Tetrahedron Vol. 42, No. 5, pp. 1511 to 1528, 1986
Printed in Great Britain.

0040-4020/86 $3.00 + .00
Pergamon Press Ltd.

SYNTHESIS OF IMIDAZO[4,5-c]PYRIDINE AND IMIDAZO[4,5-d][1,2]DIAZEPINE SYSTEMS AND THEIR RIBONUCLEOSIDES

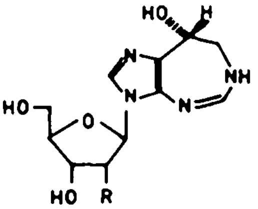
ANDRZEJ FRANKOWSKI

Politechnika Łódzka, Instytut Chemii Organicznej, 90-924 Łódź, Żwirki 36, Poland

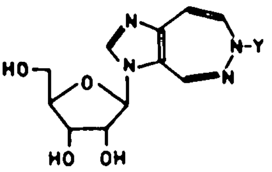
(*Received in UK* 13 *December* 1985)

Abstract - UV Irradiation of the fused N-iminopyridinium ylides 11 and 16, prepared from imidazo[4,5-c]pyridine (9), resulted in the regiospecific formation of the 4-aminoimidazo[4,5-c]pyridine derivatives 13 and 17 respectively. The fused N-iminopyridinium ylide 27, which can be obtained from 1-benzyl-1,3-dihydroimidazo[4,5-c]pyridin-2-one (24), undergoes photoinduced transformation to the isomeric aminopyridine derivatives 28 and 29. In contrast, starting from 1,3-dihydroimidazo[4,5-c]pyridin-2-one (23), the monocyclic N-iminopyridinium ylide 30 was obtained. In photochemical reaction 30 gives the isomeric 1,2-diazepines 31a and 31b, of the ratio dependent of the solvent used. The monocyclic diazepine 31a undergoes recyclisation to the imidazo[4,5-d][1,2]diazepine derivative 34. N-Ribosidation of 23 leads via O-benzoylated nucleosides 35a and 36a to two monoribonucleosides 35b and 36b. N-Ribosidation of the fused diazepine 34 gives three O-benzoilated nucleosides: monoribosides 38a and 39a and the diriboside 40. Deprotection of 38a and 39a leads to nucleosides 38b and 39b respectively. The diriboside 40, under debenzoylation conditions, undergoes transformation in 1,2-diazepine nucleus to give the 4-amino-1,3-dihydroimidazo[4,5-c]pyridin-2-one derivative 41.

Imidazo[4,5-d][1,3]diazepine system appears as the heterocyclic moiety of two nucleosides - pentostatine (1a)[1] and coformycine (1b)[2] - the potent inhibitors of adenosine deaminase[3]. Because of our interest in these biologically and therapeutically active nucleosides 1, we have directed our attention to the synthesis of ribonucleosides that contain the imidazo[4,5-d][1,2]diazepine system 2.



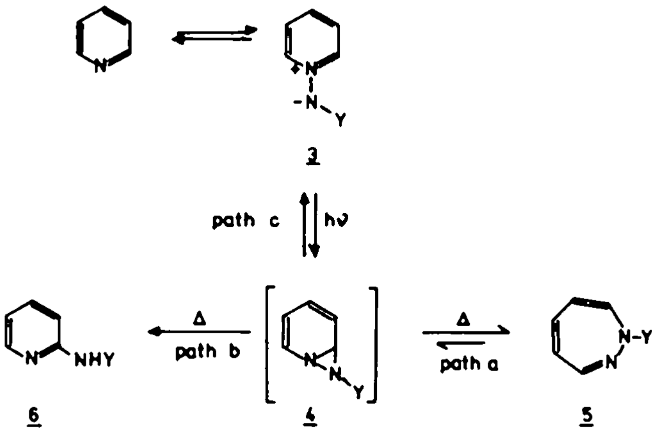
1 a R-H
b R-OH



2

Y = stabilising chromophore,
e.g. -COR, $-CO_2R$, $-SO_2R$
where R is an alkyl or aryl group

1,2-Diazepines 5 have been achieved by photoinduced rearrangements of the N-iminopyridinium ylides 3[4-7].



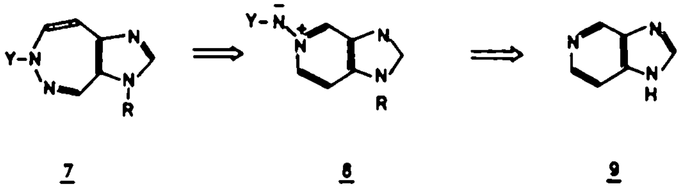
Y = $-CO_2R$, $-COR$, $-SO_2R$,
where R = alkyl or aryl group

Scheme 1

The diaziridine 4 has been postulated as an intermediate[5,8], which could result from a photo-induced concerted electrocyclic ring closure of the N-iminopyridinium ylide 3 as the aromatic 1,3-dipolar species. The intermediate 4 may undergo either ring expansion (valence tautomerisation) to give the 1,2-diazepines 5[4-9], or N-N bond fission to give the 2-aminopyridine derivatives 6[9,10], or return to the ylide 3 followed by N-N fragmentation resulting in the parent pyridine[8,11-13].

It is known that irradiation of N-imino-quinolinium, -isoquinolinium and related -pyridinium ylides condensed with aromatic heterocyclic rings such as pyridine, thiophene, furan and pyrrole gives, depending on the nature of the starting ylide and irradiation conditions, either the corresponding fused 1,2-diazepines[14-16] or 2-aminopyridine derivatives[16-20].

In connection with the above results, it was of interest to examine the possibility of obtaining the desired imidazo[4,5-d][1,2]diazepine system 7 from imidazo[4,5-c]pyridine (9) via the ylide 8 accordingly to the following retro-synthetic scheme 2:



Y = $-CO_2Et$
R = H or protecting group

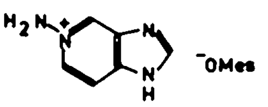
Scheme 2

Studies in the 1H-imidazo[4,5-c]pyridine series

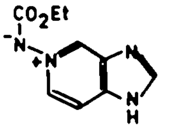
To begin with we prepared imidazo[4,5-c]pyridine (9) from 4-amino-pyridine. Reaction of 4-aminopyridine with ethyl chloroformate gave 4-ethoxycarbonylaminopyridine[21] which, by nitration was converted to 4-ethoxycarbonylamino-3-nitropyridine[22]. Hydrolysis of the latter followed by Na_2S reduction gave 3,4-diaminopyridine[23] which, after condensation with formic acid produced imidazo[4,5-c]pyridine (9)[24] in 41% overall yield.

Before the synthesis of the N-iminopyridinium ylide 8, consisting a suitable stabilizing chromofore was performed, we protected the imidazole ring, to exclude tautomerisation of the corresponding ylide to the photochemically inactive 5-ethoxycarbonylamino-5H-imidazo[4,5-c]pyridine (12). This type of tautomerisation was observed for N-imino-pyrrolo[2,3-b]pyridinium ylides[15]. Thus, reaction of 9 with chloromethyl pivalate[25] in the presence of potassium carbonate resulted in formation of the isomeric N-1 and N-3 pivaloyloxymethyl derivatives 14a and 14b in 7.5:2.5 ratio, respectively in 88% overall yield. Reaction of 14a with O-mesitylenesulfonylhydroxylamine (MSH) in methanol according to Tamura procedure[26], followed by treatment of the resulting N-amine mesitylenesulfonate 15 with ethyl chloroformate in the presence of potassium carbonate, led to the N-iminopyridinium ylide 16 in 56% overall yield. UV-Irradiation of 16 in acetonitrile gave regiospecifically 4-ethoxycarbonylamino-1-pivaloyloxymethyl-imidazo[4,5-c]pyridine (17) (25%) and 4-pivaloylamino-1-pivaloyloxymethylimidazo[4,5-c]pyridine (18) (8%). Deprotection of 17 with methanolic ammonia furnished 4-ethoxycarbonylaminoimidazo[4,5-c]pyridine (13) in 57% yield.

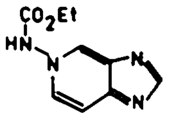
On the other hand we have confirmed that the compound 13 could also be prepared in a more straightforward manner, but in poor yield, from unprotected imidazo[4,5-c]pyridine (9). Thus, reaction of 9 with MSH in methanol gave the N-aminopyridinium mesitylenesulfonate 10 which functionalised with ethyl chloroformate afforded the ylide 11 in 16% overall yield. In cotrast to the previous findings in pyrrolo[2,3-b]pyridine series[15], the unprotected ylide 11 does not tautomerize to 12 and undergoes photorearrangement to form 13 in 43% yield.



