Photochemical and Thermal Reactions of Azido-oligopyridines: Diazepinones, a New Class of Metal-Complex Ligands

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Azido-oligopyridines were prepared, and their photochemical reactions resulted in diazepinones linked to pyridine moieties. The thermal reactions of azido-oligopyridines with triple bonds yielded 2*H*-azirines directly attached to oligopyridines.

Introduction. – Due to their versatile reactions, the chemistry of azides and nitrenes has attracted much attention. The chemistry of the azido group has been extensively investigated, and some reviews have been published [1–4]. The typical reactions of azides are: *i*) the unimolecular decomposition by light or heat to yield nitrenes which react inter- or intramolecularly, *ii*) acid-catalyzed decomposition yielding the nitrenium ions, which may react at N- or C-atoms, *iii*) *Staudinger* reactions, *iv*) *Curtius* and *Schmidt* rearrangements, *v*) reduction to amines, *vi*) cycloadditions to multiple bonds, *vi*) nucleophilic attack at the azide terminus, resulting in azidation, diazo transfer, and amination. In addition, another interesting aspect of the azide group is its ability to form complexes with transition metals [5].

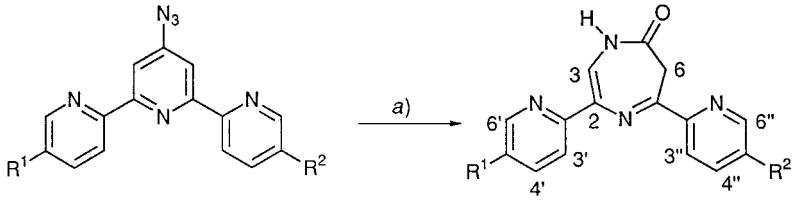
Among heterocyclic compounds, azidopyridines and azidoquinolines have been investigated. Some thermal and photochemical reactions of 4-azidopyridines and 4-azidoquinolines have been examined [6]. However, under basic conditions, the photochemical reactions of 4-azidopyridines and 4-azidoquinolines, resulted in ring expansion to diazepine derivatives [7–8].

We have recently described the synthesis of derivatives of 4′-azido-2,2′:6′,2″-terpyridine (tpy) in good yields [9]. We now report the photochemical and thermal reactions of derivatives of 4′-azido-2,2′:6′,2″-terpyridines, 4-azido-2,2′-bipyridines, and 4′-azido-2,2′:6′,2″:6″,2‴-quaterpyridine.

Results and Discussion. – *Photochemical Reactions.* The two symmetrical typ ligands **1** and **2** [9] were each irradiated in MeOH/dioxane 1:1 containing NaOMe for 3 h. A brownish red solution resulted, from which the yellow crystalline compounds **3** and **4**, respectively, were isolated in 60–70% yields (*Scheme 1*). The structures of the new diazepinones **3** and **4** were elucidated from their spectroscopic data.

The IR spectra of **3** and **4** exhibited bands at *ca.* 1700 cm^{-1} assigned to the carbonyl group of the lactame substructure. In the ^{1}H-NMR spectra of **3** and **4**, due to the loss of symmetry, 11 (**3**) and 9 signals (**4**) in the aromatic range were observed, in addition to the two Me groups of **4**. The methylene group gave rise to a broad signal at δ 4.09 (**3**) and 4.06 (**4**). The NH group was observed as a *d* at δ 8.29 (**3**) and 8.19 (**4**), while the adjacent

Scheme 1



1 $R^1=R^2=$ H
2 $R^1=R^2=$ Me
3 $R^1=R^2=$ H
4 $R^1=R^2=$ Me

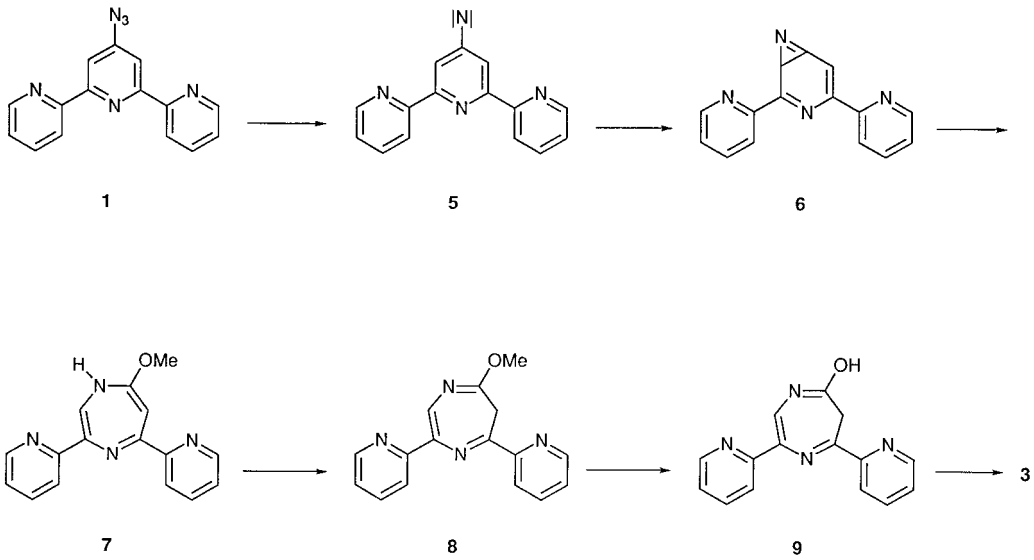
a) NaOMe, MeOH/dioxane, 25°, *hν*, 3 h; 63–70%.

H-atom was observed as a *d* at *δ* 7.38 (**3**) and 7.29 (**4**). In the MALDI-TOF mass spectra of **3** and **4**, the M^+ peak appeared at *m*/*z* 264 (**3**) and 292 (**4**).

