avoid the formation of **4** by applying less acidic oxidizing conditions. The results from a series of experiments are

given in Table 1.

Attempts to prepare **2** by a slow addition of **1** to aqueous hydrogen peroxide gave a bisaromatic compound **(3)** as the major product. The identity of **3** proved difficult to establish directly as no crystalls of sufficient quality for X-ray crystallography or elemental analysis were obtainable. However, refluxing of **3** with sulfuric acid in methanol for 65 h. afforded the derivative **5** with mp and spectroscopic properties identical with those reported for 5,5'-azoxy-2,2'-dimethoxypyridine.[8] Thus, the identity of 3 was 5,5'-azoxypyridine-2,2'-disulfonic acid.

Andeno and coworkers[9] have achieved oxidation of aniline to nitrobenzene by applying sodiumpercarbonate (SPC) in the presence of acetonitrile, wet alcoholic solvent and ultrasound. Under these conditions SPC releases hydrogen peroxide which reacts with acetonitrile to give peroxycarboxyimidic acid. However, gradual addition of **1** to a premade mixture of SPC, acetonitrile and wet methanol subjected to ultrasound gave only compound **3.**

Table 1 Oxidation of 5-hydroxyaminopyridine-2-sulfonic acid (**1**)

Entry	oxidizing media	temp	2[a]	3[a]	4[a]	5[b]
		ºC	%	%	%	% (mp,[c] ºC)
a	HNO_3[d]	50	37	0	63	
b	H_2O_2 / H_2O	50	5	95	0	
c	SPC / MeCN / MeOH					
	H_2O / ultrasound	20	0	100	0	
d	H_2O_2 / TFA[d]	5	77	20	3	
e	UHP / TFA[d]	5-20	80	20	0	
f	H_2O_2 / HOAc	50	69	31	0	
g	SPB / HOAc	50	98	2	0	43.8 (102.0-104.5)
h	SPB / H_2O	50	20	80	0	
i	NaOCl / H_2O	20	99	1	0	42.4 (101.0-105.0)
j	$KMnO_4$ / H_2O	20	98	2	0	57.1 (108.0-109.0)

Composition of the reaction mixture determined by ^{1}H NMR; b) Isolated yield of 2-methoxy-5-nitropyridine **(5)** determined over two steps from **1**; c) lit.,[19] 109 – 110 ºC; d) The oxidant was added to a stirred solution of 5-hydroxymethylpyridine-2-sulfonic acid **(1)**.

Taylor and McKillop have published the oxidation of nitrosopyrimidines to nitropyrimidines with 30 % hydrogen peroxid in trifluoroacetic acid (TFA).[10] The reactive specie in these reactions is believed to be pertrifluoroacetic acid. Due to low solubility of **1** in TFA, 35 % hydrogen peroxide was added to a suspension of **1** in TFA at 5 °C (entry d). After 20 h the reaction mixture consisted of the compounds **2** (77 %), **3** (20 %) and **4** (3%). After crystallization of this product mixture from nitromethane, the structure of **2** was established by X-ray crystallography to be 5-nitropyridine-2-sulfonic acid (see Figure 1).

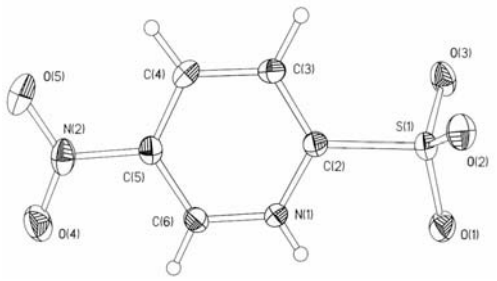


Figure 1. X-ray structure of 5-nitropyridine-2-sulfonic acid (**2**).

Attempts to oxidize **1** under anhydrous conditions using urea hydrogenperoxide (UHP) in TFA[11] proceeded much slower. The reaction gave the same amount of **3**, but no traces of **4** were observed.

Peracetic acid has been reported as a reagent for oxidation of aromatic amines.[12] Addition of **1** to a mixture of 30 % hydrogen peroxide in acetic acid (entry f) gave a mixture of **2** and **3** in a ratio 69 : 31, as well as several other unidentified byproducts.