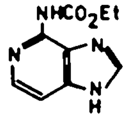
10



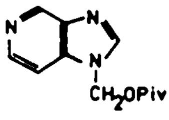
11



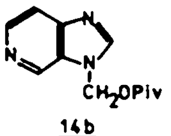
12



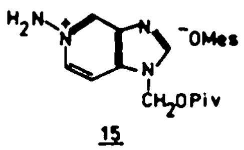
13



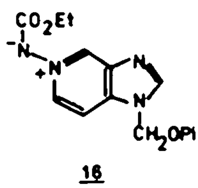
14a



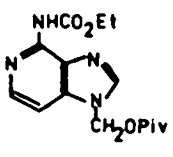
14b



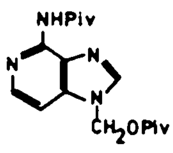
15



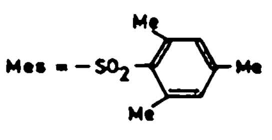
16

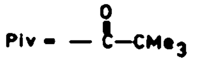


17



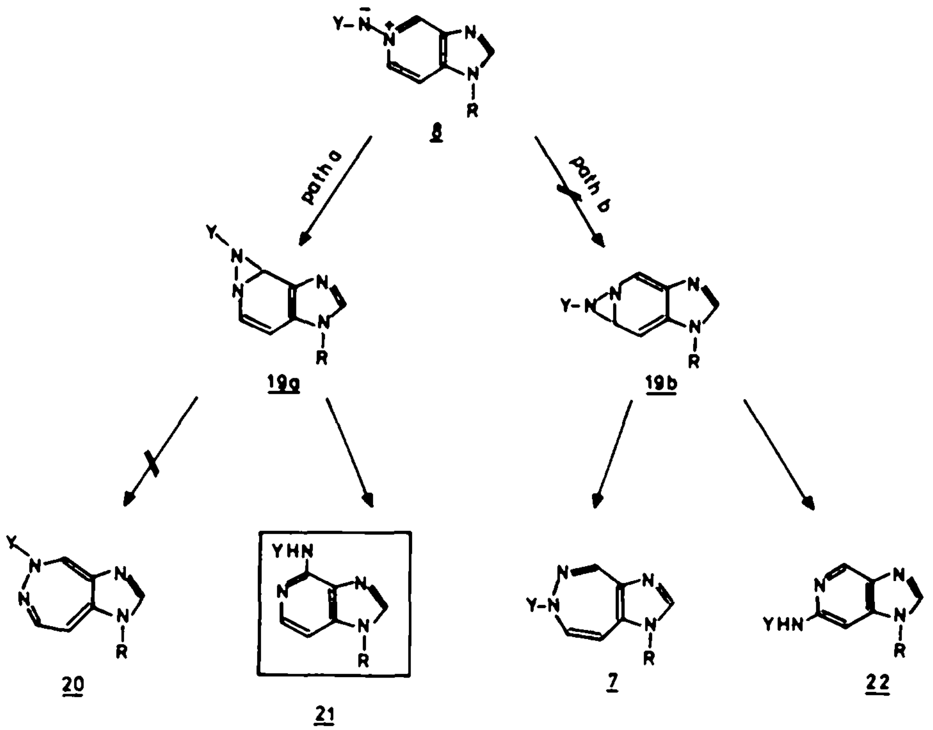
18





$$\mathrm{Piv} = -\overset{\mathrm{O}}{\overset{\|}{\mathrm{C}}}-\mathrm{CMe_3}$$

The presented results of the regiospecifically proceeding photolysis are consistent with the proposed intermediacy of diaziridine structures. The initial photo-induced rearrangement of the ylide 8 may take place at both sides of the pyridine nitrogen with the formation of two kinds of diaziridine intermediates 19a (path a) and 19b (path b) respectively, as shown in Scheme 3. The former (19a) may then rearrange by the ring expansion into imidazo[4,5-e] [1,2]diazepine system 20 or by N-N bond fission into 4-aminoimidazo[4,5-c]pyridine derivative 21. The latter 19b may rearrange into imidazo[4,5-d] [1,2]diazepine system 7 or 6-aminoimidazo[4,5-c]pyridine derivative 22. However diaziridine 19b with o-quinonoid system would be less stable than their isomeric diaziridine 19a, in which aromatic imidazole ring system is conserved, and thus path a is privileged over path b. Furthermore examination of Dreiding models shows that the imidazo[4,5-e] [1,2]diazepine system 20 is highly sterically strained. Thus, 4-aminoimidazo[4,5-c]pyridine derivative 21 is the most favored photo-rearrangement product of ylide 8.



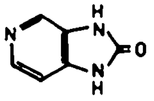
Scheme 3

Studies in the 2H-1,3-dihydroimidazo[4,5-c]pyridin-2-one series

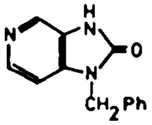
As it is well seen from Scheme 3, the desirable imidazo[4,5-d] [1,2] diazepine system 7 is accesible via the intermediate diaziridine 19b by the pathway b. According to the already discussed arguments one may expect, that diminished aromaticity of the five membered heterocyclic ring fused with pyridine moiety, would accelerate the photo-induced rearrangement represented by the pathway b (see Scheme 3). For these reasons we focused our attention on 1,3-dihydroimidazo[4,5-c] pyridin-2-one (23) as the starting material. It should be emphasized that the imidazolidin-2-one nucleus constitutes a fragment of biologically active compounds such as biotin. It also occurs in products of γ-radiolysis of cytosine[27] and of the oxidation of uric acid[28].

To begin with we prepared 1-benzyl-1,3-dihydroimidazo[4,5-c]pyridin-2-one (24). The starting material for this synthesis was 4-chloro-3-nitropyridine, which in the reaction with benzylamine in the presence of potassium carbonate gave 4-benzylamino-3-nitropyridine[29] in 62% yield. The latter compound was reduced with Na_2S to 3-amino-4-benzylaminopyridine[29], which after cyclisation with phosgene gave 1-benzyl-1,3-dihydroimidazo[4,5-c]pyridin-2-one (24) in 71% overall yield. The compound 24 was then aminated with MSH[26] in methanol to afford the corresponding N-aminopyridinium mesitylenesulfonate 26 in 80% yield. Treatment of 26 with ethyl chloroformate in the presence of potassium carbonate gave the N-iminopyridinium ylide 27 in 22% yield. Irradiation of the ylide 27 in methanol resulted in the formation of two isomeric N-N bond fission products: 1-benzyl-4-ethoxycarbonylamino-1,3-dihydroimidazo[4,5-c]pyridin-2-one (28) and 1-benzyl-6-ethoxycarbonylamino-1,3-dihydroimidazo[4,5-c]pyridin-2-one (29) in ca 1:1 ratio in 54% overall yield. In addition parent 1-benzyl-1,3-dihydroimidazo[4,5-c]pyridin-2-one (24) was also isolated in 33% yield, but no ring-expansion products were observed.

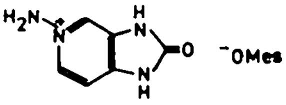
In contrast, quite different course of the above reaction sequence has been observed when 1,3-dihydroimidazo[4,5-c]pyridin-2-one (23) was utilised as the starting material. The compound 23 has been synthesized according to procedure of Barlin[31] utilising a thermal reaction of 3,4-diaminopyridine with urea. N-Amination of 23 with MSH in methanol gave N-aminopyridinium mesitylenesulfonate 25 in 81% yield. Treatment of 25 with two equivalents of ethyl chloroformate in the presence of potassium carbonate in ethanol gave 3,4-diethoxycarbonylamino-1-ethoxycarbonyliminopyridinium ylide (30) in 35% yield as the sole product.



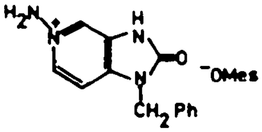
23



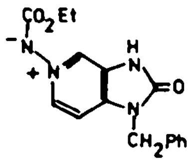
24



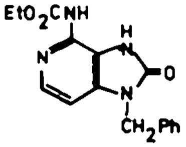
25



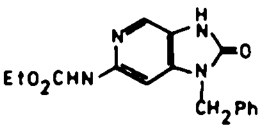
26



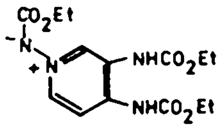
27



28

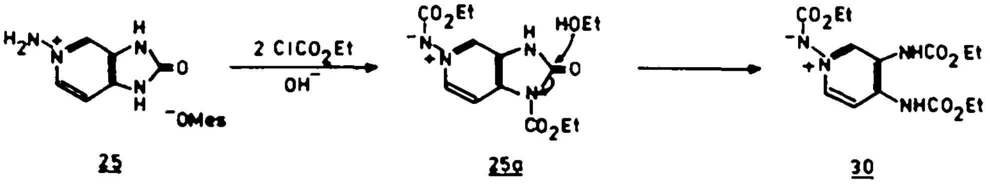


29



30

It is likely that the imidazolidin-2-one ring opening occurs via the nucleophilic attack of ethanol at the C-2 of the intermediate ylide 25a followed by C-2 - N-1 bond cleavage, as shown in Scheme 4.



Scheme 4

To confirm such a sequence, we carried out the reaction of 25 with excess of ethyl chloroformate in the absence of ethanol, receiving the unseparable mixture of products, in which no ylide 30 was detected (TLC).

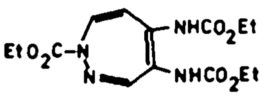
It is to note, that an electron-donating group $NHCO_2Et$ in the position 4 of the monocyclic pyridinium ylide 30, according to Snieckus findings[9], should favour the photoinduced ring expansion process. On the other hand it supresses the stability of pyridine ring, diminishing the possibility of N-N bond fission to 2-aminopyridine derivative. According to these predictions all irradiations of the ylide 30 gave the mixture of two diazepines 31a and 31b, of the ratio and of the yields dependent on the solvent used, as seen from Table 1.

Table 1. Photochemical syntheses of 1,2-diazepines 31a and 31b from ylide 30

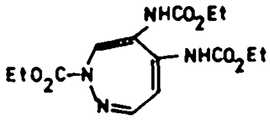
Solvent	λmax of 30 (nm)	Reaction time (hr)	Product ratio 31a : 31b	Total yield 31a + 31b(%)	Other products (Yield)
Methanol[a]	312,5	3,5	1 : 1,5	79	33 (8%)
Acetonitrile[a]	340	3,0	6 : 1	91	-
Benzene[b]	344	1,5	1 : 2	52	32 (42%)
Methylene chloride[c]	340	0,5	1 : 2,5	38	32 (51%)

a - 1 mmole of ylide 30 in 500 ml of solvent were used
b - 0,3 mmole of ylide 30 in 1000 ml of solvent were used
c - 0,3 mmole of ylide 30 in 500 ml of solvent were used

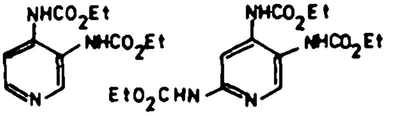
In particular, polar solvents (alcohols, acetonitrile) favour the formation of the diazepines 31 in high yields, moreover the solvent of choice appeared to be acetonitrile in which the diazepine 31a was formed in high yield and in a remarkable dominance. In fact, only the diazepine 31a is capable to generate imidazo[4,5-d][1,2]diazepine system 7 by recyclisation of the imidazolidin-2-one ring (vide infra). In contrast, when the ylide 30 was irradiated in nonpolar solvents (benzene, methylene chloride) the parent 3,4-diethoxycarbonylaminopyridine (32) becames the major product. Additionally, when irradiation was performed in methanol, some quantities of 2,4,5-triethoxycarbonylaminopyridine (33) (8%) were also isolated. These solvent effects are analogous to those observed in photolysis of N-iminoisoquinolinium and - quinolinium ylides[19] and also of pyridine N-oxides[32].