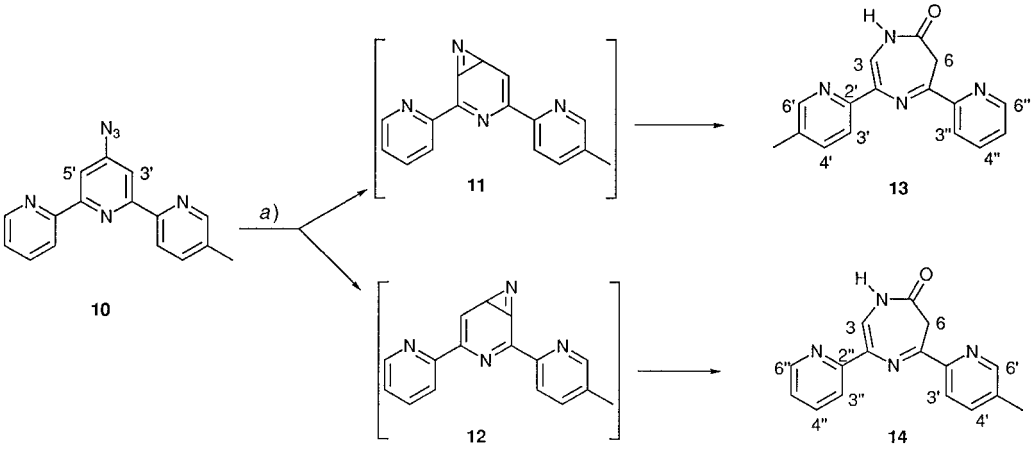
The singlet terpyridine nitrene **5**, generated from azido compound **1**, reacts intramolecularly with the pyridine ring to give compound **6** (*Scheme 2*) [7]. On nucleophilic addition of NaOMe to **6**, followed by electrocyclic ring opening of the diazanorcaradiene moiety, the unstable antiaromatic NH-diazepine **7** was formed, which isomerized to the more stable CH-form **8** by proton shift. Under the workup conditions, compound **8** is not stable and loses MeOH to give compound **9**, which then tautomerizes to **3**.

The unsymmetrical 4′-azido-2,2′:6′,2″-terpyridine **10** may ring-close in either of two directions to give two isomeric azirine intermediates **11** and **12**, each of which may react with the MeO^- ion to afford the 1,4-diazepinones **13** and **14** (*Scheme 3*). Indeed, both

Scheme 2



Scheme 3



a) NaOMe, MeOH/dioxane, 25°, *hv*, 3 h; 60%.

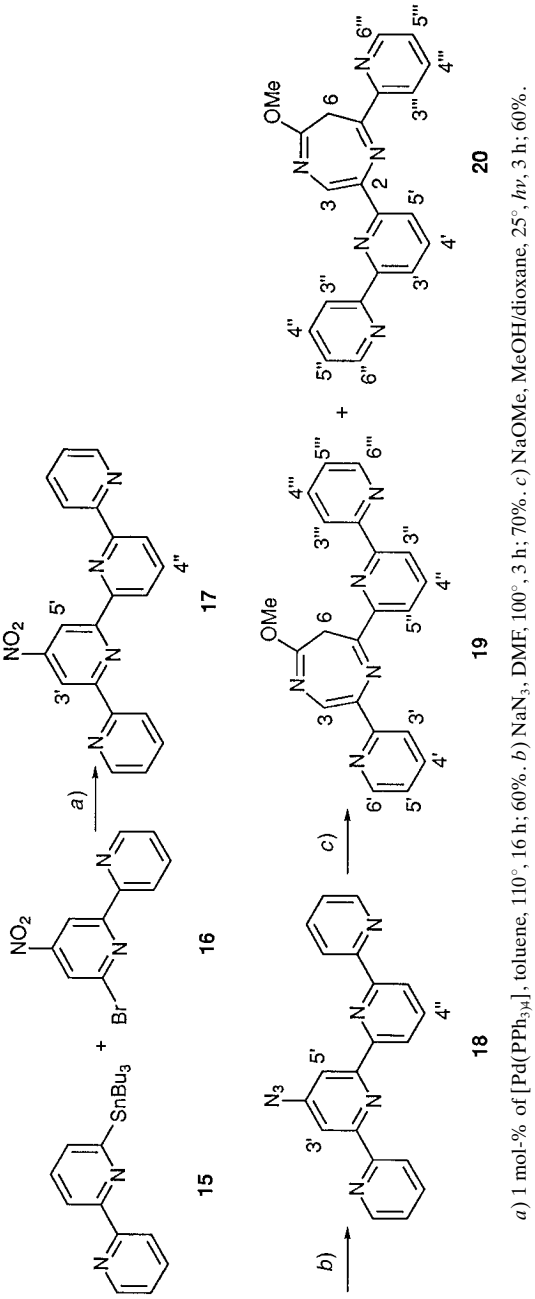
isomers **13** and **14** were obtained in a 1:1 ratio (by ^{1}H-NMR) and were separated by reversed-phase HPLC.

While **13** and **14** possess almost identical IR, UV, and mass spectra and elemental analyses, it was possible to distinguish the isomers by ^{1}H- and ^{13}C-NMR spectroscopy. In the ^{1}H-NMR spectra, the Me group was observed at δ 2.37 and 2.40 respectively. The assignment of the isomers **13** and **14** was confirmed by COSY and heteronuclear multiple-bond correlations (HMBC) and heteronuclear multiple-quantum correlations (HMQC) between the H- and the C-atoms. As already shown in oligopyridines, both compounds exhibit an *s-trans* conformation [9], even in solution, so that no NOE of the methylene group was observed. Almost all of the H-signals of both isomers were identical in the ^{1}H-NMR spectra, and the only way to distinguish them was to establish interactions between $H-$C(3) and C(2′) in the case of **13** or between $H-$C(3) and C(2″) in the case of **14**. Indeed, a long-range coupling between $H-$C(3) and C(2′) rather than C(2″) was observed in the case of **13**. By these applied methods, the two isomers **13** and **14** could correctly be assigned. In the ^{13}C-NMR spectrum of **13**/**14**, all 32 signals were observed.

Oligopyridines have been synthesized by the following methods: *i*) by *Ullman* coupling of bromopyridines [10], *ii*) by cross-coupling methods such as the *Stille* reaction [11] the *Suzuki* reaction [12], and nickel-mediated reactions [13], *iii*) by the α-oxoketene dithioacetal methodology [14], *iv*) by the *Kröhnke* methodology [15], or *v*) by the *Jameson* methodology [16]. We have already applied the *Stille* coupling reaction to obtain derivatives of 4′-nitro-2,2′:6′,2″-terpyridine in good yields [17][18]. Thus, the unsymmetrical 4′-nitro-2,2′:6′,2″:6″,2‴-quaterpyridine (**17**) was synthesized in 60% yield as a yellow microcrystalline solid by means of the *Stille* coupling [11] of tributyl ([2,2′-bipyridin]-6-yl)stannane (**15**) [19] and 6-bromo-4-nitro-2,2′-bipyridine (**16**) [18] (*Scheme 4*).