McKillop and Tarbin have reported sodium perborate (SPB) in glacial acetic acid as an efficient reagent for the oxidation of various electron deficient anilines to nitroarenes, although 3-aminopyridine was said to give only black tar.[13] However, addition of an aqueous solution of **1** to a solution of SPB in 95 % acetic acid at 50 °C afforded **2** with only minor amounts of the azoxy compound **3** (entry g). Work-up of this mixture afforded a crude brown product, which proved difficult to purify efficiently. The surplus mass obtained indicated the presence of large amounts of inorganic impurities. The real nature of the active oxidant is not clear, but the presence of the acetic acid seems to be crucial since oxidation of **1** with SPB dissolved in just water gave a ratio of **2 : 3** = 20 : 80 (entry h). Comparison with the results obtained for oxidation with hydrogen peroxide in acetic acid (entry f) indicate that the active specie may be some kind of peracetoxyboron specie[14] rather than plain peracetic acid.

Recently, Cicchi and co-workers[15] reported oxidations of hydroxylamines to nitrones with commercial bleach. We found that **1** may be transformed to **2** with high selectivity (99 %) at room temperature, using household bleech as oxidant.Unfortunatly, the resulting orange/brown product was difficult to purify efficiently.

All these attempts either gave a low yield of **2** and **3** as the major product, or gave mixtures difficult to work up. However, potassium permanganate was another possible oxidant.[16] Oxidation of **1** with $KMnO_4$ in water indeed afforded the desired nitro compound **2** as a light yellow powder with only minor amounts (2 %) of **3** present. Again, the yield was difficult to establish, probably due to inorganic impurities even after treatment with acidic ion exchange resin. In an attempt to estimate the yield, the isolated product was refluxed in methanol to form 2-methoxy-5-nitropyridine **(6).** From ^{1}H NMR this appeared to be a 100 % clean reaction. The yield of **6** was 57 % based on **1**. Similar treatment of the crude products obtained by oxidation of **1** with SPB/HOAc or NaOCl afforded **6** in 44 and 42 % yields, respectively. From this, we

estimate the yield of 5-nitropyridine-2-sulfonic acid **(2)** from 5-hydroxyaminopyridine-2-sulfonic acid **(1)** by $KMnO_4$ oxidation to be 60 – 65 %.
In conclusion, oxidation of **1** with potassium permanganate appears to be the most efficient method for preparation of **2**. The sulfonyl group may be substituted with water or methanol. The versatility of **1** in nucleophilic aromatic substitution reactions is currently beeing investigated**.**

Experimental Section

General Procedures. The spectroscopic and analytical equipment used have been reported elsewhere.[1] 5-Hydroxyaminopyridine-2-sulfonic acid (**1**) was prepared as previously described.[4] The concentration of "household bleech" was determined by titration according to Larrow *et al.*[17]

Oxidation of 1 with HNO_3. 5-Hydroxyaminopyridine-2-sulfonic acid **(1)** (0.50 g, 2.63 mmol) was added nitric acid (65 %, 5 ml). The resulting mixture quickly turned green while brown, nitrous gases evolved. The reaction was kept at 50 °C. After 30 min the reaction turned yellow. At this point ^{1}H NMR of the mixture indicated complete convertion of **1** to 5-nitropyridine-2-sulfonic acid **(2)** (37 %) and 2-hydroxy-5-nitropyridine **(4)** (63 %). Heating of the reaction for another 3 h at 80 °C converted all of **2** to compound **4**. The mixture was then added ethanol (200 ml). The solvents were evaporated under reduced pressure to give 0.50 g of a solid material. Crystallization from 80 % ethanol afforded 53 mg of orange crystalls, which showed the same spectroscopic properties as commercial 2-hydroxy-5-nitropyridine (4). Sublimation of a sample for analysis afforded crystalls with mp. 185.5 – 186.5 °C (lit.[18] 186 °C). A mixture melting point with an authentic specimen showed no depression.
Oxidation of 1 with hydrogen peroxide. A solution of hydrogen peroxide (35 %, 0.23 ml) in water (20 ml) was warmed to 50 ºC and added a solution of **1** (0.1002g, 0.53 mmol) in water (20 ml) at a rate of 0.25 ml/min. ^{1}H NMR of the reaction mixture 15 h after the addition was completed showed complete convertion of **1** to compounds **2** (5 %) and 3 (95 %). Physical data for 3 are given under oxidation of 1 with SPC.
Oxidation of 1 with sodium percarbonate (SPC). A mixture of SPC (0.5502g, 3.50 mmol), acetonitrile (20 ml) and water (0.5 ml) was treated with ultrasound for 30 min before a solution of **1** (0.2504 g, 1.32 mmol) in methanol (55 ml) and water (2.5 ml) was added at a rate of 0.25 ml/min. The reaction mixture turned brick red with some white precipitate. The ultrasound was switched off 30 min after the addition was completed and the reaction stirred at room temperature for 16 h. ^{1}H NMR of the mixture indicated complete convertion of **1** to one product, 3. The reaction mixture was added water (30 ml), warmed to 50°C and added aqueous $NaHSO_3$ (satd.) untill a negative peroxide test was obtained. The mixture was cooled to room temperature and passed through a column of Ion Exchanger Amberlite® IR-120 (15 cm long, 2.5 cm id). The solvent was evaporated under reduced pressure to give a semicrystalline, yellow product. Crystallization (ethanol / water) afforded 0.1428 g of beige crystalls (60.0 % yield) which

