Thermal Rearrangement of Pyridylnitramines

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N-Methyl-*N*-pyridylnitramines form corresponding methylamino-nitropyridines in 74—90 % yield when heated (120—130 °C) in chlorobenzene without an acidic catalyst. *N*-(2-Pyridyl)nitramine behaves analogously while remaining primary pyridylnitramines rather decompose than rearrange. The rearrangement can be carried out in the anisole or *m*-xylene solutions without cross-nitration, hence migration of the nitro group must have an intramolecular character. Some analogies in the thermal and acid-catalyzed rearrangements have been observed. Various *ortho/para* ratios can be explained assuming different mechanisms of hydrogen transfer in the intermediary σ-complexes.

Nitramine rearrangement involves migration of the nitro group from the amino or heterocyclic nitrogen to the carbon atom, three or five nodes far [1]. The *N*-nitro compounds prone to the rearrangement can be divided into three groups. The first one comprises *N*-phenylnitramines and their secondary analogues. They are very reactive and rearrange readily under influence of diluted mineral acids, yielding corresponding *o*-nitroanilines as the main products [2, 3]. The reaction is of the first-order in nitramine and hydronium ion [4]. The mechanism, suggested by *White* [5], involves a cleavage of protonated nitramine into NO_2 radical and a cation-radical held together as a pair in the solvent cage. The second group consists of *N*-nitroazoles which can be prepared from some aza heterocycles under influence of mixed anhydrides, and *N*-nitroenamines obtained from the isomerization of corresponding nitrimines. Although these are not true nitramines, they rearrange analogously when heated neat or in an inert, high-boiling solvent without an acidic catalyst [6, 7]. Kinetic data for the rearrangement of 1-nitropyrazole in hot (166 °C) nitrobenzene are in agreement with the character of the first-order reactions [8]. The mechanism of *N*-nitroazoles isomerization involves [1, 5] sigmatropic shift followed by tautomerization, as suggested by *Habraken* and *Cohen-Fernandes* [9].

To the third class belong *N*-pyridylnitramines, 2-thiazolylnitramine, their *N*-alkyl and ring-substituted derivatives as well as *N*-phenylnitramines bearing at least two nitro groups on the aromatic ring. These nitramines are resistant to diluted mineral acid. Rearrangement occurs in concentrated sulfuric or perchloric acids in which phenylnitramines decompose violently with evolution of gases. The nitro group migrates to the more distant (*para*) position [10, 11]. The reaction rate displays the second-order dependence on nitramine; if the rearrangement is performed in the presence of acetanilide, a cross-nitration is observed [12]. Another well known feature of the pyridylnitramines rearrangement is that *N*-(3-pyridyl)nitramine cannot be isomerized; when heated to 60 °C in concentrated sulfuric acid, it forms mainly 3-hydroxypyridine [13]. Analogously, treatment of *N*-(2-pyridyl)nitramine with 11.5 M sulfuric acid produces mainly (88 %) 2-pyridone (2-hydroxypyridine) [14]. Formation of phenolic compounds in the phenylnitramine series has never been observed.

Despite of the diversity of structures and properties of the *N*-nitro compounds, their rearrangement may follow the same path since the transformation is essentially the same. In several papers on the nitramine rearrangement, published so far, the differences in reaction conditions required for the nitro group migration were emphasized. Now we want to demonstrate that pyridylnitramines can be rearranged thermally, as *N*-nitroazoles, and *o*-nitroaminopyridines predominate among the products, as in the phenylnitramine series. The differences can find simple explanations hence there is no reason to postulate different mechanisms.

EXPERIMENTAL

Aminopyridines and 2-methylaminopyridine were commercial compounds. 3-Methylaminopyridine was obtained *via* corresponding formamide as described before [15]. Oxidation of pyridine and nitration with mixed acids gave 4-nitropyridine *N*-oxide (m.p. = 163—164 °C, yield 76 %). It was boiled in concentrated hydrochloric acid for 24 h yielding 4-chloropyridine *N*-oxide (155—156 °C, 75 %). Substitution of the chlorine atom required 48 h heating to 140 °C in a sealed tube with a large excess of aqueous *N*-methylamine. 4-Methylaminopyridine *N*-oxide (186—196 °C, 95 %) was hydrogenated under atmospheric pressure in the

presence of 10 % Pd/C in ethanolic solution to give 4-methylaminopyridine (125.5—127 °C, 86 %). *N*-(2-Pyridyl)nitramine (198—203 °C, 83 %), *N*-(3-pyridyl)nitramine (181.5—182 °C, 57 %), and *N*-(4-pyridyl)nitramine (153—154 °C, 68 %) were obtained analogously as *N*-methyl-*N*-(4-pyridyl)nitramine (described below).