Upon displacement of the nitro group of **17** by NaN_3 in DMF [9], the 4′-azido-2,2′:6′,2″:6″,2‴-quaterpyridine (**18**) was obtained as a pink microcrystalline solid in 70% yield (IR: 2110 cm^{-1} (-N_3)). The irradiation of **18** in MeOH/dioxane under basic conditions resulted, once again, in two isomers, **19** and **20**, in a 1:1 ratio and in 66% yield. The two isomers were easily separated by chromatography on silica gel, although methoxydiazepines are extremely susceptible to decomposition on silica gel or

Scheme 4



a) 1 mol-% of [Pd(PPh$_3$)$_4$], toluene, 110°, 16 h; 60%. *b*) NaN_3, DMF, 100°, 3 h; 70%. *c*) NaOMe, MeOH/dioxane, 25°, *hν*, 3 h; 60%.

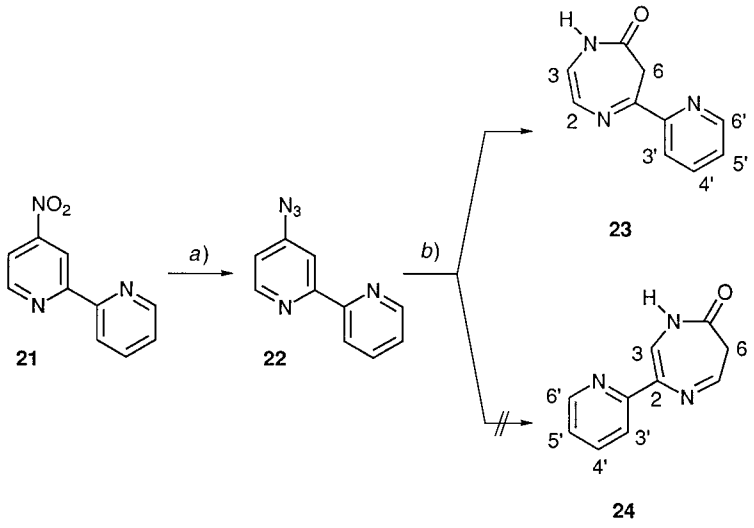
aluminium oxide [7]. Compounds **19** (less polar) and **20** were identified by spectroscopic means.

In the ^{1}H-NMR spectrum of **17**, 2*d* due to H–C(3′) and H–C(5′) were observed at δ 9.32 and 9.21, respectively. The *t* assigned to H–C(4″) appeared at δ 8.06. In the IR spectrum, the two absorptions at 1535 and 1356 cm^{-1} were assigned to the nitro group.

Interestingly, in the IR spectra of both **19** and **20**, no bands at 1700 cm^{-1} due to the lactam group were observed. However, in their MALDI-TOF mass spectra, the M^+ peak at *m*/*z* 355 was present. The isomer **19** and **20** exhibited similarities to compounds **13** and **14** in ^{1}H-NMR spectra. Thus, the signal of H–C(5′) of **19** was observed as *ddd* at δ 7.17, while the signal of H–C(5‴) of **20** was shifted to low field and observed at δ 7.32. The methoxy and methylene groups, both, were observed at δ 3.78 (**19**) and 3.81 (**20**), respectively.

In a typical reaction, 4-nitro-2,2′-bipyridine (**21**) [20] in DMF was converted to the unsymmetrical 4-azido-2,2′-bipyridine (**22**) [9] (IR: 2108 cm^{-1} (-N_3)) in 70% yield (*Scheme 5*). Irradiation of **22** in MeOH/dioxane under basic conditions resulted in two main products which were separated by chromatography (silica gel) and identified by their spectra as **23** (34%) and 2,2′-bipyridin-4-amine [20] (30%). Interestingly, thus, under these reaction conditions, 4-azido-2,2′-bipyridine (**22**) was partially reduced to the corresponding amine, and no **24** was formed.

Scheme 5



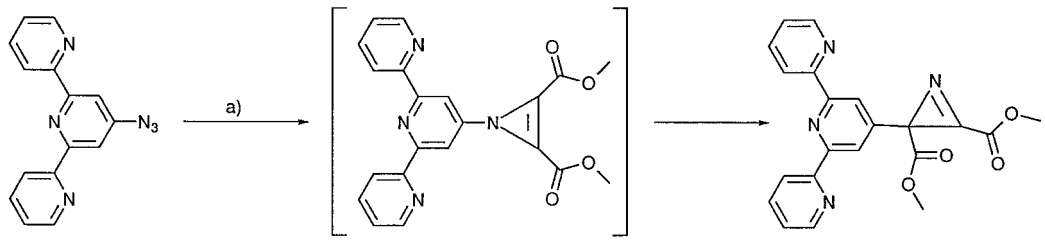
a) NaN_3, DMF, 100°, 3 h; 75%. *c*) NaOMe, MeOH/dioxane, 25°, *hν*, 3 h; **23** (34)%.

The IR spectrum of the yellow microcrystalline **23** exhibited a strong band at 1657 cm^{-1} assigned to the carbonyl group. In the MALDI-TOF-MS, the M^+ peak was observed at *m*/*z* 187. The assignment of the compound, however, was based on the ^{1}H-NMR data, **23** exhibiting the expected *dd* of H–C(3) at δ 6.02 and the *d* of H–C(2) at δ 6.89.

Thermal Reactions. Just two reactions were chosen to examine the possibility of azides undergoing further reactions. The 4′-azido-2,2′:6′,2″-terpyridine (**1**) was treated with dimethyl acetylenedicarboxylate (DMA) in chlorobenzene to yield **26**, in which

the 2*H*-azirine ring is directly attached to the tpy ligand (*Scheme 6*). The structure of the 2*H*-azirine derivative **26** was elucidated from its spectral data. The antiaromatic 1*H*-azirines such as **25** are known to be very short-lived or are postulated as intermediates that immediately rearrange to give more stable 2*H*-azirines [21].