exhibited spectroscopic properties which could be explained by the structure of 5,5'-azoxypyridine-2,2'-disulfonic acid (3). No definet melting point up to 350 ºC; δ_H [300 MHz; D_2O; $(CH_3)_3SiCD_2CD_2CO_2Na$] 8.12 (1H, d, J = 8.6), 8.20 (1H, d, J = 8.6), 8.85 (1H, dd, J = 2.3, 8.6), 8.90 (1H, dd, J = 2.5, 8.6), 9.22 (1H, d, J = 2.1), 9.53 (1H, d, J = 2.4); δ_C(75 MHz; D_2O; $(CH_3)_3SiCD_2CD_2CO_2Na$] 124.3, 124.5, 136.1, 137.1, 143.9, 146.8, 147.9, 149.6, 161.2, 164.1; IR (KBr): ν 3455 (br. m), 3098 (w), 1643 (w)1589 (w), 1462 (w), 1377 (w), 1309 (w), 1242 (s), 1224 (s), 1160 (m), 1118 (w), 1045 (s), 1017 (m), 915 (w), 839 (w), 706 (m), 639 (m), 606 (m), 564 (w) cm^{-1}; MS (250 °C, 70 eV) *m/z* (% rel. int.) 258 (9), 255 (38), 192 (14), 162 (5), 160 (30), 128 (22), 111 (5), 97 (7), 96 (6), 85 (8), 83 (7), 81 (5), 71 (11), 69 (9), 66 (8), 64 (100), 57 (19), 55 (8), 43 (9).

Oxidation of 1 with hydrogen peroxide in trifluoroacetic acid. A suspension of 1 (1.25 g, 6.58 mmol) and trifluoroacetic acid (500 ml) was stirred in an ice-water bath for 30 min. To this H_2O_2 (35 %, 3 ml) was added dropwise over a period of 5 min. The reaction gradually changed colour from yellow to green. The reaction was maintained in the ice-waterbath for 20 h. By this time all starting material was dissolved and the reaction mixture had retained a yellow colour. A negative peroxide test was obtained and the solvents were evaporated under reduced pressure to give 2.30 g of a yellow oil. ^{1}H NMR of this crude product indicated the presence of **2** (76 %), 3 (19.5 %), **4** (3.0 %) and an unidentified compound (1.5 %). The crude product was washed with CH_2Cl_2 (100 ml). Drying of the residue afforded 1.63 g of a light brown powder. A sample (0.50 g) of this product was crystallized from nitromethane to give 0.020 g yellow crystalls which were identified as 5-nitropyridine-2-sulfonic acid **(2)** by X-ray analysis. mp 160.5 °C (decomp.) δ_H [300 MHz; D_2O; $(CH_3)_3SiCD_2CD_2CO_2Na$] 8.17 (H^4, d, J = 8.6), 8.81 (H^3, dd, J = 2.5, 8.6), 9.42 (H^6, d, J = 2.3); δ_C [75 MHz; D_2O; $(CH_3)_3SiCD_2CD_2CO_2Na$] 124.8, 137.5, 147.9, 148.2, 166.0; IR (KBr): ν 3448 (br. s), 3114 (m), 2906 –2268 (br. w), 2088 (w), 1854 (s), 1601 (w), 1552 (s), 1526 (m), 1424 (m), 1362 (s), 1274 (s), 1229 (s), 1181 (s), 1134 (m), 1049 (s), 1010 (w), 997 (m), 862 (m), 833 (w), 753 (s), 646 (s), 547 (m), 462 (m) cm^{-1}; MS (250 °C, 70 eV) *m/z* (% rel. int.) 140 (100), 110 (16), 94 (9), 93 (10), 66 (15), 64 (93). Crystal data: $C_5H_6N_2O_6S.H_2O$, FW = 222.18, orthorhombic, a = 6.9651(4) Å, b = 10.1328(6) Å, c = 11.8650(7) Å, U = 836.30(8) $Å^3$, T = 150 K, space group $P2_12_12_1$, Z = 4, absorption coeffiecient 0.396 cm^{-1}, 15540 reflections collected, 3120 unique (R_{int} = 0.0470), final R indices [$I > 2\sigma(I)$] R_1 = 0.0386, wR_2 = 0.0933, R indices (all data) R_1 = 0.0446, wR_2 = 0.0977.