31a

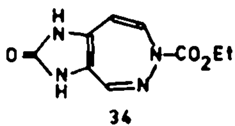


31b



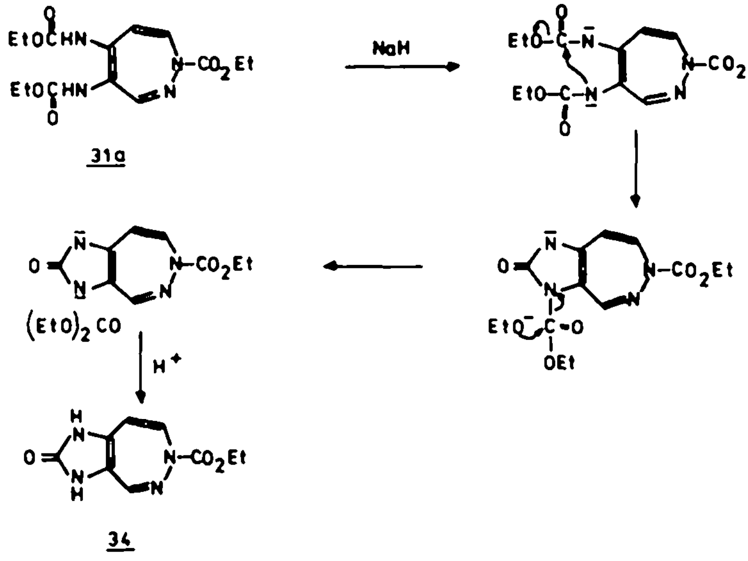
32

33



34

Our next aim was the internal recyclisation of the diazepine 31a to obtain the desired imidazo[4,5-d][1,2]diazepine system 7. Thus, reaction of 31a with sodium hydride in THF followed by quenching with methanol and treatment with Amberlite IRC-50, resulted in the formation of 6-ethoxycarbonyl-1,3-dihydroimidazo[4,5-d][1,2]diazepin-2-one (34) in 52% yield, accompanied by abstraction of diethylcarbonate, according to the postulated mechanism as shown in Scheme 5.



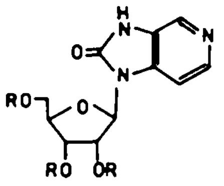
Scheme 5

Attempts to obtain the imidazo[4,5-e][1,2]diazepine system 20 from the diazepine 31b under analogous conditions have been unsuccessful for previously discussed steric reasons.

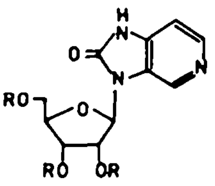
Syntheses of ribonucleosides

Before the planed synthesis of the ribonucleosides containing imidazo[4,5-d][1,2]diazepine system 7 as a heterocyclic moiety, we carried out, a model N-ribosidation of 1,3-dihydroimidazo[4,5-c]pyridin-2-one (23) by Vorbrüggen method[33]. Trimethylsililation of 23 with hexamethyldisilazane (HMDS) and trimethylsilyl chloride in anhydrous pyridine yielded corresponding silyl derivative. Treatment of this crude compound with 1-O-acetyl-2,3,5-tri-O-benzoyl-β-D-ribofuranose[34] and SnCl$_4$ as a catalyst, in 1,2-dichloroethane/acetonitrile mixture followed by a flash column chromatography[35], gave two monoribonucleosides 35a and 36a in 0.55:0.45 ratio in 42% overall yield. Deprotection of 35a and 36a with methanolic ammonia furnished 1,3-dihydro-1-β-D-ribofuranosylimidazo[4,5-c]pyridin-2-one (35b) and 1,3-dihydro-3-β-D-ribofuranosylimidazo[4,5-c]pyridin-2-one (36b) in 85% and 90% yield respectively. The structures of both received nucleosides 35b and 36b were confirmed on the basis of independent synthesis. Thus, N-ribosidation of 1-benzyl-1,3-dihydroimidazo[4,5-c]pyridin-2-one (24), carried out employing the procedure used for the ribosidation of 1,3-dihydroimidazo[4,5-c]pyridin-2-one (23) yielded the N-3 riboside 37a in 31% yield. Debenzoylation of 37a with methanolic ammonia gave the riboside 37b, which after catalytic hydrogenolysis led to the riboside 36b in 83% overall yield in respect to 37a, identical with one of those previously prepared.

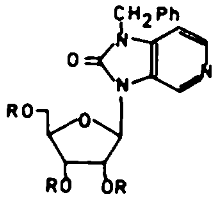
Next, we applied the above model reactions for N-ribosidation of 6-ethoxycarbonyl-1,3-dihydroimidazo[4,5-d][1,2]diazepin-2-one (34). N-Ribosidation, followed by a standard workup and flash column chromatography, yielded three ribonucleoside products consisting of two monoribonucleosides 38a and 39a and the diribonucleoside 40 in molar ratio 0.42:0.32:0.26 respectively in 48% overall yield. Each of the isolated nucleosides was deprotected in methanolic ammonia. Deprotection of 38a and 39a gave the desired ribonucleosides with the imidazo[4,5-d][1,2] diazepine moiety 38b and 39b in 82% and 75% yield respectively. In contrast, under the same conditions the diribonucleoside 40 undergoes base catalysed transformation to 4-amino-1,3-dihydro-1,3-bis(β-D-ribofuranosyl)imidazo[4,5-c]pyridin-2-one (41) in 58% yield.



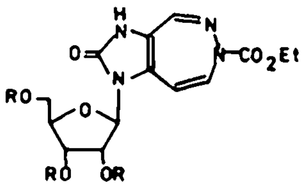
35 a R=Bz
b R=H



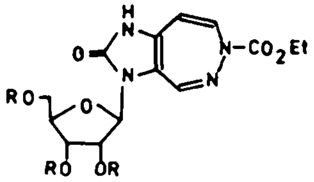
36 a R=Bz
b R=H



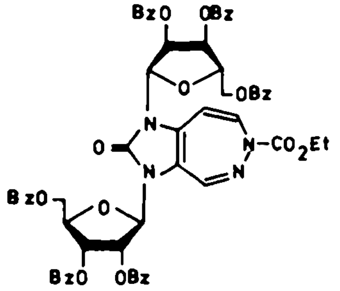
37 a R=Bz
b R=H



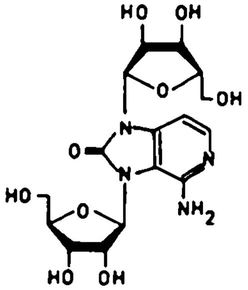
38 a R=Bz
b R=H



39 a R=Bz
b R=H

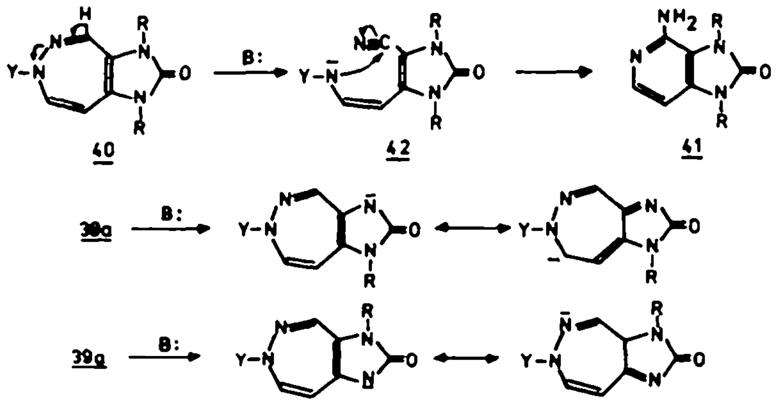


40



41

These results are analogous to those observed by J.Streith[4,5] for monocyclic 1,2-diazepines bearing hydrogen atom at C-3 under strong basic (RO⁻, HO⁻) reaction conditions. We found for the first time that this type of reaction occurs also in mild basic conditions (methanolic ammonia, room temperature) in the case of the diribonucleoside 40 accordingly to the following Scheme 6:

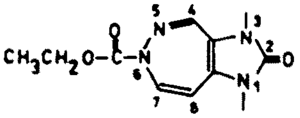


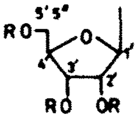
Scheme 6

In presence of ammonia the diribonucleoside 40 undergoes ring opening of the 1,2-diazepine moiety to form the cis-cis-dienaminonitrile derivative 42, then after recyclisation of 42 and saponification of the urethane moiety, the aminopyridine derivative 41 is produced. In contrast, monoribonucleosides 38a and 39a are stable in methanolic ammonia, for the negative charge generated at N-1 or N-3 stabilizes the 1,2-diazepine ring.

The structures of all nucleosides containing the 1,3-dihydroimidazo[4,5-d][1,2]diazepine-2-one moiety were assigned on the basis of 400 MHz ^{1}H NMR spectral data (see Table 2).