Scheme 6



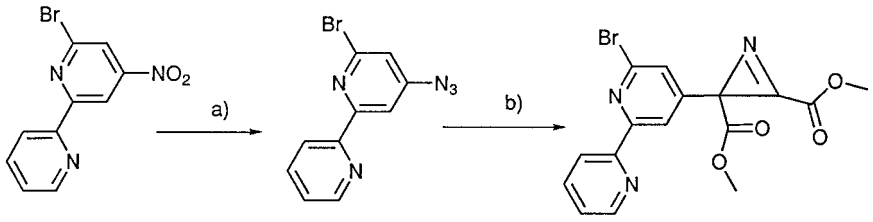
1 **25** **26**

a) DMA (excess), chlorobenzene, 150°, 20 h; 50%.

The IR spectrum of **26** exhibited two bands at 1740 and 1723 cm^{-1}, assigned to the two ester carbonyl groups. In the ^{1}H-NMR spectrum, due to the symmetry of the tpy unit, the expected 5 signals in the aromatic range were observed. The *s* of the two MeO groups, however, appeared at δ 4.05 and 4.04. In the ^{13}C-NMR spectrum, 12 signals were observed instead of the expected 14 signals (two overlapped). The two MeO groups, however, exhibited 2 signals at δ 54.11 and 52.77.

The 6-bromo-4-nitro-2,2′-bipyridine (**16**) [18] was converted to azido-bpy **27** [9] in 60% yield. In a similar reaction, **27** was then treated with DMA to yield the azirine derivative **28** in 40% yield (*Scheme 7*).

Scheme 7



16 **27** **28**

a) NaN_3, DMF, 100°, 3 h; 60%. *b*) DMA (excess), chlorobenzene, 150°, 20 h; 40%.

In the IR spectrum of **28**, two carbonyl bands were observed at 1742 and 1722 cm^{-1}. The ^{1}H-NMR spectra exhibited the signals of the Me groups at δ 4.05 and 4.03, in addition to the typical six signals due to the bipyridine unit. In the ^{13}C-NMR spectrum, all 16 signals were observed, the two MeO groups appearing at δ 54.25 and 52.86.

In conclusion, the above described methodologies allow the formation of diazepinone rings within oligopyridines. Benzo-fused diazepinones are of special interest in medicine and have been applied as tranquilizers and neuropharmaca (*e.g.*,

Librium®, *Diazepam*®) [22]. Diazepinones directly linked to oligopyridines are a new class of ligands able to form complexes with transition metals, in addition to the known five- and six-membered heterocyclic ring ligands [23]. Due to their versatile reactions, *i.e.* photochemical and thermal reactions as well as cycloadditions, the azirine and aziridine rings play an important role in synthetic chemistry [21]. Both, the biological activities especially of benzo-annulated analoga and the reactions with transition metals are currently under investigation.

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Experimental Part

1. *General*. All reagents were used as supplied. Photolysis was carried out under N_2 in an immersion apparatus equipped with a 400-W high-pressure Hg lamp and a *Pyrex* filter internally cooled with running water. Column chromatography (CC): silica gel (0.060–0.200 mm) from *Chemie Uetikon* and aluminium oxide (type *507 C* neutral; 100–125 mesh) from *Fluka*. HPLC: *Waters* instruments. M.p.: *Büchi 535*, not corrected. UV Spectra: *Perkin Elmer Lambda 19*; λ_{max} in nm. IR Spectra: *Mattson-Genesis-Fourier*-transform spectrophotometer; KBr discs in cm^{-1}. ^{1}H- and ^{13}C-NMR Spectra: *Bruker-AM-250* spectrometer; δ in ppm rel. to Me_4Si, J in Hz; for COSY, HMBC, and HMQC experiments, *Bruker DRX 500*. MALDI time-of-flight (TOF) MS: *PerPespective Biosystems Voyagers-RP Biospectrometry* workstation.

2. *Photolysis of the Azides: General Procedure 1*. A mixture of azido-oligopyridine (100 mg), Na (200 mg, in excess) in MeOH (10 ml), and MeOH/dioxane 1:1 (50 ml) was irradiated for 3 h. After evaporation, H_2O (40 ml) was added, the mixture extracted with CH_2Cl_2 (3 × 30 ml), the combined org. phase dried ($MgSO_4$) and evaporated, and the product purified by CC (silica gel, CH_2Cl_2/AcOEt 3:1) and then recrystallized from EtOH.

*4,6-Dihydro-2,7-di(pyridin-2-yl)-5*H*-1,4-diazepin-5-one* (**3**): 70 mg (70%). M.p. 237–238°. UV (MeCN): 285, 353; min. 333. IR: 2920*m*, 1703*s*, 1688*m*, 1607*m*, 1592*m*, 1562*s*, 1478*m*, 1464*m*, 1433*m*, 1280*m*, 1135*m*, 1066*m*, 781*s*. ^{1}H-NMR ($CDCl_3$): 8.74 (*md*, J = 4.88, H–C(6′)); 8.56 (*md*, J = 4.88, H–C(3′)); 8.41 (*d*, J = 7.80, H–C(6″)); 8.29 (br. *d*, J = 4.88, NH); 7.95 (*d*, J = 7.80, H–C(3′)); 7.79 (*ddd*, J = 8.30, 7.80, 1.95, H–C(4′)); 7.73 (*ddd*, J = 8.30, 7.80, 1.95, H–C(4″)); 7.38 (*d*, J = 7.80, H–C(3)); 7.36 (*ddd*, J = 8.30, 7.80, 1.95, H–C(5′)); 7.20 (*ddd*, J = 8.30, 7.80, 1.95, H–C(5″)); 4.09 (br. *s*, CH_2(6)). ^{13}C-NMR ($CDCl_3$): 163.37; 154.95; 154.08; 153.16; 149.21; 148.98; 136.73; 136.45; 135.99; 124.77; 122.81; 122.41; 120.08; 115.16; 39.47. MALDI-TOF-MS: 264. Anal. calc. for $C_{15}H_{12}N_4O$: C 68.17, H 4.58, N 21.20; found: C 68.11, H 4.65, N 21.18.

