Available online at www.sciencedirect.com
SCIENCE DIRECT®
Tetrahedron Letters 46 (2005) 8249–8251
Tetrahedron Letters

The redox behaviour of cyclic tetraaminoethenes derived from 2,2′-biimidazole

M. Matschke, C. Käpplinger, D. Weiß and R. Beckert*

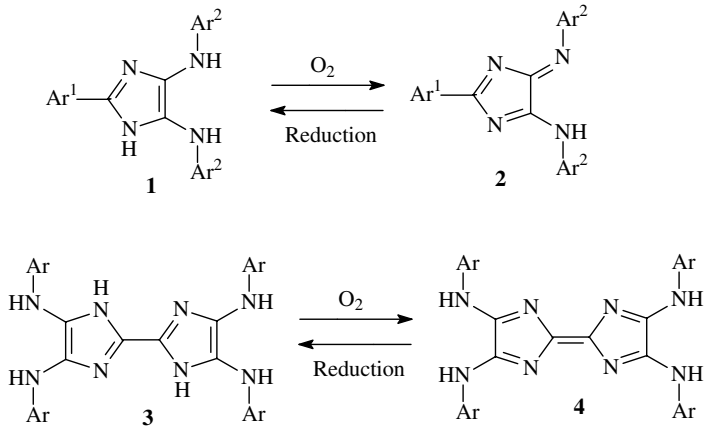
Institute of Organic and Macromolecular Chemistry, Friedrich Schiller University, D-07743 Jena Humboldtstr. 10, Germany

Received 19 July 2005; revised 2 September 2005; accepted 9 September 2005
Available online 11 October 2005

Abstract—Syntheses and redox chemistry of the nearly unknown 4,4′,5,5′-tetraamino derivatives of 2,2′-biimidazole are studied. These cyclic versions of electron-rich ethenes are only stable under strictly anaerobic conditions. In the presence of oxygen, a fast oxidation reaction occurs to form stable, deeply coloured tetraazafulvalenes. Leuco-forms, however, can be stabilized towards air by acylation reactions. This accounts for the hexa-Boc derivative **6**. Based on these findings, we present the first synthesis of tetraazafulvalenes, which possess four peripheric secondary amine functions.

Imidazole and its derivatives are of paramount importance in the chemistry of biologically interesting molecules. Although the substitution of all ring positions in imidazole itself is well documented, the synthesis of 4,5-diamino-imidazoles still remains relatively unexplored.

Preparation of 4,5-diaminoimidazoles via methods[1,2] involving reductions of aminonitroimidazoles was unsuccessful due to the fact that the diamines are readily oxidized. However, in some cases the 4,5-diaminoimidazoles formed in situ could be stabilized by acetylation[1] or by ring closure with biacetyl.[3] We recently developed a protocol for the synthesis of stable *N*,*N*′-substituted 4,5-diaminoimidazoles[4] **1** (Scheme 1), which involves reduction of 4*H*-imidazoles **2** in the presence of metallic lithium and subsequent alkylation of the formed trianion. The resulting 4,5-dianilinoimidazoles are only



Scheme 1.

Keywords: 2,2′-Biimidazole; Tetraazafulvalenes; Electron-rich olefins; Redox chemistry.
* Corresponding author. Tel.: +49 3641 948 230; fax: +49 3641 948 212; e-mail: c6bera@uni-jena.de

0040-4039/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.tetlet.2005.09.076

stable under strictly anaerobic conditions whereas in the presence of air they are immediately reoxidized to the starting material.[5]

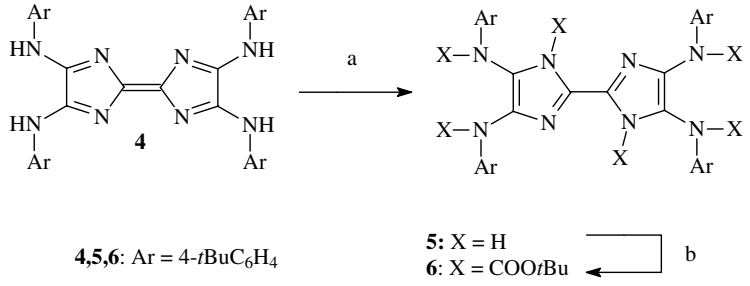
During the past few years, 2,2′-biimidazole 'glycosine' **7a** has become an important building block for constructing macrocycles and supramolecular architectures.[6] By exploiting halogen-exchange reactions at either the 4,4′- and/or 5,5′-positions, a series of derivatives can be obtained. As an example, nucleophilic displacement of bromine from 4,4′,5,5′-tetrabromo-2,2′-biimidazole with substituted anilines yielded new lipophilic tetradentate ligands.[7] However, instead of the desired tetrakis(arylamino)-2,2′-biimidazoles the corresponding oxanilides were isolated. As early as 1943, Lehmstedt and Rolker[8] reported reactions of 4,4′,5,5′-tetrabromo-2,2′-biimidazole with aromatic amines. The structure of these deeply coloured products was, however, misinterpreted as meriquinoid dyes. In our opinion, these compounds are the first examples of 1,4,5,8-tetraazafulvalenes of type **4** and were obtained by simple aminolysis reactions of all bromine residues and subsequent oxidation of the tetramine **3** to yield the stable heterofulvalenes **4** (Scheme 1). We therefore repeated Lehmstedt's protocol; the data (UV/vis, ^{13}C NMR, ^{1}H NMR) of the deeply red compounds were identical to those of tetraazafulvalenes synthesized by the cyclization of formamidine.[9]