Table 2. ^{1}H NMR spectral data of compounds 34, 38a, 39a, 38b, 39b and 40 [a]





δ(ppm)	34 [b]	38a [c]	39a [c]	38b [d]	39b [d]	40 [c]
H 4	7.73	7.79	8.05	7.81	8.41	8.02
H 7	6.06	6.27	6.19	6.66	6.02	6.27
H 8	5.98	5.79	6.06	6.05	5.92	5.86
H 1'		5.97	5.83	5.57	5.80	6.00, 5.82
H 2'		6.06-6.12	6.22	4.56	4.57	6.03-6.10, 6.22
H 3'			6.08	4.19	4.30	6.03-6.10(2H)
H 4'		4.65	4.70	3.97	4.11	4.68, 4.70
H 5'		4.6-4.7	4.69-4.82	3.78	3.85	4.77-4.83 4.65-4.71
H 5"		4.84		3.70	3.74	
OCH_2	4.30	4.33	4.34	4.29	4.16	4.32
CH_3	1.34	1.35	1.35	1.32	1.15	1.34

J(i,j) (Hz)	34	38a	39a	38b	39b	40
7,8	7.0	7.0	7.0	7.0	7.0	7.0
1',2'		4.5	4.5	6.7	6.5	4.5, 4.5
2',3'		strongly coupled	6.0	6.0	6.0	strongly coupled
3',4'			6.0	3.5	3.5	
4',5'			strongly coupled	3.0	3.0	
4',5"				4.0	3.5	
5',5"				12.5	12.0	

a. Recorded at 400 MHz with TMS as internal standard.
b. Solvent: $CDCl_3$ + DMSO-d_6.
c. Solvent: $CDCl_3$.
d. Solvent: CD_3OD.

Experimental

M.p.s were determined on a Büchi SMP-20 apparatus and on a Boetius m.p. microscope and are uncorrected. UV Spectra were recorded on Varian UV-VIS 635 instrument in MeOH, and IR spectra on Spectromom 2000 MOM instrument for KBr discs. ^{1}H NMR spectra were obtained with Bruker 90 MHz, Model HFX-72 and Tesla 80 MHz, BS 487C instruments, using TMS as an internal standard, chemical shifts are given in δ values. Mass spectral data were recorded on CCMS-LKB-type 9000S mass spectrometer. Elemental analyses were determined in Laboratory of Microanalysis of the Technical University in Lodz. Photochemical experiments were carried out under Ar atm. in Pyrex glass reactor with the Hanovia cooling finger type, utilising 125 W Philips HPK high pressure mercury lamp. TLC was carried out on silica gel plates 60F$_{254}$ (Merck). Column chromatography was performed according to Still's flash chromatography procedure[35] utilizing silica gel 230-400 mesh (Merck).

Synthesis of 5-aminoimidazo[4,5-c]pyridinium mesitylenesulfonate (10). To a stirred soln of 9[24] (1.19g; 0.01 mole) in dry MeOH (50 ml) was added dropwise a soln of O-mesitylenesulfonylhydroxylamine (MSH)[26] (2.15g; 0.01 mole) in dry MeOH (50 ml), the resulting mixture was stirred at room temp. for 3 hr. After evaporation of the solvent in vacuo, addition of EtOH (300 ml) led to crystallization of 10, 2.27 g, (68%), m.p. 201-203°, recrystallized from EtOH; ^{1}H NMR (CD$_3$OD): 9.26 (1H, J = 1.2 Hz, H-4), 8.74 (1H, s, H-2), 8.51 (1H, dd, J = 7.0 and 1.2 Hz, H-6), 8.05 (1H, d, J = 7.0 Hz, H-7), 6,80 (2H, s, CH $^-$OMes), 2.58 (6H, s, o-Me), 2.20 (3H, s, p-Me); MS: m/e 200(M$^+$ - 134), 134(M$^+$ - 200). (Found: C, 53,7; H, 5,4; N, 16.6. Calc. for $C_{15}H_{18}N_4O_3S$: C, 53.88; H, 5.43; N, 16.75%).

Synthesis of 5-ethoxycarbonyliminoimidazo[4,5-c]pyridinium ylide (11). To a stirred suspension of 10 (1.67 g; 5 mmole) in abs EtOH (50 ml) was added dropwise ethyl chloroformate (1.08 g; 10 mmole) in abs EtOH (10 ml) followed by anhyd.K_2CO_3 (2.8 g). After about 12 hr at room temp., the inorganic salts were filtered off and the remaining soln was evaporated to dryness in vacuo. After column chromatography of the residue with CHCl$_3$-EtOH 4/1 v/v mixture, 11, 334 mg (24%) was obtained, m.p. 181-183°. UV λ_{max} 276 and 295 nm (ε = 6000 and 5900 resp.); IR 1730 and 1630 cm^{-1}(C=O); ^{1}H NMR(CD$_3$OD): 9.04(1H, d, J = 1.8 Hz, H-4), 8.56(1H, s,H-2), 8.23(1H, dd, J = 7.0 and 1.8 Hz, H-6), 7.86(1H, d, J = 7.0 Hz, H-7), 4.25(2H, q, J = 7.0 Hz, CH$_2$), 1.30(3H, t, J = 7.0 Hz, CH$_3$), MS: m/e 206(M$^+$). (Found: C, 52.2, H, 5.0, N, 26.9. Calc. for $C_9H_{10}N_4O_2$: C, 52,42, H, 4.89, N, 27.17%).

Photoinduced synthesis of 4-ethoxycarbonylaminoimidazo[4,5-c] pyridine (13) from ylide 11. A soln of 11 (206 mg; 1 mmole) in acetonitrile (500 ml) was irradiated for 40 min, whence all starting material was consumed. After evaporation of the solvent in vacuo and column chromatograpy with a CHCl$_3$-EtOH 4/1 v/v mixture, two compounds were eluted: imidazo[4,5-c]pyridine (9), 54 mg (45%); 4-ethoxycarbonylaminoimidazo[4,5-c]pyridine (13), 88 mg (43%); m.p. 170-174°; UV λ_{max} 248 and 276 nm (ε= 5000 and 5500 resp.); IR 1640 cm^{-1}; ^{1}H NMR (CD$_3$OD): 8.27 (1H, s, H-2), 8.05 (1H, d, J = 5.6 Hz, H-6), 7.41 (1H, d, J = 5.6 Hz, H-7), 4.30 (2H, q, J = 7.0 Hz, CH$_2$), 1.27(3H, t, J = 7.0 Hz, CH$_3$); MS: m/e 207(M$^+$+1),206(M$^+$).(Found: C, 52.2; H, 4.7; N, 27.0. Calc. for $C_9H_{10}N_4O_2$: C, 52.42; H, 4.89; N, 27.17%).

Synthesis of 1- and 3-pivaloyloxymethylimidazo[4,5-c]pyridine (14a) and (14b). To a stirred soln of 9(3.57 g; 0.03 mole) in dry DMF (100 ml) was added dropwise chloromethyl pivalate[25] (4.52 g; 0.03 mole) in dry DMF (10 ml) followed by anhyd. K_2CO_3 (4.2 g). After stirring for about 48 hr at room temp., the inorganic salts were filtered off and the remaining soln was evaporated to dryness in vacuo.After column chromatography of the mixture with a $CHCl_3$-EtOH 9/1 v/v two isomers 14a and 14b were obtained, 6.13 g (88%) in ratio 7.5:2.5 respectively.

1-Pivaloyloxymethylimidazo[4,5-c]pyridine (14a), m.p. 105-107°, recrystallized from hexane-acetone mixture; IR 1730 cm^{-1} (C=O); ^1H NMR ($CDCl_3$): 9.12 (1H, d, J = 0.9 Hz, H-4), 8.50 (1H, d, J = 5.6 Hz, H-6), 8.19 (1H, s, H-2), 7.56 (1H, dd, J = 5.6 and 0.9 Hz, H-7), 6.15 (2H, s, CH_2), 1.15 (9H, s, tBu); MS: m/e 233 (M^+). (Found: C, 61.6, H, 6.4, N, 18.1. Calc. for $C_{12}H_{15}N_3O_2$: C, 61.79, H, 6.48, N, 18.01%).

3-Pivaloyloxymethylimidazo[4,5-c]pyridine (14b), m.p. 114-116°, recrystallized from hexane-acetone mixture; IR 1730 cm^{-1} (C=O); ^1H NMR ($CDCl_3$) : 9.00 (1H, d, J = 0.9 Hz, H-4), 8.38 (1H, d, J = 5.6 Hz, H-6), 8.25 (1H, s, H-2), 7.73 (1H, dd, J = 5.6 and 0.9 Hz, H-7), 6.20 (2H, s, CH_2), 1.15 (9H, s, t-Bu); MS: m/e 233 (M^+). (Found: C, 61.7, H, 6.3, N, 17.9. Calc. for $C_{12}H_{15}N_3O_2$: C, 61.79, H, 6.48, N, 18.01%).

Synthesis of 5-amino-1-pivaloyloxymethylimidazo[4,5-c]pyridinium mesitylenesulfonate (15). To a stirred soln of 14a (4.7 g; 0.02 mole) in CH_2Cl_2 (15 ml) was added dropwise a soln of MSH[26] (4.3 g; 0.02 mole) in CH_2Cl_2 (30 ml), the resulting mixture being kept at room temp. overnight. Addition of diethyl ether (150 ml) led to crystallization of 15, 6.5 g (72.5%), m.p. 150-152°; UV λ_{max} 274 nm (ε = = 6200); IR 1740 cm^{-1}; ^1H NMR (CD_3OD): 9.30 (1H, d, J = 1.2 Hz, H-4), 8.86 (1H, s, H-2), 8.64 (1H, dd, J = 7.0 and 1.2 Hz, H-6), 8.30 (1H, d, J = 7.0 Hz, H-7), 6.81 (2H, s, CH $^-$OMes), 6.37 (2H, s, CH_2), 2.58(6H, s, 2Me $^-$OMes), 2.21 (3H,s, Me $^-$OMes), 1.14 (9H, s, t-Bu). (Found: C, 56.1, H, 6.3, N, 12.3. Calc. for $C_{21}H_{28}N_4O_5S$: C, 56.23, H, 6.29, N, 12.49%).