*4,6-Dihydro-2,7-bis(5-methylpyridin-2-yl)-5*H*-1,4-diazepin-5-one* (**4**): 75 mg (72%). M.p. 230–231°. UV (MeCN): 286, 354; min. 334. IR: 2922*m*, 1678*s*, 1655*m*, 1609*m*, 1556*m*, 1059*m*. ^{1}H-NMR ($CDCl_3$): 8.55 (br. *s*, H–C(6′)); 8.38 (br. *s*, H–C(6″)); 8.28 (*d*, J = 7.80, H–C(3″)); 8.19 (br. *d*, J = 5.40, NH); 7.82 (*d*, J = 7.80, H–C(3′)); 7.58 (*dd*, J = 7.80, 1.95, H–C(4′)); 7.52 (*dd*, J = 7.80, 1.95, H–C(4″)); 7.29 (*d*, J = 7.80, H–C(3″)); 4.06 (br. *s*, CH_2(6)); 2.40 (*s*, Me); 2.35 (*s*, Me). ^{13}C-NMR ($CDCl_3$): 163.47; 153.24; 152.46; 151.73; 149.63; 149.36; 137.22; 136.98; 136.18; 134.79; 131.91; 122.41; 119.65; 114.21; 39.47; 18.46; 18.19. MALDI-TOF-MS: 292. Anal. calc. for $C_{17}H_{16}N_4O$: C 69.85, H 5.52, N 19.16; found: C 69.71, H 5.65, N 19.19.

*4,6-Dihydro-2-(5-methylpyridin-2-yl)-7-(pyridin-2-yl)-5*H*-1,4-diazepin-5-one* (**13**) *and 4,6-Dihydro-7-(5-methylpyridin-2-yl)-2-(pyridin-2-yl)-5*H*-1,4-diazepin-5-one* (**14**). Irradiation of 4′-azidoterpyridine **10** (100 mg) according to the *General Procedure 1*: 60 mg (60%) of **13**/**14**. A sample of **13**/**14** (12 mg) was separated by semi-prep. HPLC (C_{18}, reversed phase, H_2O(MeCN 4:1). **13**/**14**: IR (KBr): 2920*m*, 1680*s*, 1660*m*, 1612*m*, 1560*m*, 1063*m*. MALDI-TOF-MS: 278. Anal. calc. for $C_{17}H_{16}N_4O$: C 69.85, H 5.52, N 19.16; found: C 69.71, H 5.65, N 19.19.

Data of **14**: 5 mg. M.p. 234–235°. UV (MeCN): 284, 353; min. 333. ^{1}H-NMR ($CDCl_3$): 8.56 (*m*, H–C(6″), H–C(6′)); 8.30 (*d*, J = 8.30, H–C(3′)); 7.99 (br. *d*, J = 4.84, NH); 7.73 (*ddd*, J = 8.30, 7.80, 1.95, H–C(4″)); 7.59 (*dd*, J = 7.80, 1.95, H–C(4′)); 7.36 (*d*, J = 4.84, H–C(3)); 7.20 (*ddd*, J = 8.30, 7.80, 1.95, H–C(5″)); 4.08 (br. *s*, CH_2(6)); 2.40 (*s*, Me). ^{13}C-NMR ($CDCl_3$): 163.42 (CO); 155.10 (C(2″)); 153.43 (C(7)); 151.78 (C(2′)); 149.66 (C(6′)); 148.93 (C(6″)); 137.01 (C(4′)); 136.73 (C(4″)); 136.06 (C(2)); 134.92 (C(5′)); 122.43 (C(5″)); 122.36 (C(3′)); 120.12 (C(3″)); 114.86 (C(3)); 39.50 (CH_2); 18.46 (Me).

Data of **13**: 5 mg. M.p. 233–234°. UV (MeCN): 285, 354; min. 333. ^{1}H-NMR ($CDCl_3$): 8.74 (*m*, H–C(6″)); 8.41 (*d*, *J* = 8.30, H–C(3″)); 8.39 (*s*, H–C(6′)); 8.01 (br. *d*, *J* = 4.84, NH); 7.84 (*d*, *J* = 8.30, H–C(3′)); 7.73 (*ddd*, *J* = 8.30, 7.80, 1.95, H–C(4″)); 7.54 (*dd*, *J* = 7.80, 1.95, H–C(4′)); 7.36 (*ddd*, *J* = 8.30, 7.80, 1.95, H–C(5″)); 7.32 (*d*, *J* = 5.85, H–C(3)); 4.08 (br. *s*, CH_2(6)); 2.37 (*s*, Me). ^{13}C-NMR ($CDCl_3$): 163.40 (CO); 155.15 (C(2′)); 152.41 (C(7)); 151.61 (C(2″)); 149.30 (C(6″)); 149.06 (C(6′)); 136.92 (C(4″)); 136.30 (C(4′)); 135.81 (C(2)); 131.76 (C(5″)); 124.53 (C(5′)); 122.16 (C(3″)); 119.51 (C(3′)); 115.00 (C(3)); 39.44 (CH_2); 18.07 (Me).