Further evidence for the low stability of the tetraamino derivatives **3** is the fast colour change from pale yellow to purple, which is observed when freshly reduced **4** (sodium dithionite in THF/H_2O) is exposed to air. This is a clear indication of a reversible oxidation to yield tetraazafulvalene **4** according to Scheme 1. This redox-cycle can be repeated several times, which was confirmed by cyclovoltammetric measurements. Under strict anerobic conditions, the derivatives **3** can be isolated as yellow compounds, which exhibit a strong greenish fluorescence in solution. Due to the extremely fast reoxidation to give **4** no MS data for compounds of type **3** could be obtained. Our observations are supported by results from Shi and Thummel[10] who studied the redox behaviour of dimers of nucleophilic carbenes. These dimers represent electron-rich tetraazafulvalenes, which are the electronic counterparts of derivatives **4**. In contrast to our systems they react on contact with oxygen irreversibly to give ureaphanes.

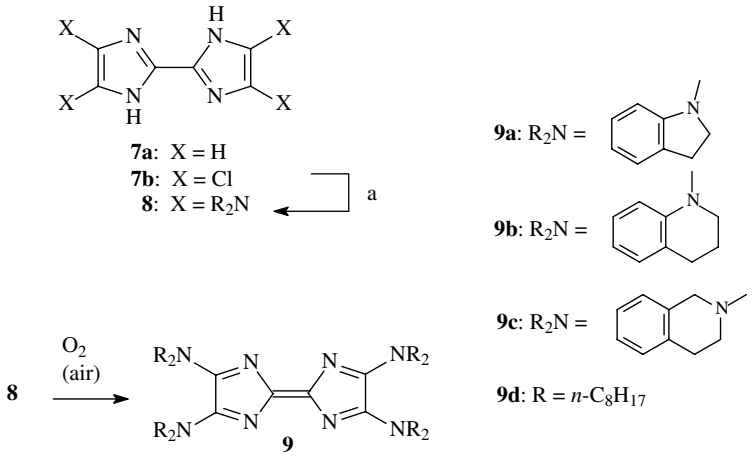
Derivatives of type **4** can easily be (fast reaction) reduced to **5** by employing sodium dithionite/THF/ultrasound irradiation.[11] This reduction of **4** to its leuco-form **5** (Scheme 2) can be monitored by UV/vis-spectroscopy. Subsequent acylation with Boc_2O resulted in a nearly colourless solution showing blue fluorescence. Elemental analysis and ms data clearly support the formation of a stable hexaacylated derivative of tetraamino-biimidazole **6**.[12] Treating **6** with trifluoroacetic acid followed by neutralization with bases (sodium carbonate) immediately gives rise to an intense purple colour due to the formation of the tetraazafulvalene **4**.

All these findings clearly underline that diaminoimidazoles of type **1** as well as the corresponding derivatives of 2,2′-biimidazole **3** are not only donor substituted heteroaromatics but also cyclic versions of electron rich tetraaminoethenes. In contrast to tetraaminoethenes known up to date, this redox process is fully reversible. Upon contact with oxygen the non-aromatic fulvenes/fulvalenes **2** and **4** could be isolated as stable final-products.

The redox-system tetraazafulvalene/tetraamino-biimidazole now offers a basis for the synthesis of new tetraazafulvalenes, which possess four peripheric secondary amine functions. Starting from 4,4′,5,5′-tetrachloro-2,2′-biimidazole **7b** the halogen exchange reaction with secondary amines should lead to tetramino derivatives of type **8**, which on contact with air are immediately oxidized to tetraazafulvalenes of type **9** (Scheme 3).[13] Accordingly, simple heating of **7b** with such amines led to deeply coloured mixtures in which tetraazafulvalenes **9a–d** could be detected by TLC. Although in many cases the products quickly decomposed using indoline as secondary amine produced a stable tetraazafulvalene **9a**, which could be purified by flash chromatography. Recrystallization from acetone gave gold-shining microcrystals, which display a deeply blue colour in solution. Elemental analysis and mass spectrum with a peak at $m/e = 601$ [M^++1] indicated the molecular composition of a tetraminosubstituted product. Furthermore, the ^{1}H and ^{13}C NMR spectra confirmed the symmetric structure of **9a** by a simple set of signals. A clear difference was revealed by their UV/vis spectra, in which the new product shows a significantly longer wavelength absorption than tetraazafulvalenes of type **4** (**4**, Ar = 4-*t*BuC$_6$H$_4$: $\lambda_{max} = 528$ nm, **9a**: $\lambda_{max} = 623$ nm). Analogously, the derivatives **9b–d** have been synthesized