The infrared spectra were recorded on an FTIR spectrometer PU 9804 (Philips) as KBr pellets. Electron impact (70 eV) mass spectra were obtained on the MX 1321 instrument (Scientific Instruments, USSR). Proton and carbon NMR spectra were recorded on a Tesla BS 567A spectrometer (2.3 T), employing decoupling technique if necessary. The assignment of the chemical shifts was based on the literature data; the results published by *Kolehmainen et al.* [16, 17] were very helpful. The thermogravimetric measurements were carried out on a Unipan 605 differential scanning calorimeter and TGA 2050 (TA Instruments) thermobalance. Thermoanalytical curves were recorded using *ca.* 20 mg samples in open platinum crucibles, in a current of dry nitrogen, with the heating rate 5 °C min^{-1}

Methylation of *N*-(2-Pyridyl)nitramine

The nitramine (5.01 g; 36 mmol) was dissolved in the mixture of aqueous sodium hydroxide (14 cm^3, 10 % NaOH) and sodium carbonate (7 cm^3, 10 % Na_2CO_3). Dimethyl sulfate (2.25 cm^3, 23 mmol) was added, the mixture was vigorously shaken until homogeneous, and warmed on the boiling water bath for 1.5 h. The solution was left overnight at 0 °C, the crude product was collected by filtration and crystallized from methanol yielding 2.17 g of light yellow needles, m.p. = 161—162 °C. The filtrate was extracted with hexane (4 × 100 cm^3), the extract was dried with magnesium sulfate and concentrated to a small volume. After cooling in dry ice, it deposited 0.3 g of *N*-methyl-*N*-(2-pyridyl)nitramine. The aqueous residue after extraction was evaporated to dryness, the solid was crystallized from acetone (200 cm^3) and methanol (100 cm^3) yielding the second crop (1.45 g, total yield 66 %) of 1,2-dihydro-1-methyl-2-nitriminopyridine, m.p. = 160—161 °C, Ref. [18] gives m.p. = 161 °C. ^{1}H NMR spectrum (DMSO-d_6), δ: 8.35 (d, 1H, C-6—H), $J_{5,6}$ = 6 Hz, 8.18 (dd, 1H, C-3—H), $J_{3,4}$ = 6 Hz, $J_{3,5}$ = 2 Hz, 8.01 (dd, 1H, C-4—H), $J_{4,5}$ = 6 Hz, 7.05 (ddd, 1H, C-5—H), 3.81 (s, 3H, CH_3). ^{13}C NMR spectrum (DMSO-d_6), δ: 150.8 (C-2), 142.4 (C-4), 142.2 (C-6), 117.3 (C-3), 114.6 (C-5), 42.6 (CH_3). Mass spectrum, m/z (I_r/%): 153 (36, M^+), 107 (100), 91 (13), 80 (39), 78 (39), 66 (14). IR spectrum (KBr), $\tilde{\nu}$/cm^{-1}: 1237, 1504 (N—NO_2), 1410, 2854, 2924 (N—CH_3).

N-Methyl-*N*-(2-pyridyl)nitramine

To the solution of 2-methylaminopyridine (2.16 g; 20 mmol) in 100 cm^3 of absolute tetrahydrofuran, ethylmagnesium bromide prepared from 30 mmol of ethyl bromide and an excess of magnesium turnings in 70 cm^3 of diethyl ether, was added. The mixture was stirred for 15 min, n-butyl nitrate (3.70 g; 31 mmol) was added and the solution was stirred for 1 h at room temperature. Water (50 cm^3) and acetic acid (2 cm^3) were added, the layers were separated and the organic solution was extracted with 25 cm^3 of aqueous 10 % sodium hydrogen sulfate. It was diluted with equal volume of hexane, dried over magnesium sulfate and evaporated. The residue was dissolved in hexane, the solution stirred with charcoal, filtered and cooled in dry ice. White needles (1.30 g, 42 %) of *N*-methyl-*N*-(2-pyridyl)nitramine were collected by filtration and dried in vacuum; m.p. = 28—29 °C, Ref. [19] gives m.p. = 30—31 °C. ^{1}H NMR spectrum ($CDCl_3$), δ: 8.57 (dd, 1H, C-6—H), $J_{5,6}$ = 5 Hz, $J_{4,6}$ = 1.5 Hz, 7.92 (ddd, 1H, C-4—H), $J_{3,4}$ = $J_{4,5}$ = 7.5 Hz, 7.72 (d, 1H, C-3—H), 7.36 (dd, 1H, C-5—H), 3.81 (s, 3H, N—CH_3). ^{13}C NMR spectrum ($CDCl_3$), δ: 152.0 (C-2), 148.6 (C-6), 138.1 (C-4), 123.0 (C-5), 121.8 (C-3), 38.1 (N—CH_3). Mass spectrum, m/z (I_r/%): 153 (8, M^+), 107 (100), 92 (7), 78 (96), 52 (15), 51 (23). IR spectrum (KBr), $\tilde{\nu}$/cm^{-1}: 1276, 1534 (N—NO_2), 1417, 2856, 2951 (N—CH_3).