3. *4′-Nitro-2,2′:6′,2″:6″,2‴-quaterpyridine* (**17**). For 16 h, tributyl ([2,2′-bipyridin]-6-yl)stannane (**15**; 350 mg, 1.08 mmol), 6-bromo-4-nitro-2,2′-bipyridine (**16**; 300 mg, 1.07 mmol) and [$Pd(PPh_3)_4$] (25 mg, 2 mol-equiv.) were heated under N_2 in toluene (50 ml) for 16 h. After cooling to r.t., sat. NH_4Cl soln. (20 ml) was added. The aq. phase was extracted with toluene (3 × 20 ml), the combined org. phase dried ($MgSO_4$) and evaporated, conc. HCl soln. (30 ml) added to the residue, and the mixture extracted with CH_2Cl_2 (3 × 30 ml). The aq. phase was cautiously neutralized with solid NaOH, the product extracted with CH_2Cl_2 (3 × 30 ml), the org. phase dried ($MgSO_4$) and evaporated, and the residue purified by CC (silica gel, CH_2Cl_2/AcOEt 4:1): 230 mg (60%) of **17**. M.p. 231°. IR: 2999*w*, 1588*w*, 1561*s*, 1535*s*, 1472*m*, 1536*m*, 1401*s*, 1356*s*, 1334*m*, 1272*m*, 1094*m*, 784*s*, 751*s*, 739*s*, 672*m*, 656*m*. ^{1}H-NMR ($CDCl_3$): 9.32 (*d*, *J* = 1.95, H–C(3′)); 9.21 (*d*, *J* = 1.95, H–C(5′)); 8.78 (*d*, *J* = 7.80, H–C(6‴)); 8.73 (*d*, *J* = 7.80, H–C(6)); 8.71 (*d*, *J* = 7.80, H–C(3)); 8.68 (*d*, *J* = 7.80, H–C(3‴)); 8.66 (*dd*, *J* = 7.80, 1.0, H–C(3″)); 8.58 (*dd*, *J* = 7.80, 1.0, H–C(5″)); 8.06 (*t*, *J* = 7.80, H–C(4″)); 7.96 (*ddd*, *J* = 8.30, 7.80, 1.45, H–C(4)); 7.92 (*ddd*, *J* = 8.30, 7.80, 1.45, H–C(4‴)); 7.44 (*ddd*, *J* = 8.30, 7.80, 1.45, H–C(5)); 7.40 (*ddd*, *J* = 8.30, 7.80, 1.45, H–C(5‴)). ^{13}C-NMR ($CDCl_3$): 158.60; 156.48; 155.96; 155.67; 154.18; 153.36; 149.57; 149.21; 138.04; 137.05; 136.83; 124.84; 124.05; 122.19; 121.44; 121.34; 121.27; 121.09; 113.46; 113.32. MALDI-TOF-MS: 355. Anal. calc. for $C_{20}H_{13}N_5O_2$: C 67.60, H 3.69, N 19.71; found: C 67.71, H 3.85, N 19.30.

4. *Substitution of the Nitro by the Azido Group in* **16**, **17**, *and* **21**: *General Procedure 2*. A mixture of 6-bromo-4-nitro-2,2′-bipyridine (**16**; 100 mg), 4′-nitro-2,2′:6′,2″:6″,2‴-quaterpyridine (**17**; 100 mg), or 4-nitro-2,2′-bipyridine **21**; 100 mg) and NaN_3 (250 mg, in excess) was heated in DMF (10 ml) for 3 h at 100°. After evaporation, H_2O (40 ml) was added, the mixture extracted with CH_2Cl_2 (3 × 30 ml), and the combined org. phase dried ($MgSO_4$) and evaporated. The desired products **27**, **18**, and **22**, respectively, were purified by CC (silica gel, CH_2Cl_2/AcOEt 1:1) and then recrystallized from EtOH: colorless solids.

4′-Azido-2,2′:6′,2″:6″,2‴-quaterpyridine (**18**): 70 mg (70%). M.p. 168°. IR: 2108*s*, 1580*s*, 1563*s*, 1470*m*, 1407*s*, 1386*m*, 1354*m*, 1266*m*, 1252*m*, 1235*m*, 993*m*, 781*s*, 741*m*. ^{1}H-NMR ($CDCl_3$): 8.72 (*d*, *J* = 7.80, H–C(6), H–C(6‴)); 8.66 (*d*, *J* = 7.80, H–C(3)); 8.65 (*dd*, *J* = 7.80, 1.0, H–C(3″)); 8.62 (*d*, *J* = 7.80, H–C(3‴)); 8.51 (*dd*, *J* = 7.80, H–C(5″)); 8.32 (*d*, *J* = 1.95, H–C(3′)); 8.21 (*d*, *J* = 1.95, H–C(5′)); 8.01 (*t*, *J* = 7.80, H–C(4″)); 7.93 (*ddd*, *J* = 8.30, 7.80, 1.45, H–C(4)); 7.88 (*ddd*, *J* = 8.30, 7.80, 1.45, H–C(4‴)); 7.39 (*ddd*, *J* = 8.30, 7.80, 1.45, H–C(5)); 7.35 (*ddd*, *J* = 8.30, 7.80, 1.45, H–C(5‴)). ^{13}C-NMR ($CDCl_3$): 157.95; 150.83; 149.65; 149.14; 138.59; 137.90; 136.96; 124.27; 124.21; 123.88; 121.62; 121.46; 121.40; 121.30; 118.58; 115.97; 111.40; 109.69; 103.72; 101.43. MALDI-TOF-MS: 323 ([$M - N_2$]$^+$). Anal. calc. for $C_{20}H_{13}N_7$: C 68.37, H 3.73, N 27.91; found: C 68.70, H 3.82, N 27.50.

4-Azido-2,2′-bipyridine (**22**): 75 mg (75%). M.p. 70–71°. IR: 2118*s*, 1581*s*, 1555*s*, 1459*m*, 1397*m*, 1305*s*, 1275*m*, 1262*m*, 1228*m*, 990*m*, 881*m*, 792*m*. ^{1}H-NMR ($CDCl_3$): 8.60 (*dd*, *J* = 7.80, 1.0, H–C(6′)); 8.47 (*d*, *J* = 5.38, H–C(6)); 8.32 (*d*, *J* = 7.80, H–C(3′)); 8.05 (*d*, *J* = 1.95, H–C(3)); 7.72 (*ddd*, *J* = 8.30, 7.80, 1.95, H–C(4′)); 7.23 (*ddd*, *J* = 8.30, 7.80, 1.95, H–C(5′)); 6.80 (*dd*, *J* = 5.38, 1.95, H–C(2)). ^{13}C-NMR ($CDCl_3$): 157.78; 155.02; 150.22; 149.51; 148.94; 136.65; 123.90; 121.05; 113.84; 110.96. MALDI-TOF-MS: 169 ([$M - N_2$]$^+$). Anal. calc. for $C_{10}H_7N_5$: C 60.91, H 3.58, N 35.51; found: C 60.70, H 3.82, N 35.35.