Oxidation of 1 with UHP in trifluoroacetic acid. A mixture of **1** (0.50g, 2.63 mmol) and trifluoroacetic acid (200 ml) was stirred on an ice-waterbath for 30 min. To this suspension UHP (0.56 g, 6.00 mmol) was added in two portions over a period of 15 min. After stirring at 5 °C for 1h the reaction was light green. The reaction was allowed to warm up to 20 °C and was stirred for 72 h. By this time the reaction had retained a yellow colour. ^{1}H NMR of the reaction mixture indicated the presence of **2** (80 %) and **3** (20 %).

Oxidation of 1 with hydrogen peroxide in acetic acid. Glacial acetic acid (40 ml) was cooled on an ice-water bath and added aqueous hydrogen peroxide (35 %, 0.44 ml). The cooling bath was removed and the mixture was allowed to reach roomtemperature. After 30 min the mixture

was warmed to 50 ºC before a solution of **1** (0.2047 g, 1.08 mmol) in water (20 ml) was added at a rate of 0.25 ml/min. ^{1}H NMR of the reaction mixture 30 min after the addition was completed, indicated complete convertion of **1** to a mixture of **2** (69 %) and 3 (31 %).

Oxidation of 1 by sodium perborate (SPB). A mixture of SPB (0.8520g, 8.53 mmol) in acetic acid (95 %, 80 ml) was warmed to 50 °C, which caused the SPB to dissolve. To this mixture was added a solution of **1** (0.4053 g, 2.13 mmol) in water (40 ml) by a dispenser pump (0.25 ml / min). After the addition was completed the reaction was stirred for 30 min. By this time the reaction was dark yellow. ^{1}H NMR indicated complete conversion of **1** to **2** (98 %) and **3** (2 %). To the reaction mixture was added aqueous $NaHSO_3$ (10 %, 1.2 ml) untill a negative peroxide test was obtained. The solvents were evaporated to give a green residue, which was dissolved in water (100 ml) and passed through a column of Ion Exchanger Amberlite® IR-120 (28 cm long, 2.5 cm id). The solvent was evaporated, the residue added dry toluene (100 ml) which was evaporated and the resulting product dried under reduced pressure to give 1.05 g of a brown, solid material. ^{1}H NMR of this crude product indicated the presence of **2** (97%) and **3** (3%).

Oxidation of 1 with sodium hypochlorite. A solution of **1** (0.50 g, 2.63 mmol) in water (50 ml) was added dropwise (0.25 ml / min) to a solution of NaOCl (0.64 M[17], 12.34 ml) in water (60 ml) at room temperature. After the addition was completed the reaction was stirred for another 8 h. ^{1}H NMR of the reaction mixture indicated the presence of **2** (97 %) and **3** (3 %). To the mixture was then added aqueous $NaHSO_3$ (10 %, 2.75 ml) untill a negative test with starch-iodide paper was obtained. The solution was passed through a column of Ion Exchanger Amberlite® IR-120 (28 cm long, 2.5 cm id) and the solvent evaporated. To the residue was added dry toluene (100 ml) which was evaporated and the resulting product dried further under reduced pressure to give 0.80 g of a brown solid material. ^{1}H NMR of this crude product indicated the presence of **2** (92 %), and **3** (3%) and 2-hydroxy-5-nitropyridine (**4**) (5%).