Neutralization of the acidic ($NaHSO_4$) solution and extraction with ether gave 1.05 g of 2-methylaminopyridine, contaminated with the nitramine; adjusted yield 83 %.

N-Methyl-*N*-(3-pyridyl)nitramine

3-Methylaminopyridine was nitrated with butyl nitrate as described above. The nitramine, m.p. = 62—63 °C (Et_2O—hexane), Ref. [20] gives m.p. = 54—55 °C, was obtained in 54 % yield. ^{1}H NMR spectrum ($CDCl_3$), δ: 8.63 (m, 2H, C-2—H, C-4—H), 7.73 (dd, 1H, C-6—H), $J_{5,6}$ = 8.5 Hz, $J_{4,6}$ = 1.5 Hz, 7.44 (dd, 1H, C-5—H), $J_{4,5}$ = 4.5 Hz, 3.76 (s, 3H, N—CH_3). ^{13}C NMR spectrum ($CDCl_3$), δ: 151.5 (C-3), 149.8 (C-2), 146.9 (C-4), 133.7 (C-5), 124.1 (C-6), 40.8 (N—CH_3). Mass spectrum, m/z (I_r/%): 153 (M^+, 29), 123 (6), 107 (68), 105 (58), 92 (60), 91 (10), 80 (39), 78 (100), 64 (39), 52 (45), 51 (44). IR spectrum (KBr), $\tilde{\nu}$/cm^{-1}: 1287, 1530 (N—NO_2), 1424, 2852, 2921 (CH_3).

N-Methyl-*N*-(4-pyridyl)nitramine

4-Methylaminopyridine (10.8 g; 0.1 mol) was dissolved in 25.2 cm^3 of sulfuric acid (96 % H_2SO_4, 0.3 mol) with cooling. The viscous solution was stirred on the ice-bath and nitric acid (0.3 mol, 12.3 cm^3 of 100 % HNO_3) was added dropwise. The mixture was maintained at 0 °C for 15 min and poured on *ca.* 700 g of crushed ice. It was neutralized and extracted continuously with methylene chloride. The solvent was evaporated and the residue crystallized from aqueous

methanol. *N*-Methyl-*N*-(4-pyridyl)nitramine (12.7 g, 83 %) was obtained as colourless plates, m.p. = 54—56 °C, Ref. [17] gives m.p. = 56.5—58 °C. ^{1}H NMR spectrum (DMSO-d_6), δ: 8.72 (d, 2H, C-2—H, C-6—H), $J_{2,3}$ = 5 Hz, 7.55 (dd, 2H, C-3—H, C-5—H), $J_{3,5}$ = 2 Hz, 3.72 (s, 3H, CH_3). ^{13}C NMR spectrum (DMSO-d_6), δ: 150.9 (C-2, C-6), 147.1 (C-4), 119.8 (C-3, C-5), 40.0 (CH_3). Mass spectrum, m/z (I_r/%): 153 (49), 107 (60), 106 (15), 92 (19), 80 (76), 78 (100), 65 (44), 52 (93). IR spectrum (KBr), $\tilde{\nu}$/cm^{-1}: 1278, 1528 (N—NO_2), 1416, 2922 (CH_3).

Rearrangement of *N*-(2-pyridyl)nitramine

A solution of the nitramine (1.39 g; 10 mmol) in 100 cm^3 of chlorobenzene was refluxed for 2 h (132 °C). The solvent was evaporated in vacuum and the residue was steam-distilled. The distillate was extracted with the chloroform—tetrahydrofuran mixture (φ_r = 1 1), the solvent was evaporated and the residue sublimed in vacuum. Yellow needles (m.p. = 166—168 °C, Ref. [21] gives m.p. = 163—164 °C) of 2-amino-3-nitropyridine were obtained in 40 % (0.56 g) yield. ^{1}H NMR spectrum (DMSO-d_6), δ: 8.41 (d, 1H, C-6—H), $J_{5,6}$ = 5 Hz, 8.39 (d, 1H, C-4—H), $J_{4,5}$ = 8 Hz, 7.88 (s, 2H, amino group), 6.77 (dd, 1H, C-5—H).

The residue after steam distillation was extracted with the same solvent mixture, the extract was evaporated to dryness and the residue purified by vacuum sublimation. 2-Amino-5-nitropyridine (0.36 g, 26 %) was obtained as yellow crystals, m.p. = 193—194 °C, Ref. [22] gives m.p. = 188 °C. ^{1}H NMR spectrum (DMSO-d_6), δ: 8.89 (d, 1H, C-6—H), $J_{4,6}$ = 1.9 Hz, 8.15 (dd, 1H, C-4—H), $J_{3,4}$ = 8.9 Hz, 6.55 (d, 1H, C-3—H), 7.55 (s, 2H, amino group).