Synthesis of 5-ethoxycarbonylimino-1-pivaloyloxymethylimidazo[4,5-c]pyridinium ylide (16). To a stirred soln of 15 (4.5 g; 0.01 mole) in abs EtOH (60 ml) was added dropwise ethyl chloroformate (1.1 g; 0.01 mole) in abs EtOH (10 ml) followed by anhyd. K_2CO_3 (2.8 g). After stirring overnight at room temp., the inorganic salts were filtered off and the remaining soln was evaporated to dryness in vacuo. After column chromatography of the residue with a $CHCl_3$-EtOH 5/1 v/v mixture one isolated 16, 2.47 g (77%), m.p. 153-155°, recrystallized from methanol-hexane mixture; UV λ_{max} 296 nm (ε = 7100); IR 1730, 1630 cm^{-1}; ^1H NMR ($CDCl_3$): 9.30 (1H, d, J = 1.2 Hz, H-4), 8.53 (1H, dd, J = 7.0 and 1.2 Hz, H-6), 8.37 (1H, s, H-2), 7.80 (1H, d, J = 7.0 Hz, H-7), 6.18 (2H, s, OCH_2), 4.18 (2H, q, J=7.0 Hz, CH_2), 1.33 (3H, t, J = 7.0 Hz, Me), 1.16 (9H, s, t-Bu); MS: m/e 320 (M^+). (Found: C, 56.3, H, 6.3, N, 17.6. Calc. for $C_{15}H_{20}N_4O_4$: C, 56.24, H, 6.29, N, 17.49%).

Photoinduced synthesis of 4-ethoxycarbonylamino-1-pivaloyloxymethylimidazo[4,5-c]pyridine (17) and 4-pivaloylamino-1-pivaloyloxymethylimidazo[4,5-c]pyridine (18) from ylide 16. A soln of 16 (480 mg; 1.5 mmole) in acetonitrile (500 ml) was irradiated, consumption of starting material being monitored by UV spectroscopy (gradual disappearance of the λ_{max} 325 nm absorption band). After 40 min no starting material remained and the soln was evapored in vacuo to dryness. The crude mixture was chromatographed over a silicic acid column with a $CHCl_3$-EtOH 9/1 v/v mixture and two compounds were eluted:

4-Ethoxycarbonylamino-1-pivaloyloxymethylimidazo[4.5-c]pyridine (17), 120 mg (25%); m.p. 202-205°, recrystallized from methanol-hexane mixture; UV λ_{max} 263 nm (ε = 14400); IR 1730 cm^{-1}; ^1H NMR ($CDCl_3$): 8.30 (1H, d, J = 5.9 Hz, H-6), 8.07 (1H, s, H-2), 7.22 (1H, d, J = 5.9 Hz, H-7), 6.08 (2H, s, CH_2), 4.30 (2H, q, J = = 7.0 Hz, CH_2 - Et), 1.34 (3H, t, J = 7.0 Hz, Me), 1.14 (9H, s, t-Bu); MS: m/e 320 (M^+). (Found: C, 56.0, H, 6.1, N, 17.3. Calc. for $C_{15}H_{20}N_4O_4$= C, 56.24, H, 6.29, N, 17.49%).

4-Pivaloylamino-1-pivaloyloxymethylimidazo[4,5-c]pyridine (18), 40 mg (8%): m.p. 186-188°, recrystallized from methanol-hexane mixture; ^{1}H NMR ($CDCl_3$): 8.32 (1H, d, J = 5.6 Hz, H-6), 8.08 (1H, s, H-2), 7.28 (1H, d, J = 5.6 Hz, H-7), 6.09 (2H, s, CH_2), 1.41 (9H, s, CO-tBu), 1.14 (9H, s, t-Bu); MS: m/e 332 (M^+).

Synthesis of 4-ethoxycarbonylaminoimidazo[4,5-c]pyridine (13) from 17. A soln of 17 (96 mg; 0.3 mmole) in MeOH freshly saturated with ammonia (10 ml) was kept at room temp. for about 100 hr. After evaporation of the solvent in vacuo the residue was chromatographed over a silicic acid column with a $CHCl_3$-EtOH 4/1 v/v mixture. 13, 35 mg (57%) is thus isolated as colourless crystals, m.p. 168-170° recrystallized from methanol, identical with the sample obtained from 11.

1-Benzyl-1,3-dihydroimidazo[4,5-c]pyridin-2-one (24) was prepared according to Clark's method[30] from 3-amino-4-benzylaminopyridine[29] and phosgene, as colourless crystals, m.p. 214°; IR 1710 cm^{-1} (C=O); ^{1}H NMR (CD_3OD): 8.40 (1H, s, H-4), 8.30 (1H, d, J = 5.6 Hz, H-6), 7.48 (5H, s, Ph), 7.21 (1H, d, J = 5.6 Hz, H-7), 5.26 (2H, s, CH_2).(Found: C, 69.4, H, 5.0, N, 18.5. Calc. for $C_{13}H_{11}N_3O$: C, 69.32, H, 4.92, N, 18.65%).

Synthesis of 5-amino-1-benzyl-1,3-dihydroimidazo[4,5-c]pyridin-2-onium mesitylenesulfonate (26). To a stirred suspension of 24 (4 g; 0.018 mole) in dry MeOH (80 ml) was added dropwise a soln of MSH[26] (4.2 g; 0.02 mole) in dry MeOH (30 ml). After stirring for 48 hr at room temp., the solvent was removed under vacuum. The resulting solid was washed with CH_2Cl_2 (85 ml) to give 26, 6.3 g (80.5%), m.p. 198-200°; ^{1}H NMR (CD_3OD): 8.42 (1H, d, J = 1.8 Hz, H-4), 8.34 (1H, dd, J =6.8 and 1.8 Hz, H-6), 7.45 (1H, d, J = 6.8 Hz, H-7), 7.36 (5H, s, Ph), 6.82 (2H, s, CH $^-$OMes), 5.18 (2H, s, CH_2), 2.59 (6H, s, o-Me), 2.21 (3H, s, p-Me). (Found:C,60.1, H, 5.3, N, 12.6. Calc. for $C_{22}H_{24}N_4O_4S$: C, 59.98, H, 5.49, N, 12.72%).

Synthesis of 1-benzyl-5-ethoxycarbonylimino-1,3-dihydroimidazo[4,5-c]pyridin-2-onium ylide (27). To a stirred suspension of 26 (2 g; 4.5 mmole) in abs EtOH (40 ml) was added dropwise ethyl chloroformate (1.7 g) in abs EtOH (10 ml) followed by anhyd. K_2CO_3 (4 g). Afted stirring overnight at room temp., the inorganic salts were filtered off and the remaining soln was evaporated to dryness in vacuo. The residue was then taken up in CH_2Cl_2 (50 ml) and after removal of the potassium mesitylenesulfonate, the soln was evaporated in vacuo to dryness. The resulting solid was chromatographed over a silicic acid column with a $CHCl_3$-EtOH 5/1 v/v mixture, to give 27, 0.31 g (22%), m.p. 206°; UV λ_{max} 304 nm (ε = 9600); IR 1750 and 1640 cm^{-1}; ^{1}H NMR (CD_3OD): 8.22 (1H, d, J = 1.5 Hz, H-4), 8.11 (1H, dd, J = = 6.8 and 1.5 Hz, H-6), 7.33 (5H, s, Ph), 7.30 (1H, d, J = 6.8 Hz, H-7),5.17 (2H, s, CH_2 - benzyl), 4.12 (2H, q, J = 7.0 Hz, CH_2 - ethyl), 1.26 (3H, t, J = 7.0 Hz, Me); MS: m/e 284 (M^+ - 28), 225, 208, 91. (Found: C, 61.5, H, 5.0, N, 17.7. Calc. for $C_{16}H_{16}N_4O_3$: C, 61.53, H, 5.16, N, 17.94%).

Photochemical reaction of ylide 27. A soln of 27 (150 mg; 0.48 mmole) in dry MeOH (450 ml) was irradiated for 30 min, whence all starting material was consumed. After evaporation of the solvent in vacuo silica gel column chromatography $CHCl_3$-EtOH 5/1 v/v mixture separated three products: R_f 0.7, 1-benzyl-4-ethoxycarbonylamino-1,3-dihydroimidazo[4,5-c]pyridin-2-one (28), 44 mg, (29.3%); R_f 0.5, 1-benzyl-6-ethoxycarbonylamino-1,3-dihydroimidazo[4,5-c]pyridin-2-one (29),37 mg, (24.7%); R_f 0.3, 1-benzyl-1,3-dihydroimidazo[4,5-c]pyridin-2-one (24), 36 mg, (33.3%) identical with the authentic sample.

1-Benzyl-4-ethoxycarbonylamino-1,3-dihydroimidazo[4,5-c]pyridin-2-one (28): colourless crystals, m.p. 320°; UV λ_{max} 285 and 247 nm (ε = 7500 and 5400 resp.); IR 1720, 1550, 1290, 1240 cm^{-1}; ^{1}H NMR(DMSO-d_6): 7.61 (5H, s, Ph), 7.56 (1H, d, J = 5.3 Hz, H-6), 7.21 (1H, d, J = 5.3 Hz, H-7), 5.35 (2H, s, CH$_2$ -benzyl), 4.59 (2H, q, J = 7.0 Hz, CH$_2$ -ethyl), 1.59 (3H, t, J = 7.0 Hz, Me); mass spectrum: m/e 312 (M$^+$), 266 (M$^+$-46), 91(Bn$^+$).

1-Benzyl-6-ethoxycarbonylamino-1,3-dihydroimidazo[4,5-c]pyridin-2-one (29): colourless crystals, m.p. 344°; UV λ_{max} 293 and 255 nm (ε = 5000 and 8500 resp.); IR 1720, 1550, 1270, 1230 cm^{-1}; ^{1}H NMR (DMSO-d$_6$) : 8.24 (1H, s, H-4), 7.86 (1H, s, H-7), 7.68 (5H, s, Ph), 5.36 (2H, s, CH$_2$ -benzyl), 4.46 (2H, q, J = 7.0 Hz, CH$_2$ -ethyl), 1.57 (3H, t, J = 7.0 Hz, Me); MS: m/e 312 (M$^+$), 266 (M$^+$-46),91(Bn$^+$).