Oxidation of 1 by $KMnO_4$. A solution of **1** (4.00 g, 21.05 mmol) in water (160 ml) was added at a rate of 0.25 ml/min to a vigorously stirred solution of potassium permanganate (6.56 g, 41.52 mmol) in water (160 ml), at room temperature. After the addition was completed (10 h, 40 min) the reaction was stirred at room temperature for another 10 h. The mixture was then added methanol (5 ml), stirred for 3 h and filtered. The yellow filtrate was concentrated to 60 ml and passed through a column of Ion Exchanger Amberlite® IR-120 (28 cm long, 2.5 cm id). The eluate was stripped of water and the residue added dry toluene (100 ml) which was subsequently evaporated. Drying under reduced pressure afforded a light yellow powder (4.273 g) with the same spectroscopic properties as 5-nitropyridine-2-sulfonic acid **(2).**

5,5′-Azoxy-2,2′-dimethoxypyridine (5). A suspension of 5,5′-azoxypyridine-2,2′-disulfonic acid (**3**) (0.5086g, 1.40 mmol) in methanol (70 ml) was added sulfuric acid (conc., 0.25 ml) and warmed with reflux for 65 h. At this point all solid material had dissolved to give a clear, yellow solution. The reaction mixture was cooled to room temperature, added water (2 ml) and neutralized by addition of $NaHCO_3$. The solvent was evaporated and the residue partitioned between chloroform (70 ml) and water (70 ml). The aqueous layer was extracted with chloroform (2 x 70 ml). The combined organic layers were washed with brine (70 ml) and dried

($MgSO_4$). Evaporation of the solvents under reduced pressure to gave 0.2524 g of a crude yellow solid. Crystallization afforded 5 (0.1757 g, 48 % yield) as bright yellow crystalls. The overall yield from **1** was 45 %. mp 132 - 133°C (from methanol) (lit.,[12] 133-134 °C). δ_H(300 MHz; $CDCl_3$; Me_4Si) 4.02 (3H, s, OCH_3), 4.03 (3H, s, OCH_3), 6.82 (1H, d, *J* = 9.0), 6.83 (1H, d, *J* = 9.0), 8.45 (1H, dd, *J* = 2.7, 9.0), 8.65 (1H, dd, *J* = 2.7, 9.0), 9.03 (1H, d, *J* = 2.5), 9.11(1H, d, *J* = 2.7); δ_C(75 MHz; $CDCl_3$; Me_4Si) 54.0, 54.3, 110.5, 110.6, 132.7, 135.3, 135.5, 138.9, 142.2, 146.3, 164.0, 165.6; IR (KBr): ν 3084 (w), 2971(w), 2939 (w), 1595 (s), 1548 (m), 1483 (s), 1385 (s), 1315 (s), 1262 (s), 1114 (m), 1095 (m), 1024 (m), 942 (w), 911 (w), 836 (m), 776 (m), 750 (w) cm^{-1}; MS (250 °C, 70 eV) *m/z* (% rel. int.) 261 (M+1, 16), 260 (M^+, 100), 259 (5), 244 (12), 232 (20), 231 (7), 218 (9), 217 (53), 189 (4), 138 (6), 136 (7), 123 (5), 122 (24), 109 (8), 108 (28), 95 (14), 93 (11), 81 (9), 80 (45).

2-Methoxy-5-nitropyridine (6), general procedure. A mixture of **2** (0.500 g) in methanol (50 ml) was heated at reflux for 18 h. The solvent was evaporated and the residue added CH_2Cl_2 (30 ml), water (20 ml) and aqueous $NaHCO_3$ (satd.) untill pH = 9. The aqueous layer was extracted with CH_2Cl_2 (2 x 10 ml). The combined organic layers were washed with brine (10 ml) and dried ($MgSO_4$). The solvent was evaporated under reduced pressure and the residue crystallized from aqueous ethanol. The yields were estimated on the basis of **1**. The melting points are given in Table 1. δ_H(300 MHz; $CDCl_3$; Me_4Si) 4.06 (3H, s), 6.83 (1H, d, *J* = 9.1), 8.36 (1H, dd, *J* = 2.8, 9.1), 9.09 (1H, d, *J* = 2.8); IR (KBr): ν 3068 (w), 3022 (w), 2956 (w), 1969 (w), 1902 (w), 1831 (w), 1606 (s), 1576 (s), 1510 (s), 1486 (s), 1434 (m), 1394 (m), 1350 (s), 1298 (s), 1169 (m), 1118 (s), 1000 (s), 953 (m), 844 (m), 806 (m), 766 (m), 722 (m), 662 (s), 626 (m), 539 (m), 509 (w) cm^{-1}; MS (250 °C, 70 eV) *m/z* (% rel. int.) 155 (M+1, 9), 154 (M^+, 100), 138 (4), 137 (4), 126 (5), 124 (14), 111 (4), 107 (14), 96 (6), 93 (6), 85 (4), 83 (4), 81 (11), 80 (14), 79 (14), 71 (6), 69 (5), 64 (4), 55 (6), 53 (9), 52 (5), 51 (9), 50 (5), 44 (11), 42 (24).