Rearrangement of *N*-(4-pyridyl)nitramine

A suspension of the nitramine (1.39 g; 10 mmol) in 100 cm^3 of *o*-dichlorobenzene was heated to the boiling point (178 °C) for 4 h. The solvent was evaporated in vacuum and the residue crystallized from water boiling with charcoal. 4-Amino-3-nitropyridine (0.18 g, 13 %) was obtained as light yellow crystals, m.p. = 206—207.5 °C, Ref. [23] gives m.p. = 200 °C. ^{1}H NMR spectrum (DMSO-d_6), δ: 9.10 (s, 1H, C-2—H), 8.25 (d, 1H, C-6—H), $J_{5,6}$ = 5.0 Hz, 8.02 (s, 2H, amino group), 7.00 (d, 1H, C-5—H).

Rearrangement of *N*-Methyl-*N*-(2-pyridyl)nitramine

The nitramine (1.53 g; 0.01 mol) dissolved in 200 cm^3 of *m*-xylene was maintained at 130 °C for 3 h. The solution was concentrated, diluted with hexane and cooled. Yellow crystals were collected by filtration and crystallized from heptane yielding 1.39 g (90 %) of 2-(*N*-methylamino)-3-nitropyridine, m.p. = 62—63 °C, Ref. [19] gives m.p. = 63—64 °C. ^{1}H NMR spectrum ($CDCl_3$), δ: 8.46 (m, 1H, C-6—H), 8.41 (m, 1H, C-4—H), 8.30 (s broad, 1H, NH), 6.65 (dd, 1H, C-5—H), $J_{5,6}$ = 4.7 Hz, $J_{4,5}$ = 8.5 Hz, 3.13 (d, 3H, N—CH_3), J_{N-Me} = 4.7 Hz.

Rearrangement of *N*-Methyl-*N*-(3-pyridyl)nitramine

A solution of the nitramine (3.06 g; 0.02 mol) in 200 cm^3 of chlorobenzene was maintained at 120 °C for 2 h. To the cooled solution 30 g of silica gel and 200 cm^3 of hexane were added and the mixture was chromatographed employing flash chromatography technique. 3-Methylamino-2-nitropyridine, m.p. = 109—110 °C, Ref. [20] gives m.p. = 110 °C, was eluted first using benzene—hexane mixture (φ_r = 1 1) as the eluent. The solution was evaporated and the residue crystallized from heptane yielding 1.58 g (52 %) of orange needles. ^{1}H NMR spectrum ($CDCl_3$), δ: 7.89 (dd, 1H, C-6—H), $J_{5,6}$ = 6.5 Hz, $J_{4,6}$ = 1.5 Hz, 7.75 (s broad, 1H, NH), 7.50 (dd, 1H, C-4—H), $J_{4,5}$ = 8.5 Hz, 7.39 (dd, 1H, C-5—H), 3.06 (d, 3H, N—CH_3), J_{N-Me} = 5 Hz.

5-Methylamino-2-nitropyridine, m.p. = 194—195 °C (sublim.), Ref. [20] gives m.p. = 188 °C, was obtained in 28 % yield (0.87 g) from the next fraction eluted with benzene. ^{1}H NMR spectrum (DMSO-d_6), δ: 8.13 (d, 1H, C-3—H), $J_{3,4}$ = 9 Hz, 7.87 (d, 1H, C-6—H), $J_{4,6}$ = 2 Hz, 7.38 (s broad, NH), 7.01 (dd, 1H, C-4—H), $J_{3,4}$ = 9 Hz, 2.84 (d, 3H, CH_3), J_{N-Me} = 4 Hz.

Rearrangement of *N*-Methyl-*N*-(4-pyridyl)nitramine

The nitramine (2.78 g; 0.02 mol) was dissolved in 50 cm^3 of hot chlorobenzene. The solution was maintained for 3 h at 130 °C. The product was isolated by the flash chromatography using hexane and hexane—benzene mixture for the solvent elution. 4-Methylamino-3-nitropyridine was eluted with chloroform, the solvent evaporated and the residue crystallized from the benzene—heptane mixture. Pure product, m.p. = 158—160 °C, was isolated in 74 % yield. For $C_6H_7N_3O_2$ (M_r = 153.14) w_i(calc.): 47.05 % C, 4.61 % H; w_i(found): 47.16 % C, 4.70 % H. ^{1}H NMR spectrum (DMSO-d_6), δ: 9.01 (s, 1H, C-2—H), 8.44 (s broad, 1H, NH), 8.29 (d, 1H, C-6—H), $J_{5,6}$ = 6.6 Hz, 6.92 (d, 1H, C-5—H), 2.98 (d, 3H, CH_3), J_{N-Me} = 5.7 Hz.