Synthesis of 5-amino-1,3-dihydroimidazo[4,5-c]pyridin-2-onium mesitylenesulfonate (25). To a stirred suspension of 23[31] (6.76 g, 0.05 mole) in dry MeOH (150 ml) was added dropwise a soln of MSH[26] (11.84 g, 0.055 mole) in dry MeOH (75 ml). After stirring for about 12 hr at room temp., colourless crystals were filtered off to yield 25, 14.2 g (81%), m.p. 297-298°, recrystallized from MeOH; ^{1}H NMR (DMSO-d$_6$): 8.42 (1H, s, H-4), 8.37 (1H, d, J = 6.5 Hz, H-6), 7.44 (1H, d, J = 6.5 Hz, H-7), 6.75 (2H,s, CH $^-$OMes), 2.51 (6H, s, o-Me), 2.17 (3H, s, p-Me); MS: m/e 200 (M$^+$-150), 150 (M$^+$-200), 135. (Found: C, 51.2, H, 5.1, N, 16.2. Calc. for $C_{15}H_{18}N_4O_4S$: C, 51.42, H, 5.18, N, 16.00%).

Synthesis of 3,4-diethoxycarbonylamino-1-ethoxycarbonyliminopyridinium ylide (30). To a stirred suspension of 25 (1.4 g; 4 mmole) in abs EtOH (60 ml) was added dropwise ethyl chloroformate (1.72 g; 16 mmole) in abs EtOH (10 ml) followed by anhyd. K_2CO_3 (4.4 g). After about 12 hr at room temp., the inorganic salts were filitered off and the remaining soln was evaporated to dryness in vacuo.The residue was taken up in acetonitrile (100 ml) and after removal of the potassium mesitylenesulfonate, the soln was evaporated in vacuo to dryness. The resulting solid material was chromatographed over a silicic acid column with a CHCl$_3$-EtOH 9/1 v/v mixture. 0.48 g (35%) of 30 were thus isolated as colourless crystals; m.p. 223-225°. UV λ_{max} 313, 268 and 241 nm (ε = 11350, 10700 and 13100 resp.); IR 1730 and 1630 cm^{-1} (C=O); ^{1}H NMR (CDCl$_3$): 8.84 (1H, d, J = 1.8 Hz, H-2), 8.70 (2H, s, NH), 8.24 (1H, d, J = 7.3 Hz, H-6), 7.79 (1H, dd, J = 7.3 and 1.8 Hz, H-5), 4.26 (2H, q, J = 7.0 Hz), 4.21 (2H, q, J = 7.0 Hz), 4.17 (2H, q, J = 7.0 Hz),1.35 (3H, t, J = 7.0 Hz), 1.32 (3H, t, J = 7,0 Hz), 1.29 (3H, t, J = 7.0 Hz); MS: m/e 340 (M$^+$). (Found: C, 49.3, H, 5.9, N, 16.6. Calc. for $C_{14}H_{20}N_4O_6$: C, 49.42, H. 5.92, N, 16.46%).

Photoinduced synthesis of 4,5-diethoxycarbonylamino-1-ethoxycarbonyl-1,2-diazepine (31a) and 5,6-diethoxycarbonylamino-1-ethoxycarbonyl-1,2-diazepine (31b). A soln of 30 in suitable solvent (see Table 1) was irradiated whence all starting material was consumed. After evaporation of the solvent in vacuo the crude mixture was chromatographed over a silicic acid column with a CH$_2$Cl$_2$-acetone 4/1 v/v mixture. Two 1,2-diazepines 31a and 31b were eluted: 4,5-diethoxycarbonylamino-1--ethoxycarbonyl-1,2-diazepine (31a), m.p. 128-131°; UV λ_{max} 351 and 262 nm (ε = = 1200 and 12800 resp.); ^{1}H NMR (CDCl$_3$): 7.32 (1H, s, H-3), 7.14 (2H, s, NH),6.31 (1H, d, J = 7.6 Hz, H-7), 5.90 (1H, d, J = 7.6 Hz, H-6), 4.04-4.44 (6H, 3q, J = = 7.0 Hz, 3CH$_2$), 1.15-1.70(9H, 3t, J = 7.0 Hz, 3 Me); MS: m/e 340 (M$^+$). (Found: C, 49.4, H, 5.9, N, 16.2. Calc. for $C_{14}H_{20}N_4O_6$: C, 49.41, H, 5.92, N, 16.46%).

5,6-diethoxycarbonylamino-1-ethoxycarbonyl-1,2-diazepine (31b), m.p.144-146°; UV λ_{max} 340 and 257 nm (ε = 550 and 11000 resp.); ^{1}H NMR (CDCl$_3$): 7.51 (1H,d, J = = 4.1 Hz, H-3), 7.05 (1H, d, J = 4.1 Hz, H-4), 6.64 (2H, s, NH), 6.45 (1H,s,H-7), 4.06-4.45 (6H, 3q, J = 7.0 Hz, 3CH$_2$), 1.19-1.63 (9H, 3t, J = 7.0 Hz); MS: m/e 340 (M$^+$). (Found: C, 49.3, H, 5.8, N, 16.5. Calc. for $C_{14}H_{20}N_4O_6$: C, 49.41, H, 5.92, N, 16.46%).

In several cases two additional compounds were eluted (see Table 1): 3,4-diethoxycarbonylaminopyridine (32), m.p. 87-92°; ^{1}H NMR ($CDCl_3$): 8.40 (1H, s, H-2), 8.34 (1H, d, J = 5.6 Hz, H-6), 7.94 (1H, d, J = 5.6 Hz, H-5), 7.81(2H, s, NH), 4.20-4.26 (4H, 2q, J = 7.0 Hz, $2CH_2$), 1.28-1.33 (6H, 2t, J = 7.0 Hz, 2Me);MS: m/e 253 (M^+). (Found: C, 52.3, H, 5.8, N, 16.4. Calc. for $C_{11}H_{15}N_3O_4$: C, 52.17, H, 5.97, N, 16.59%).

2,4,5-triethoxycarbonylaminopyridine (33), no melted under 320°; ^{1}H NMR (DMSO-d_6): 8.50 (1H, s, H-6), 8.20 (1H, s, H-3), 4.15-4.30 (6H, 3q, J = 7.0 Hz), 1.24-1.40 (9H, 3t, J = 7.0 Hz); MS: m/e 340 (M^+). (Found: C, 49.2, H, 5.8,N,16.6. Calc. for $C_{14}H_{20}N_4O_6$: C, 49.41, H, 5.92, N, 16.46%).

Synthesis of 6-ethoxycarbonyl-1,3-dihydroimidazo[4,5-d][1,2]diazepin-2-one (34). To a stirred suspension of 50% NaH (200 mg) in dry THF (10 ml) was added dropwise a soln of 31a (204 mg; 0.6 mmole) in dry THF (20 ml) at room temp. under dry Ar. After about 5 hr at room temp., the mixture was treated at 5° with MeOH (10 ml). The red soln was stirred for another hr at 5° with Amberlite IRC-50(H)to achieve pH = 7. The ion exchange resin was filtered off and in the remaining soln diethyl carbonate was detected (GLC). After evaporation of the solvent in vacuo at 25°, the residue was chromatographed over a silicic acid column with $CHCl_3$-EtOH 5/1 v/v mixture. Diazepine 34, 68 mg (51.5%) was thus isolated as yellow crystals, m.p. 302-305°; UV λ_{max} 372, 267 and 232 nm (ε = 830, 7550 and 5500 resp.); ^{1}H NMR (DMSO-d_6): 7.80 (1H, s, H-4), 6.15 (1H, d, J = 7.0 Hz, H-7), 6.00 (1H, d, J = 7.0 Hz, H-8), 4.19 (2H, q, J = 7.0 Hz, CH_2) 1.23 (3H,t,J=7.0 Hz, Me); MS: m/e 222 (M^+). (Found: C, 48.6, H, 4.5, N, 25.1. Calc. for $C_9H_{10}N_4O_3$: C, 48.65, H, 4.54, N, 25.21%).

Synthesis of 1-(2,3,5-tri-O-benzoyl-β-D-ribofuranosyl)-1,3-dihydroimidazo[4,5-c]pyridin-2-one (35a) and 3-(2,3,5-tri-O-benzoyl-β-D-ribofuranosyl)-1,3-dihydroimidazo[4,5-c]pyridin-2-one (36a). To a stirred suspension of dry 23 (100 mg; 0.74 mmole) in dry pyridine (2 ml) was added hexamethyldisilazane (HMDS) (0.5 ml) at room temp. under dry Ar. A catalytic amount of trimethylsilyl chloride(2 drops) was added to the suspension. The mixture was heated at reflux for 7 hr under dry Ar, at which point the solied had dissolved. The solvent was removed in vacuo (50°, 5 torr). To the white crystalline residue was added 1-O-acetyl-2,3,5-tri-O-benzoyl-β-D-ribofuranose^{34} (373 mg; 0.74 mmole) (dried previously at 80° for 24 hr, 1 torr) dissolved in a mixture of 1,2-dichloroethane and acetonitrile (2ml/2ml). To the resulting suspension cooled to 0° $SnCl_4$ (0.1 ml) was added and the soln was stirred at 0° for 7 hr under dry Ar. The reaction was quenched with a saturated $NaHCO_3$ aqueous soln, and the precipitate was removed by filtration through Celite. The organic layer was dried over Na_2SO_4, filtered, and evaporated in vacuo at 30°. The residue was chromatographed over silicic acid column with $CHCl_3$-EtOH 95/5 v/v mixture. Two ribonucleosides 35a (98 mg) and 36a (81 mg) were eluted:

1-(2,3,5-tri-O-benzoyl-β-D-ribofuranosyl)1,3-dihydroimidazo[4,5-c]pyridin-2-one (35a), 98 mg (23%), colourless crystals, m.p. 105-110°, recrystallized from a mixture $CHCl_3$-hexane. UV λ_{max} 275 nm (ε = 9000); ^{1}H NMR ($CDCl_3$): 8.35 (1H, s, H-4), 8.12 (1H, d, J = 5.3 Hz, H-6), 7.16 (1H, d, J = 5.3 Hz, H-7), 7.32-8.07 (15H, m, 3 benzoyl), 6.07-6.29 (3H, m, 1', 2' and 3' H), 4.68-4.88 (3H, m, 4' and 5' H); MS: m/e 445 (M^+ - $C_6H_4N_3O$), 135 (base), 105 ($PhCO^+$), 77 (Ph^+). (Found: C, 66.0, H, 4.1, N, 7.3. Calc. for $C_{32}H_{25}H_3O_8$: C, 66.30, H, 4.35, N, 7.25%).