Acknowledgements

Generous support from The Norwegian Research Council is gratefully acknowledged.

References

1. Bakke, J. M.; Ranes, E; Riha, J.; Svensen, H. *Acta Chem. Scand.* **1999**, *50*, 141 and references cited therein.
2. Scriven, E. F. V. in book of absracts from the *17th International Congress of Heterocyclic Chemistry,* IL-33, Vienna, 1999.
3. (a) Bakke, J. M.; Svensen, H.; Trevisan, R. *J. Chem. Soc. Perkin Tran.* 2001, 376; (b) Bakke, J. M. Svensen, H. *Tetrahedron Lett.* **2001**, *42*, 4393.
4. Bakke, J. M.; Ranes, E.; Rømming, C.; Sletvold, I. *J. Chem. Soc. Perkin Tran.* **2000**, 1241.

5. Caldwell, W. T.; Kornfeld, E. C. *J. Am. Chem. Soc.* **1942**, *64*, 1695.
6. (a) Mahapatro, S. N.; Panigrahi, G. P.; Panda, A. K. *Current Science* **1980**, *49*, 227. (b) Wiley R. H. Hartman, J. L. *J. Am. Chem. Soc.* **1951**, *73*, 494. (c) Hauck A. E. and Giam, C. S. *Synth. Commun.* **1978**, *8*, 109. (d) Greenspan, F. P. *Ind. Eng. Chem.,* **1947**, *39*, 847.
7. (a) Reinheimer, J. D.; Gerig, J. T.; Garst, R.; Schrier, B. *J. Am. Chem. Soc.* **1962**, *84*, 2770;. (b) Reinheimer, J. D.; McFarland, J. T.; Amos, R. A.; Wood, J. M.; Zahniser, M.; Bowman, W. *J. Org. Chem.* **1969**, *34*, 2068.
8. Suwiński, J.; Wagner, P.; Holt, E. M. *Tetrahedron* **1996**, *52*, 9541.
9. Ando, T.; Cork, D. G.; Kimura, T. *Chem. Lett.* **1986**, 665.
10. Taylor, E. C.; McKillop, A. *J. Org. Chem.* **1965**, *30*, 3135.
11. Ballini, R.; Marcantoni, E.; Petrini, M. *Tetrahedron Lett.* **1992**, *33*, 4835.
12. (a) Emmons, W. D. *J. Am. Chem. Soc.* 1957, *79*, 5528. (b) Iben-Rasa, K. M. and Edwards, J. O. *J. Am. Chem. Soc.* **1962**, *84*, 763. (c) Iben-Rasa, K. M.; Lauro, C. G. and Edwards, J. O. *J. Am. Chem. Soc.* **1963**, *85*, 1165.
13. (a) McKillop, A.; Tarbin, J. A. *Tetrahedron Lett.* **1983**, *24*, 1505. (b) McKillop, A.; Tarbin, J. A. *Tetrahedron* **1987**, *43*, 1753.
14. (a) McKillop, A; Sanderson, W. R. *Tetrahedron* **1995**, *51*, 6145. (b) Muzart, J. *Synthesis* **1995**, 1325.
15. Cicchi, S.; Corsi, M.; Goti, A. *J. Org. Chem.* **1999**, *64*, 7243.
16. (a) Bamberger, E.; Meimberg, F. *Chem. Ber.* **1893**, *26*, 496. (b) Kornblum, N.; Clutter, R. J. and Jones, W. J. *J. Am. Chem. Soc.* **1956**, *78*, 4003.
17. Larrow, J.F.; Verhoeven, T.R.; Ryan, K. M.; Senanayake, C. H.; Reider, P. J.; Jacobsen, E. N. *Org. Synth.* **1998**, *76*, 46.
18. Chichibabin, A. E. *Ber.* **1925**, *58B*, 1707.
19. Gruber, W. *Can. J. Chem.* **1953**, *31*, 1020.