1-Methyl-2-pyridone

The solution of 1,2-dihydro-1-methyl-2-nitriminopyridine (1.53 g; 10 mmol) in 100 cm^3 of *o*-dichlorobenzene was maintained for 48 h at the boiling point. It was cooled, diluted with 100 cm^3 of hexane and

separated by the flash chromatography technique. *o*-Dichlorobenzene was removed with the hexane—benzene mixture (φ_r = 1 1), the main product was eluted with chloroform. The eluate was evaporated and the residue distilled in vacuum (b.p. = 110 °C/1.4 kPa). 1-Methyl-2-pyridone (0.60 g, 55 %) was obtained as colourless liquid. ^{1}H NMR spectrum ($CDCl_3$), δ: 7.34 (m, 2H, aromatic protons), 6.55 (d, 1H, aromatic proton), ^3J = 11 Hz, 6.17 (dd, 1H, aromatic proton), ^3J = 6.5 Hz, 3.55 (s, 3H, N—CH_3). Mass spectrum, m/z (I_r/%): 109 (M^+, 55), 94 (2), 81 (100), 80 (82), 66 (6), 55 (15), 54 (9), 53 (13), 39 (30). IR spectrum (neat), $\tilde{\nu}$/cm^{-1}: 3080, 3030 (aromatic C—H); 2925, 2852 (aliphatic C—H); 1659 (carbonyl band); 1583, 1319, 1155 (skeletal vibrations).

RESULTS

The primary pyridylnitramines were obtained by the action of mixed acids on amino-pyridines, as described in the literature [21]. Moderate yields of the products are due to their good water solubility. Methylation of pyridylnitramines gave corresponding secondary nitramines in very poor (5—10 %) yields irrespective of the reagents (MeI, Me_2SO_4, CH_2N_2) and conditions employed; alkylation on heterocyclic nitrogen prevailed in all cases. The corresponding nitrimines were obtained in 60—66 % yield. *N*-(3-Pyridyl)nitramine formed zwitterionic 1-methyl derivative in 34 % yield when methylated with dimethyl sulfate in an alkaline acetone solution. Secondary pyridylnitramines were prepared from the methylaminopyridines. Nitration of 2- and 3-methylaminopyridine with mixed acids at 0 °C gave nitramines contaminated with the rearrangement products; hence, the amines were transformed into Grignard reagent by the action of ethylmagnesium bromide and *N*-nitrated with butyl nitrate as described before [24]. *N*-Methyl-*N*-(4-pyridyl)nitramine was much less prone to the rearrangement and was obtained in good yield under acidic conditions.

When *N*-(2-pyridyl)nitramine was heated in a differential scanning calorimeter, the DTA curve showed a sharp endothermic peak around 200 °C, followed immediately by a strong exothermic peak with maximum at 215 °C. The first one was assigned to the melting of the nitramine with partial rearrangement, the exothermic effect, accompanied with *ca.* 80 % mass loss, came from decomposition of the sample. It should be mentioned here that 5- and 3-nitro-2-aminopyridines were thermally stable up to 250 °C. *N*-(3-Pyridyl)- and *N*-(4-pyridyl)nitramine did not melt, when the temperature reached 164 °C and 232 °C, respectively (*ca.* 20 °C below the melting point observed on the Boëtius apparatus), violent decomposition of the sample occurred. The strong exothermic effect was accompanied with 80 % mass loss. Some ring-substituted *N*-methyl-*N*-phenylnitramines having high melting points behave analogously.

N-(2-Pyridyl)nitramine, when heated slowly in the argon atmosphere, decomposed violently at 157 °C; a tarry mixture contained rearrangement products which could be detected by TLC. Traces of aminonitropyridines had been found also after 36 h heating in boiling toluene (110 °C), however most of the substrate was recovered unchanged. Rearrangement carried out in diluted solution in boiling chlorobenzene (132 °C) gave 2-amino-3-nitropyridine (40 %) and 2-amino-5-nitropyridine (26 %). The yields obtained in the anisole solution (154 °C) were 42 % and 18 %, respectively. Complete conversion of *N*-(3-pyridyl)nitramine as the suspension in chlorobenzene required 2 h heating to the boiling point, however the yields of the expected rearrangement products were surprisingly low. Also *N*-(4-pyridyl)nitramine, which rearranged at higher temperature, formed 4-amino-3-nitropyridine in 13 % yield only because most of the substrate turned into intractable tar. With *N*-(2-pyridyl)nitramine dissolved in chlorobenzene below its boiling point the rearrangement occurred in solution. The other isomers were insoluble, hence the reaction proceeded in the solid state and some intermolecular processes competed with the rearrangement. In the FTIR spectra, registered in solid state, *N*-methyl-*N*-pyridylnitramines displayed strong bands in the $\tilde{\nu}$ = 1276—1287 cm^{-1} and 1527–1534 cm^{-1} regions, exactly the same ($\tilde{\nu}$ = 1285—1299 cm^{-1} and 1517—1536 cm^{-1}) as in the case of secondary *N*-phenylnitramines [25]. Unequivocal interpretation of the spectra of primary *N*-pyridylnitramines is difficult; this is also the case with corresponding 1,2- or 1,4-dihydro-1-methylpyridylnitrimines. Similarity of these spectra suggests that primary *N*-pyridylnitramines exist in solid state in the nonaromatic imino forms. Very strong hydrogen bond, which shifts the frequency of the N—H stretching vibrations to $\tilde{\nu}$ = 2700—2800 cm^{-1}, complicates this picture to some extent. Only in the case of *N*-(2-pyridyl)nitramine it may have an intramolecular character, the remaining isomers form probably intermolecular bridges leading to multimolecular association, responsible for the limited solubility in nonpolar media.