3-(2,3,5-tri-O-benzoyl-β-D-ribofuranosyl)-1,3-dihydroimidazo[4,5-c]pyridin-2-one (36a), 81 mg (19%), colourless crystals, m.p. 185-190°, recrystallized from a mixture $CHCl_3$-hexane. UV λ_{max} 275 nm (ε = 6000) ^{1}H NMR ($CDCl_3$): 8.47 (1H,s,H-4), 8.24 (1H, d, J = 5.3 Hz, H-6), 7.03 (1H, d, J = 5.3 Hz, H-7), 7.32-8.12 (15H, m, 3 benzoyl), 5.80-6.50 (3H, m, 1', 2' and 3'H), 4.66-4.76 (3H, m, 4' and 5'H); MS: m/e 445 (M$^+$ - $C_6H_4N_3O$), 135 (base), 105 (PhCO$^+$), 77 (Ph$^+$). (Found: C, 66.2, H, 4.4, N, 7.5. Calc. for $C_{32}H_{25}N_3O_8$: C, 66.30, H, 4.35, N, 7.25%).

Deprotection of O-benzoylated ribonucleosides 35a and 36a. Deprotection of 35a and 36a was accomplished by the following general procedure. The protected ribonucleoside (58 mg; 0.1 mmole) was kept in dry methanolic ammonia (5 ml) at room temp. until TLC ($CHCl_3$-EtOH 9/1 v/v mixture) indicated completion of the reaction, normally 24-48 hr. Removal of the solvent in vacuo gave a solid residue. This residue was washed with hot toluene to remove methyl benzoate and benzamide, and the insoluble residue was crystallized from the appropriate solvent to give the pure deprotected ribonucleoside.

1,3-Dihydro-1-β-D-ribofuranosylimidazo[4,5-c]pyridin-2-one (35b). Deprotection of 35a and crystallization from MeOH/MeCN gave 35b (85%); m.p. 144-147°. UV λ_{max} 274 nm (ε = 6500); ^{1}H NMR (DMSO-d_6): 8.33 (1H, s, H-4), 8.25 (1H, d, J = 5.3 Hz, H-6), 7.66 (1H, d, J = 5.3 Hz, H-7), 5.77 (1H, d, J = 7.0 Hz, H-1'), 4.61 (1H, dd, J = 7.0 and 5.6 Hz, H-2'), 4.18 (1H, dd, J = 5.6 and 2.6 Hz, H-3'), 3.94-4.06 (1H, m, H-4'), 3.94 (2H, s, H-5'); MS: m/e 267 (M$^+$). (Found: C, 49.4, H, 4.7, N, 15.5. Calc. for $C_{11}H_{13}N_3O_5$: C, 49.44, H, 4.90, N, 15.72%).

1,3-Dihydro-3-β-D-ribofuranosylimidazo[4,5-c]pyridin-2-one (36b). Deprotection of 36a and crystallization from MeOH/MeCN gave 36b (90%); m.p. 201-203°. UV λ_{max} 274 nm (ε = 5000); ^{1}H NMR (DMSO-d_6): 8.71 (1H, s, H-4), 8.28 (1H, d, J = 5.3 Hz, H-6), 7.16 (1H, d, J = 5.3 Hz, H-7), 5.81 (1H, d, J = 7.0 Hz, H-1'), 4.57 (1H, dd, J = 7.0 and 5.6 Hz, H-2'), 4.20 (1H, dd, J = 5.6 and 2.6 Hz, H-3'), 3.98 (1H, dd, J = 2.6 and 3.2 Hz, H-4'), 3.72 (2H, d, J = 3.2 Hz, H-5'); MS: m/e 267 (M$^+$). (Found: C, 49.6, H, 5.0, N, 15.6. Calc. for $C_{11}H_{13}N_3O_5$: C, 49.44, H, 4.90, N, 15.72%).

Synthesis of 1-benzyl-3-(2,3,5-tri-O-benzoyl-β-D-ribofuranosyl)-1,3-dihydroimidazo[4,5-c]pyridin-2-one (37a). In a typical procedure to a suspension of 1-benzyl-1,3-dihydroimidazo[4,5-c]pyridin-2-one (24) (338 mg; 1.5 mmole) in anhydrous pyridine (4 ml) were added HMDS (1 ml) and trimethylsilyl chloride (6 drops). The suspension was heated at reflux under dry Ar for 7 hr, at which time the reaction mixture was a clear solution. Removal of the solvent under vacuum at 50° gave a white solid, which was dissolved in anhydrous dichloroethane (4 ml). To this soln was added 1-O-acetyl-2,3,5-tri-O-benzoyl-β-D-ribofuranose^{34} (757 mg; 1.5 mmole) dissolved in anhydrous acetonitrile (4 ml). To the resulting suspension cooled to 0° $SnCl_4$ (0.2 ml) was added and the reaction mixture was stirred at 0° for 7 hr, after which time TLC ($CHCl_3$-EtOH 9/1 v/v mixture) indicated completion of the reaction. The reaction was quenched by the slow addition to a suspension of an excess of $NaHCO_3$ aqueous soln. The mixture was filtered to remove the tin salts. The solid was washed with hot 1,2-dichloroethane (10 ml), and the wash was added to the filtrant. The organic and aqueous layers were separated, and the aqueous layer was extracted with 1,2-dichloroethane (2 x 5 ml). The combined organic layers were dried over Na_2SO_4, the solvent was removed under vacuum to give a white crystalline solid. Column chromatography (CH_2Cl_2-acetone 4/1 v/v mixture) gave analytical pure 37a, 310 mg (31%), colourless crystals, m.p. 170-175°, recrystallized from a mixture acetone-hexane. UV λ_{max} 274 nm (ε = 7300); ^{1}H NMR ($CDCl_3$): 8.54 (1H, s, H-4), 8.25 (1H, d, J = 5.3 Hz, H-6), 7.40 (1H, d, J = 5.3 Hz, H-7), 7.89-8.17 (6H, m, CH-benzoyl), 7.34-7.63 (9H, m, CH-benzoyl), 7.28 (5H, s, CH-benzyl), 6.81 (1H, d, J = 5.6 Hz, H-1'), 6.10-6.33 (3H, m, H-2', 3' and 4'), 5.03 (2H, s, CH_2- benzyl), 4.80 (2H, s, H-5'); MS: m/e 669 (M$^+$). (Found: C, 69.7, H, 4.6, N, 6.3. Calc. for $C_{39}H_{31}N_3O_8$: C, 69.95, H, 4.67, N, 6.27%).

Synthesis of 1-benzyl-1,3-dihydro-3-β-D-ribofuranosylimidazo[4,5-c]pyridin-2-one (37b). The methanolic ammonia deprotection of 37a (268 mg; 0,4 mmole) was accomplished by the general procedure to give after column chromatography ($CHCl_3$-EtOH 4/1 v/v mixture) 37b, 134 mg (94%), colourless hygroscopic semi-crystalline compound. UV λ_{max} 274 nm (ε = 3000); ^1H NMR (CD_3OD): 8.91 (1H, s, H-4), 8.37 (1H, d, J = 5.3 Hz, H-6), 7.52 (5H, s, CH-benzyl), 7.32 (1H, d, J = 5.3 Hz, H-7), 6.14 (1H, d, J = 7.0 Hz, H-1'), 5.31 (2H, s, CH_2-benzyl), 4.92 (1H, dd, J = 7.0 and 6.5 Hz, H-2'), 4.50 (1H, dd, J = 6.5 and 3.0 Hz, H-3'), 4.30 (1H, m, H-4'), 4.02 (2H, s, H-5'); MS: m/e 357 (M^+). (Found: C, 60.5, H, 5.1, N, 11.7. Calc. for $C_{18}H_{19}N_3O_5$: C, 60.50, H, 5.36, N, 11.76%).

Formation of 1,3-dihydro-3-β-D-ribofuranosylimidazo[4,5-c]pyridin-2-one (36b) from N-benzylated nucleoside 37b. To a stirred suspension of 10% Pd on charcoal (50 mg) in 98% EtOH (5 ml) in Parr apparatus at room temp. under H_2 the soln of 37b (72 mg; 0.2 mmole) in 98% EtOH (10 ml) was added. The suspension was then heated at reflux under H_2 for ca 6 hr, at which time TLC ($CHCl_3$-EtOH 4/1 v/v mixture) showed complete reaction of 37b to form 36b. The catalyst was filtered through Celite and washed with hot EtOH, and the combined filtrates were evaporated under vacuum at 30° to dryness. The resultant 36b, white solid, 47 mg (88%) was identical by ^1H NMR with the sample obtained by deprotection of 36a, m.p.200-205°, recrystallized from a mixture hexane/acetone/methanol.

N-Ribosidation of 6-ethoxycarbonyl-1,3-dihydroimidazo[4,5-d][1,2]diazepin-2-one (34). In a typical N-ribosidation procedure (see synthesis of 35a and 36a mixture) to a suspension of 34 (222 mg; 1 mmole) in anhydrous pyridine (4 ml) were added HMDS (0.8 ml) and trimethylsilyl chloride (4 drops). The reaction mixture became clear and was heated at reflux under dry Ar for 6 hr. Removal of the solvent under vacuum (50°, 5 torr) gave a brown solid residue. The soln of 1-O-acetyl-2,3,5-tri-O-benzoyl-β-D-ribofuranose[34] (505 mg; 1 mmole) in a mixture of anhydrous MeCN (4 ml) and anhydrous 1,2-dichloroethane (4 ml) was then added. To the resulting suspension cooled to 0° $SnCl_4$ (0.4 ml) was added and the reaction mixture was stirred at 0° for 7 hr, at which time TLC (CH_2Cl_2-acetone 4/1 v/v mixture) revealed complete reaction. The reaction was quenched with $NaHCO_3$ aqueous soln. The solid was filtered through Celite, washed with hot 1,2-dichloroethane(20 ml), and the wash was added to the filtrant. The organic and aqueous layers were separated, and the aqueous layer was extracted (2 x 5 ml) with dichloroethane. After the organic layers were combined and dried over Na_2SO_4, the solvent was removed under vacuum (30°, 5 torr) to give a pink crystalline solid. The residue was chromatographed over a silicic acid column with CH_2Cl_2-acetone 4/1 v/v mixture. Three N-ribosidation products were eluted, and identified as the following: R_f 0.9, 1,3-bis(2,3,5-tri-O-benzoyl-β-D-ribofuranosyl)-6-ethoxycarbonyl-1,3-dihydroimidazo[4,5-d][1,2]diazepin-2-one (40; 140 mg, 12.6%); R_f 0.5, 3-(2,3,5-tri-O-benzoyl-β-D-ribofuranosyl)-6-ethoxycarbonyl-1,3-dihydroimidazo[4,5-d][1,2]diazepin-2-one (39a, 102 mg, 15.3%); R_f 0.3, 1-(2,3,5-tri-O-benzoyl-β-D-ribofuranosyl)-6-ethoxycarbonyl-1,3-dihydroimidazo[4,5-d][1,2]diazepin-2-one (38a, 136 mg, 20.4%).