4-Azido-6-bromo-2,2′-bipyridine (**27**): 60 mg (60%). M.p. 122–123°. IR: 2116*s*, 1582*s*, 1542*s*, 1415*m*, 1398*m*, 1320*m*, 1235*m*, 1147*m*, 1127*m*, 909*m*, 793*m*, 738*m*. ^{1}H-NMR ($CDCl_3$): 8.68 (*d*, *J* = 7.80, H–C(6′)); 8.41 (*d*, *J* = 8.30, H–C(3′)); 8.09 (*d*, *J* = 1.95, H–C(3)); 7.84 (*ddd*, *J* = 8.30, 7.80, 1.95, H–C(4′)); 7.37 (*ddd*, *J* = 8.30, 7.80, 1.95, H–C(5′)); 6.96 (*d*, *J* = 1.95, H–C(5)). MALDI-TOF-MS: 248 ([$M - N_2$]$^+$).

5. *7-([2,2′-Bipyridin]-6-yl)-2-(pyridin-2-yl)-5-methoxy-6*H*-1,4-diazepine* (**19**) *and 2-([2,2′-Bipyridin]-6-yl)-6-(pyridin-2-yl)-5-methoxy-6*H*-1,4-diazepine* (**20**). According to the *General Procedure 1*, with **18**.

Data of **19**: 25 mg (37%). M.p. 157°. IR: 1600*m*, 1582*s*, 1562*m*, 1517*m*, 1470*m*, 1427*m*, 1409*m*, 1322*s*, 1264*m*, 1219*m*, 1178*m*, 786*m*. ^{1}H-NMR ($CDCl_3$): 8.70 (*md*, *J* = 4.88, H–C(6‴)); 8.65 (*d*, *J* = 7.80, H–C(3‴)); 8.60 (*md*, *J* = 4.88, H–C(6′)); 8.48 (*dd*, *J* = 7.80, H–C(3″)); 8.39 (*dd*, *J* = 7.80, 1.0, H–C(5″)); 8.11 (*s*, H–C(3)); 8.06 (*d*, *J* = 8.30, H–C(3′)); 7.91 (*t*, *J* = 7.80, H–C(4″)); 7.89 (*ddd*, *J* = 8.30, 7.80, 1.95,H–C(4‴)); 7.72 (*ddd*, *J* = 8.30, 7.80, 1.95, H–C(4′)); 7.34 (*ddd*, *J* = 8.30, 7.80, 1.95, H–C(5‴)); 7.17 (*ddd*, *J* = 8.30, 7.80, 1.95, H–C(5′)); 3.78 (*s*, Me, CH_2). ^{13}C-NMR ($CDCl_3$): 156.79; 156.01; 155.22; 153.34; 149.13; 149.04; 148.84; 144.29; 137.45; 136.95; 136.81; 136.46; 128.28; 123.85; 123.53; 121.82; 121.51; 121.25; 120.17; 55.33 (MeO); 35.77 (CH_2). MALDI-TOF-MS: 355. Anal. calc. for $C_{20}H_{15}N_5O$: C 70.37, H 3.85, N 20.51; found: C 70.70, H 3.82, N 20.99.

Data of **20**: 20 mg (29%). Viscous oil. IR: 1601*m*, 1580*s*, 1558*m*, 1512*m*, 1474*m*, 1424*m*, 1412*m*, 1320*s*, 1260*m*, 1214*m*, 1169*m*, 782*m*. ^{1}H-NMR ($CDCl_3$): 8.73 (*md*, *J* = 4.88, H–C(6″)); 8.68 (*md*, *J* = 4.88, H–C(6‴)); 8.59 (*d*, *J* = 7.80, H–C(3‴)); 8.43 (*dd*, *J* = 7.80, 1.0, H–C(3‴)); 8.42 (*s*, H–C(3)); 8.31 (*dd*, *J* = 7.80, 1.0, H–C(3′)); 8.02 (*d*, *J* = 8.30, H–C(5′)); 7.85 (*t*, *J* = 7.80, H–C(4′)); 7.83 (*ddd*, *J* = 8.30, 7.80, 1.95, H–C(4″)); 7.80 (*ddd*, *J* = 8.30, 7.80, 1.95, H–C(4‴)); 7.33 (*ddd*, *J* = 8.30, 7.80, 1.95, H–C(5″)); 7.32 (*ddd*, *J* = 8.30, 7.80, 1.95, H–C(5‴)); 3.81 (*s*, Me, CH_2). ^{13}C-NMR ($CDCl_3$): 156.54; 155.79; 155.05; 154.10; 149.01; 148.98; 144.36; 137.47; 136.78; 136.60; 136.46; 128.16; 124.32; 123.71; 123.58; 121.24; 120.10; 119.16; 55.33 (MeO); 35.57 (CH_2). MALDI-TOF-MS: 355.

6. *4,6-Dihydro-7-(pyridin-2-yl)-5*H*-1,4-diazepin-5-one and 2,2′-Bipyridin-4-amine.* According to the *General Procedure 1*, with **22**.

Data of **23**: 30 mg (34%). M.p. 145–146°. IR: 2944*m*, 1657*s*, 1609*m*, 1585*m*, 1556*m*, 1431*m*, 1349*m*, 776*s*. ^{1}H-NMR ($CDCl_3$): 9.51 (br. *s*, NH); 8.68 (*d*, *J* = 4.90, H–C(6′)); 8.17 (*d*, *J* = 8.30, H–C(3′)); 7.72 (*ddd*, *J* = 8.30, 7.80, 1.95, H–C(4′)); 7.29 (*ddd*, *J* = 8.30, 7.80, 1.95, H–C(5′)); 6.89 (*d*, *J* = 6.82, H–C(2)); 6.02 (*dd*, *J* = 6.82, 5.38, H–C(3)); 3.91 (*s*, CH_2). ^{13}C-NMR ($CDCl_3$): 164.55; 154.03; 153.54; 149.08; 136.38; 126.81; 124.52; 122.63; 115.52; 39.37. MALDI-TOF-MS: 187. Anal. calc. for $C_{10}H_9N_3O$: C 64.16, H 4.85, N 22.45; found: C 64.01, H 3.90, N 21.93.