We have examined some other high-boiling solvents: aliphatic ethers, as cellosolve and diglyme were inconvenient because primary and secondary pyridylnitramines decomposed to the corresponding aminopyridines in such solutions. The rearrangement could be carried out in quinoline, but separation of the products presented a serious problem.

Behaviour of *N*-methyl-*N*-pyridylnitramines resembles closely that of *N*-methyl-*N*-phenylnitramine, the only difference is that the pyridine derivatives are more volatile; 1 % mass loss was observed around 80 °C. The minima on the DTA curves accorded with the observed melting points. Broad exothermic peaks

with the maxima in the 160—170 °C region corresponded exactly to the maxima on DTG curves. The diluted (35 mmol dm^{-3}) solution of *N*-methyl-*N*-(2-pyridyl)nitramine in *m*-xylene turned yellow at 117 °C; after 3 h at 130 °C the rearrangement was completed. 2-Methylamino-3-nitropyridine was isolated in high yield; the second isomer was only detected chromatographically in the mother liquors. *N*-Methyl-*N*-(3-pyridyl)nitramine also rearranged smoothly in the chlorobenzene solution (2 h at 120 °C) forming 3-methylamino-2-nitropyridine (52 %) as the main product and 5-methylamino-2-nitropyridine in 28 % yield; the third isomer was not detected. Rearrangement of *N*-methyl-*N*-(4-pyridyl)nitramine in chlorobenzene (3 h at 130 °C) gave 4-methylamino-3-nitropyridine in high (74 %) yield. Secondary nitramines appeared to be more adequate model compounds for investigations of the rearrangements of pyridylnitramines.

Some explanations of the different properties of the primary and secondary nitramines can be found in their spectra. In the tautomeric nitrimino forms the Ar—N bond should display higher bond order. Rotational energy barrier (96 kJ mol^{-1}) in *N*-nitrosodimethylamine used to be explained with the partial double N—N bond character [26], hence in the NMR spectrum methyl protons display two separate (δ = 3.09 and 3.82) singlets. Analogously, two isopropyl groups in 2,4-dimethyl-3-(nitrimino)pentane are not magnetically equivalent: chemical shifts of the α-carbons *cis* and *trans* to the *N*-nitro group differ for $\delta = 4$ [27]. However, in the spectrum of 1,4-dihydro-4-nitriminopyridine the signals of H-3 and H-5 protons are isochromic and in the carbon NMR spectrum only three peaks are observed (Scheme 1).

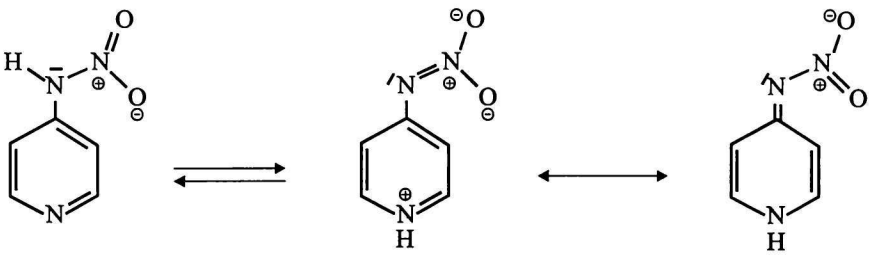
Consequently, the imino and zwitterionic structures should be considered as the mesomeric forms contributing to the comparable extent to the resonance hybrid. Prototropic tautomerism disturbs charge distribution within the nitramino group and may be responsible for the relative resistance of *N*-(4-pyridyl)nitramine to elevated temperature. In fact, our attempts to rearrange 1,4-dihydro-1-methyl-4-nitriminopyridine were unsuccessful while 2-nitrimino isomer gave after prolonged heating multicomponent mixture; the only isolable product appeared to be 1-methyl-2-pyridone.