40: yellow crystals,m.p. 100-102°, recrystallized from a mixture acetone-hexane. UV λ_{max} 352 and 274 nm (ε = 1600 and 18300 resp.); ^1H NMR data - see Table 2. (Found: C, 65.7, H, 4.4, N, 5.0, Calc. for $C_{61}H_{50}N_4O_{17}$: C, 65.94, H, 4.54,N,5.04%).

39a: yellow crystals, m.p. 110-112°, recrystallized from a mixture acetone-hexane. UV λ_{max} 349 and 268 nm (ε = 1000 and 9500 resp.); ^1H NMR data - see Table 2.(Found: C, 63.1, H, 4.5, N, 8.2. Calc. for $C_{35}H_{30}N_4O_{10}$: C, 63.06, H, 4.54,N,8.40%).

38a: yellow crystals, m.p. 112-114°, recrystallized from a mixture acetone-hexane. UV λ_{max} 335 and 266 nm (ε = 1100 and 6200 resp.); ^1H NMR data - see Table 2.(Found: C, 63.2, H, 4.5, N, 8.3. Calc. for $C_{35}H_{30}N_4O_{10}$: C, 63.06, H, 4.54, N. 8.40%).

6-Ethoxycarbonyl-1,3-dihydro-1-β-D-ribofuranosylimidazo[4,5-d][1,2]diazepin-2-one (38b) was obtained by deprotection of 38a in a typical procedure as a yellow semi-solid compound (82%). UV λ_{max} 370 and 264 nm (ε = 1000 and 6200 resp.); ^{1}H NMR data - see Table 2; MS: m/e 354 (M^+). (Found: C, 47.3, H, 5.1, N, 15.6. Calc. for $C_{14}H_{18}N_4O_7$: C, 47.46, H, 5.12, N, 15.81%).

6-Ethoxycarbonyl-1,3-dihydro-3-β-D-ribofuranosylimidazo[4,5-d][1,2]diazepin-2-one (39b) was obtained by deprotection of 39a in a typical procedure and was recrystallized from a mixture acetone-hexane as yellow hygroscopic crystals (75%), m.p. 112-115°. UV λ_{max} 348 and 265 nm (ε = 1800 and 6400 resp.); ^{1}H NMR data see Table 2; MS: m/e 355 (M^+ + 1). (Found: C, 47.2, H, 5.2, N, 15.9. Calc. for $C_{14}H_{18}N_4O_7$: C, 47,46, H, 5.12, N, 15.81%).

4-Amino-1,3-dihydro-1,3-bis(β-D-ribofuranosyl)imidazo[4,5-c]pyridin-2-one(41) was obtained during the methanolic ammonia deprotection of 40 for 24 hr at room temp. After evaporation to dryness, extraction of the solid residue with hot toluene followed by column chromatography ($CHCl_3$-EtOH 9/1 v/v mixture) gave an analytically pure colourless crystals of 41 (58%), m.p. 143-145°, recrystallized from a mixture acetone-hexane. UV λ_{max} 292, 251 and 229 nm (ε = 2200, 3000 and 6200 resp.); ^{1}H NMR (CD_3OD): 7.73 (1H, d, J = 5.9 Hz, H-6), 7.00 (1H, d, J = 5.9 Hz, H-7), 5.90 (1H, d, J = 6.5 Hz, H-1′), 5.80 (1H, d, J = 6.5 Hz, H-1″); MS: m/e 415 (M^+ + 1), 150 (base), 133 ($C_5H_{10}O_4^+$). (Found: C, 46,2, H, 5.3, N, 13.5. Calc. for $C_{16}H_{22}N_4O_9$: C, 46.38, H, 5.35, N, 13.52%).

Acknowledgements - The author is very grateful to Prof. H. Fritz (Basel) for having kindly arranged determination and for interpretation of 400 MHz NMR spectra, and to Dr. R. Bodalski for some helpful discussions. We thank also Prof. J. Streith for his encouragement and fruitful discussions. We are especially indebted to Mrs C. Seliga for her experimental assistance and technical support. This work was supported by the Polish Academy of Sciences, Grant MR I - 12.7.

REFERENCES

1. P.W.K. Woo, H.W. Dion, S.M. Lange, L.F. Dahl and L.J. Durham, J. Heterocycl. Chem. 11, 641 (1974); D.C. Baker and S.R. Putt, J. Am. Chem. Soc. 101, 6127 (1979)
2. M. Ohno, N. Yagisawa, H. Nakamura, S. Kondo, K. Maeda; H. Umezawa, G. Koyama an Y. Iitaka, J. Am. Chem. Soc. 96, 4327 (1974)
3. R.P. Agarwal, T. Spector and R.E. Parks Jr., Biochem. Pharmacol. 26, 359 (1977)
4. J. Streith and J.M. Cassal, Angew. Chem. 80, 117 (1968); Ibid. Int. Ed. Engl. 7, 129 (1968); Bull. Soc. Chim. France 2175 (1969)
5. J. Streith, J.P. Luttringer and M. Nastasi, J. Org. Chem. 36, 2962 (1971)
6. T. Sasaki, K. Kanematsu and A. Kakehi, Chem. Commun. 432 (1969)
7. V. Snieckus, Ibid. 831 (1969)
8. T. Sasaki, K. Kanematsu, A. Kakehi, I. Ichikawa and K. Hayakawa, J. Org. Chem. 35, 426 (1970)
9. A. Balasubramanian, J.M. McIntosh and V. Snieckus, J. Org. Chem. 35, 433 (1970)
10. J. Streith and J.L. Schuppiser, Tetrahedron Letters, 4859 (1976)
11. V. Snieckus and G. Kan, Chem. Commun. 172 (1970)
12. K.T. Potts and R. Dugas, Ibid, 732 (1970)
13. S.F. Gait, C.W. Rees and R.C. Stoor, Ibid. 1545 (1971)

14. T. Tsuchiya, J. Kurita and V. Snieckus, J. Org. Chem. 42, 1856 (1977)
15. T. Tsuchiya, M. Enkaku, J. Kurita and H. Sawanishi, Chem. Pharm. Bull. 27, 2183 (1979)
16. T. Tsuchiya, M. Enkaku and H. Sawanishi, Heterocycles 9, 621 (1978);Idem.Ibid. 12, 1471 (1979); M. Enkaku, J. Kurita and T. Tsuchiya, Ibid., 1923 (1981); T. Tsuchiya, M. Enkaku and S. Okajima, Chem. Pharm. Bull. 29, 3173 (1981); J.Kurita, M. Enkaku and T. Tsuchiya, Chem. Pharm. Bull. 30, 3764 (1982)
17. T. Tsuchiya, H. Sawanishi, M. Enkaku and T. Hirai, Chem. Pharm. Bull.29, 1539 (1981)
18. Y. Tamura, H. Ishibashi, N. Tsujimoto and M. Ikeda, Chem. Pharm. Bull. 19, 1285 (1971)
19. Y. Tamura, S. Matsugashita, H. Ishibashi and M. Ikeda, Tetrahedron 29, 2359 (1973)
20. T. Shiba, K. Yamane and H. Kato, Chem. Commun. 1592 (1970)
21. C. Richter and P. Sieber (Cilag Ltd), Pat. Swiss. 324, 439 (1957); C.A; 52, 18475f (1958)
22. J.W. Clarck-Lewis and R.P.Singh, J. Chem. Soc. 2379 (1962)
23. E. Koenigs, H. Bueren and G. Jung, Chem. Ber. 69, 2690 (1936)
24. A. Albert and C. Pedersen, J. Chem. Soc. 4683 (1956)
25. M. Rasmussen and N.J. Leonard, J. Am. Chem. Soc. 89, 5439 (1967)
26. Y. Tamura, Y. Miki, T. Honda and M. Ikeda, J. Heterocyclic Chem. 9, 865 (1972)
27. B.S. Hahn, S.Y. Wang, J.L. Flippen and I.L. Karle, J. Am. Chem. Soc. 95, 2711 (1973)
28. M. Poje, E.F. Paulus and B. Ročič, J. Org. Chem. 45, 65 (1980)
29. O. Bremer, Liebigs Ann. Chem. 518, 274 (1935)
30. R.L. Clark, A.A. Pessolano, T.Y. Shen, D.P. Jacobus, H. Jones, V.J. Lotti and L.M. Flataker, J. Medicinal Chem. 21, 965 (1978)
31. G.B. Barlin, J.Chem. Soc. B. 285 (1966)
32. G.G. Spence, E.C. Taylor and O. Buchardt, Chem. Rev. 70, 231,(1970)
33. U. Niedballa and H. Vorbrüggen, J. Org. Chem. 39, 3654, 3660, 3664,3668(1974)
34. E.F. Recondo and H. Rinderknecht, Helv. Chim. Acta 42, 1171 (1959)
35. W.C. Still, M. Kahn and A.Mitra,J. Org. Chem. 43, 2923 (1978)