7. *Reaction of Azides with DMA: General Procedure 3.* A mixture of 4′-azido-2,2′:6′,2″-terpyridine (**1**; 50 mg) or 4-azido-6-bromo-2,2′-bipyridine (**27**; 100 mg) and dimethyl acetylenedicarboxylate (DMA; 500 mg, in excess) was heated in chlorobenzene (10 ml) during 20 h at 150°. The solvent was evaporated and H_2O (40 ml) added. The residue was extracted with CH_2Cl_2 (3 × 30 ml) and the combined org. phase dried ($MgSO_4$) and evaporated. The desired products **26** and **28**, respectively, were purified by CC (silica gel, CH_2Cl_2/AcOEt 9:1) and then recrystallized from EtOH: colorless solids.

*Dimethyl 2-([2,2′:6′,2″-Terpyridin]-4′-yl)-2*H*-azirine-2,3-dicarboxylate* (**26**): 35 mg (50%). M.p. 169–170°. IR: 1740*s*, 1723*s*, 1582*m*, 1561*m*, 1303*m*, 1290*m*, 1241*m*, 1145*m*, 1101*m*, 1072*m*, 792*m*. ^{1}H-NMR ($CDCl_3$): 8.75 (*s*, H–C(3′), H–C(5′)); 8.72 (*d*, *J* = 7.80, H–C(6), H–C(6″)); 8.66 (*d*, *J* = 8.30, H–C(3), H–C(3″)); 7.91 (*ddd*, *J* = 8.30, 7.80, 1.95, H–C(4), H–C(4″)); 7.40 (*ddd*, *J* = 8.30, 7.80, 1.95, H–C(5), H–C(5″)); 4.05, 4.04 (2*s*, 2 MeO). ^{13}C-NMR ($CDCl_3$): 159.88; 159.17; 157.74; 154.29; 149.32; 144.27; 136.94; 124.58; 121.21; 114.36; 54.11; 52.77. MALDI-TOF-MS: 388. Anal. calc. for $C_{21}H_{16}N_4O_4$: C 64.94, H 4.15, N 14.43; found: C 64.48, H 4.25, N 14.99.

*Dimethyl 2-(6-Bromo-[2,2′-bipyridin]-4-yl)-2*H*-azirine-2,3-dicarboxylate* (**28**): 26 mg (40%). M.p. 154–155°. IR: 1742*s*, 1722*s*, 1583*m*, 1561*s*, 1441*m*, 1302*m*, 1241*m*, 1146*m*, 1068*m*. ^{1}H-NMR ($CDCl_3$): 8.68 (*d*, *J* = 7.80, H–C(6′)); 8.61 (*d*, *J* = 1.95, H–C(3)); 8.47 (*d*, *J* = 8.30, H–C(3′)); 7.87 (*ddd*, *J* = 8.30, 7.80, 1.95, H–C(4′)); 7.69 (*d*, *J* = 1.95, H–C(5)); 7.40 (*ddd*, *J* = 8.30, 7.80, 1.95, H–C(5′)); 4.05, 4.03 (2*s*, 2 MeO). ^{13}C-NMR ($CDCl_3$): 159.66; 158.85; 152.83; 152.27; 149.49; 144.85; 142.35; 137.15; 125.14; 121.61; 121.42; 117.79; 113.51; 113.21; 54.25; 52.86. MALDI-TOF-MS: 390. Anal. calc. for $C_{16}H_{12}BrN_3O_4$: C 49.25, H 3.10, N 10.77; found: C 49.01, H 3.25, N 10.53.

REFERENCES

[1] E. F. V. Scriven, K. Turnbull, *Chem. Rev.* **1988**, *88*, 297.
[2] 'The Chemistry of the Azide Groups', Ed. S. Patai, J. Wiley, New York, 1971.
[3] 'The Chemistry of Functional Groups. Supplement D. The Chemistry of Halides, Pseudohalides and Azides', Eds. S. Patai and Z. Rapoport, Wiley, New York, 1982.
[4] A. Hassner, in 'Houben-Weyl, Methoden der Organischen Chemie', Georg Thieme Verlag, Stuttgart, 1990, Vol. E16a, Part 2, p. 1243.
[5] 'Encyclopedia of Inorganic Chemistry', Ed. R. B. King, J. Wiley, Chichester, 1994, Vol. 1, p. 140.
[6] T. Itai, S. Kamiya, *Chem. Pharm. Bull.* **1961**, *9*, 87.
[7] H. Sawanishi, K. Tajima, T. Tsuchiya, *Chem. Pharm. Bull.* **1987**, *35*, 3175.
[8] H. Sashida, A. Fujii, T. Tsuchiya, *Chem. Pharm. Bull.* **1987**, *35*, 3182.
[9] R.-A. Fallahpour, M. Neuburger, M. Zehnder, *Synthesis* **1999**, 1051.
[10] G. T. Morgan, F. H. Burstall, *J. Chem. Soc.* **1932**, 20; F. H. Burstall, *J. Chem. Soc.* **1938**, 1662.
[11] V. Farina, V. Krishnamurthy, W. J. Scott, *Org. React.* **1997**, *50*, 1.
[12] N. Miyaura, A. Suzuki, *Chem. Rev.* **1995**, *95*, 2457.
[13] V. N. Kalinin, *Synthesis* **1992**, 413.
[14] K. Potts, *Bull. Soc. Chim. Belg.* **1990**, *99*, 741.

[15] F. Kröhnke, *Synthesis* **1976**, 1.
[16] D. L. Jameson, L. E. Guise, *Tetrahedron Lett* **1991**, *32*, 1999.
[17] R.-A. Fallahpour, *Eur. J. Inorg. Chem*. **1998**, 1205.
[18] R.-A. Fallahpour, M. Neuburger, M. Zehnder, *New J. Chem*. **1999**, *23*, 53.
[19] F. S. Hanan, U. S. Schubert, D. Volkmer, E. Rivière, J.-M. Lehn, N. Kyritsakas, J. Fischer, *Can. J. Chem*. **1997**, *75*, 169.
[20] T. Q. Nguyen, F. Qu, X. Huang, A. F. Janzen, *Can. J. Chem*. **1992**, *70*, 2089.
[21] J. Backes, in 'Houben-Weyl, Methoden der Organischen Chemie', Georg Thieme Verlag, Stuttgart, 1992, Vol. E16c, p. 317.
[22] G. A. Archer, L. H. Sternbach, *Chem. Rev.* **1968**, *68*, 747.
[23] E. C. Constable, *Tetrahedron* **1992**, *48*, 10013.

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