DISCUSSION

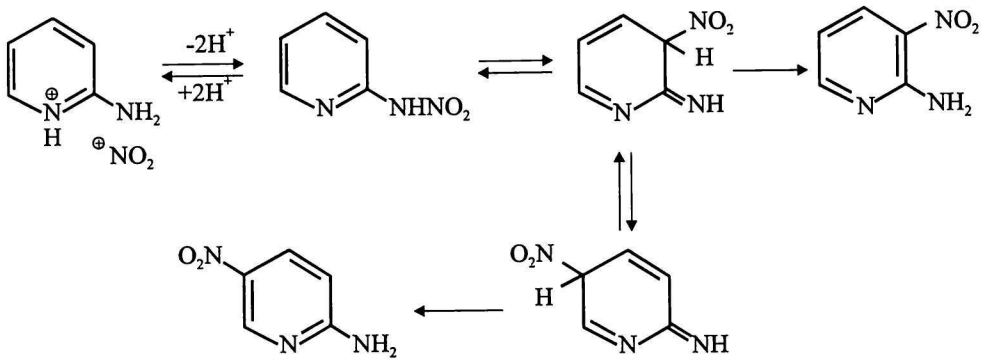
Deady et al. demonstrated that the primary, ring-substituted 2- and 4-pyridylnitramines in concentrated sulfuric acid dissociate into aminopyridinium and nitronium cations [12]. Later studies on the isomers distribution and kinetics of the rearrangement suggested that formation of the conventional σ-complex was preceded by recombination of these fragments [28, 29]. Consequently, amino-nitropyridines might have been formed either according to the aromatic substitution mechanism or intramolecularly, from the *N*-nitro precursors. The experiments carried out in concentrated acid could not resolve this alternative. Thermal rearrangement of pyridylnitramines demonstrates that the nitro group is covalently bonded to the aminopyridine residue during migration. Homolytic cleavage of the N—N bond followed by recombination of radicals is impossible because nitrogen(IV) oxide molecules cannot be maintained in solution in boiling chlorobenzene. Heterolytic cleavage must produce some electrophilic species (NO_2^+ or $ArNR^+$) able to attack solvent, especially anisole or *m*-xylene. We have not observed such side reactions in any case. The results support the *Deady*'s suggestion [29] that in spite of reversible acidolysis of the substrate, the σ-complexes (ring-protonated in an acidic solution) emerge from the nitramine by intermolecular migration of the nitro group (Scheme 2).

Deady's investigations on the influence of ring substituents on the isomers distribution led to the conclusion that rearrangement of pyridylnitramines is "mechanistically complex" [29]. Indeed, a ring substituent may influence the protonation equilibrium, facilitate or retard migration due to the electronic or steric effects and determine the relative stabilities of *ortho* and *para* σ-complexes. The last factor seems to be the most important since the influence of the acid concentration on the *ortho/para* ratio is negligible [14].

Płażek et al. have demonstrated that the rearrangement of *N*-methyl-*N*-(3-pyridyl)nitramine in cold, concentrated sulfuric acid gives mainly 3-methylamino-2-nitropyridine (40 %) and 5-methylamino-2-nitropyridine (2 %) as the side product [20]. The same compounds we have obtained from the thermal rearrangement, the third isomer was also lacking, so the



Scheme 1



Scheme 2

distance of the migration is not a decisive factor for the isomers distribution. The observation can be rationalized simply if we assume that the σ-complexes remain in the equilibrium state, *i.e.* the nitro group shifts several times (three nodes in each step), before the hydrogen transfer fixes its position. The mechanism of the last step is a separate problem.

Rearrangement of *N*-(2-pyridyl)- and *N*-methyl-*N*-(2-pyridyl)nitramines in sulfuric acid gave similar isomers distribution (*ca.* 10 1) with the preponderance of the 5-nitro isomer [12, 30]. Under thermal conditions mainly *ortho* isomers were formed. The mechanism of the rearomatization must be different and may influence significantly the *ortho/para* ratio. Transformation of a σ-complex into aromatic product used to be considered as the prototropic tautomerization, with the interference of a proton transfer agent. In an inert, neutral medium only the *ortho*-σ-complex may rearrange intramolecularly, according to the antarafacial [1, 3] sigmatropic shift. As demonstrated by *Bailey* and *Baylouny*, 1-methylene-2,4-cyclohexadiene transforms smoothly into toluene [31], consequently analogous migration may be the last step in various aromatic rearrangements and electrophilic substitutions.

N-Methyl-*N*-pyridylnitramines behave similarly at elevated temperatures when heated neat or in solutions, while their primary analogues display significant differences. *N*-(4-Pyridyl)nitramine is much less prone to the rearrangement, both under acidic [10] and thermal conditions. *N*-(3-Pyridyl)nitramine cannot be rearranged; when heated to 60 °C in concentrated sulfuric acid it forms mainly 3-hydroxypyridine [30]. Probably, 2, 4 or 6 position, conjugated with the heterocyclic nitrogen atom is an unfavourable migration terminus of the nitro group, so that some other reactions can compete. Analogously, treatment of *N*-(2-pyridyl)nitramine with 11.5 M sulfuric acid produces mainly (88 %) 2-pyridone (2-hydroxypyridine) [14]. In this case unfavourable reaction conditions retard the rearrangement and facilitate some side reaction. The provenience of the oxygen atom has not been investigated, however transformation of *N*-(1,2-dihydro-1-methyl-2-pyridyl)nitrimine into 1-methyl-2-pyridone in boiling *o*-dichlorobenzene suggests that it may come from the *N*-nitro group: $ArNHNO_2 \rightarrow ArOH + N_2O$. The nature of this transformation is obscure, however an analogous one has been encountered within the nitrimine series. Nitrosation of some aliphatic oximes gives a mixture of the carbonyl compound and nitrimine, which are formed from the common intermediate, *viz.* *N*-nitroso-nitrone [32]. Reversed reaction path may be responsible for the rearrangement of pyridylnitramines into corresponding pyridones or hydroxypyridines.

REFERENCES

1. Shine, H. J., *MTP Int. Rev. Sci., Org. Chem., Ser. One*, Vol. *3*, p. 65. (Zollinger, H., Editor.) Butterworth, London, 1973.
2. Banthorpe, D. V., Hughes, E. D., and Williams, D. L. H., *J .Chem. Soc. 1964*, 5349.
3. Hughes, E. D. and Jones, G. T., *J. Chem. Soc. 1950*, 2678.
4. White, W. N. and Klink, J. R., *J. Org. Chem. 35*, 965 (1970).
5. White, W. N. and Golden, J. T., *Chem. Ind.* (London) *1962*, 138.
6. Janssen, J. W. A. M., Koeners, H. J., Kruse, G. G., and Habraken, C. L., *J. Org. Chem. 38*, 1777 (1973).
7. Büchi, G. and Wüest, H., *J. Org. Chem. 44*, 4116 (1979).
8. Janssen, J. W. A. M. and Habraken, C. L., *J. Org. Chem. 36*, 3081 (1971).
9. Habraken, C. L. and Cohen-Fernandes, P *J. Chem. Soc., Chem. Commun. 1972*, 37
10. Deady, L. W. and Korytsky, O. L., *Aust. J. Chem. 36*, 1159 (1983).
11. Nemes, A. and Tóth, G., *Acta Chim. Acad. Sci. Hung. 87*, 257 (1975).
12. Deady, L. W., Grimmett, M. R., and Potts, C. H., *Tetrahedron 35*, 2895 (1979).
13. Tschitschibabin, A. E. and Kirsanov, A. V *Ber 60*, 2433 (1927).
14. Kokocińska, H., Thomas, A., Tomasik, P and Zalewski, R., *Bull. Pol. Acad. Sci., Chem. 24*, 535 (1976).
15. Daszkiewicz, Z., Domański, A., and Kyzioł, J. B., *Chem. Papers 47*, 109 (1993).

16. Kolehmainen, E., Laihia, K., Rissanen, K. Rasała, D., and Gawinecki, R., *Magn. Reson. Chem. 30*, 527 (1992).
17. Kolehmainen, E., Laihia, K., Kaupinen, R., Gawinecki, R., and Rasała, D., *Magn. Reson. Chem. 31*, 659 (1993).
18. Tschitschibabin, A. E. and Konovalova, R. A., *Ber. 58*, 1712 (1925).
19. Tschitschibabin, A. E. and Kirsanov, A. V., *Zh. Russ. Phys.-Khim. Obshch. 60*, 973 (1928).
20. Płażek, E., Marcinków, A., and Stammer, Ch., *Rocz. Chem. 15*, 365 (1935).
21. Tschitschibabin, A. E. and Razorenov, B. A., *Zh. Russ. Phys.-Khim. Obshch. 47*, 1286 (1915).
22. Tschitschibabin, A. E., *Zh. Russ. Phys.-Khim. Obshch. 46*, 1236 (1914).
23. Sepioł, J. and Tomasik, P., *Acta Chim. Hung. 113*, 159 (1983).
24. Daszkiewicz, Z., Domański, A., and Kyzioł, J. B., *Org. Proc. Prep. Int. 26*, 337 (1994).
25. Daszkiewicz, Z., Nowakowska, E., Preżdo, W. W and Kyzioł, J. B., *Pol. J. Chem. 69*, 1537 (1995).
26. Dai, Q. and Fu, X., *Theochem, J. Mol. Struct. 280*, 117 (1993).
27. Adamopoulos, S., Boulton, A. J., Tadayoni, R., and Webb, G. A., *J. Chem. Soc., Perkin 1 1987*, 2073.
28. Deady, L. W., Korytsky, O. L., and Rowe, J. E., *Aust. J. Chem. 35*, 2025 (1982).
29. Deady, L. W. and Korytsky, O. L., *Aust. J. Chem. 35*, 2035 (1982).
30. Tschitschibabin, A. E. and Kirsanov, A. V *Ber. 61*, 1223 (1928).
31. Bailey, W. J. and Baylouny, R. A., *J. Org. Chem. 27*, 3476 (1962).
32. Guziec, F. S. and Russo, J. M., *Synthesis 1984*, 479.