Scheme 2. Reagents and conditions: (a) $Na_2S_2O_4$, THF/H_2O, ultrasound, rt, 15 min (97%); (b) THF, (tBuOCO)$_2$O, DMAP, rt, 18 h (65%).



Scheme 3. Reagents and conditions: (a) excess (10 equiv) of R_2NH, 140 °C, 15 min (2–6%).

from **7b** and the corresponding secondary amine in low yields.

Earlier attempts to synthesize similar derivatives by alkylation of exocyclic nitrogen of tetraaryl derivatives **4** failed. Employing methyl iodide in the presence of bases resulted in *E*/*Z*-mixtures of compounds that are alkylated at exocyclic as well as at ring nitrogen atoms.[9]

Acknowledgement

This work was supported by the Deutsche Forschungsgemeinschaft (SFB 436).

References and notes

1. (a) Kochergin, P. M.; Verenikina, S. G.; Bushueva, K. S. *Khim. Geterotsikl. Soedin.* **1965**, *1*, 765–769; (b) Kochergin, P. M.; Verenikina, S. G. *Khim. Geterotsikl. Soedin.* **1965**, *1*, 770–773.
2. Schubert, H.; Heydenhauss, D. *J. Prakt. Chem.* **1963**, *22*, 304–308.
3. Panzica, R. P.; Townsend, L. B. *J. Chem. Soc., Perkin Trans. 1* **1973**, 244–248.
4. Atzrodt, J.; Beckert, R.; Görls, H. *Heterocycles* **1999**, *51*, 763–783.
5. Gebauer, T.; Beckert, R.; Weiß, D.; Knop, K.; Käpplinger, C.; Görls, H. *Chem. Commun.* **2004**, 1860–1861.
6. (a) Nonell, S.; Borrell, J.; Borros, S.; Coloninas, C.; Rey, O.; Rubio, N.; Sanchez-Garcia, D.; Teixido, J. *Eur. J. Org. Chem.* **2003**, 1635–1640; (b) Allen, W.; Fowler, C.; Lynch, V.; Sessler, J. *Chem. Eur. J.* **2001**, 721–729.
7. Crossley, M. J.; Gorjian, S.; Sternhell, S.; Tansey, K. M. *Aust. J. Chem.* **1994**, *47*, 723–738.
8. Lehmstedt, K.; Rolker, H. *Chem. Ber.* **1943**, *76*, 879–891.
9. Käpplinger, C.; Beckert, R.; Günther, W.; Görls, H. *Liebigs Ann./Recueil* **1997**, 617–622.
10. Shi, Z.; Thummel, R. P. *Tetrahedron Lett.* **1995**, 2741–2744.
11. *Typical procedure for the reduction of tetraazafulvalenes of type* **4**: A mixture of **4a** (0.1 mmol), 50 ml of THF and 10 ml of a solution of $Na_2S_2O_4$ (0.06 M) was irradiated with ultrasound at rt for 15 min. During the reduction the colour of the solution changed from deeply red to yellow. The solvent was removed in vacuo. Leuco-form **5** was obtained as a yellowish solid.
Compound **5**: UV/vis (THF): $\lambda_{max} = 314$ nm, Fluorescence (THF): $\lambda_{max,em} = 468$ nm, ^{1}H NMR (250 MHz, THF-d_8): $\delta = 6.99$ (8H, d, $J = 8.4$ Hz), 6.53 (8H, d, $J = 8.3$ Hz), 1.16 (36H, s).
12. Compound **6**: Brownish powder. UV/vis (THF): λ_{max} (lg ε) = 235 nm (4.58), IR: ν (cm^{-1}, KBr): 1758, 1719 (C=O), ^{1}H NMR (250 MHz, $CDCl_3$): $\delta = 7.41$–7.08 (16H, m, Ar–H), 1.43 (18H, s, $C(CH_3)_3$), 1.41 (18H, s, $C(CH_3)_3$), 1.34 (18H, s, $C(CH_3)_3$), 1.33 (18H, s, $C(CH_3)_3$), 1.32 (18H, s, $C(CH_3)_3$), MS (micro-ESI, acetone/methanol): *m*/*z* (Int): 1323 (M^+, 2), 1199 (6), 1099 (100), 1014 (54), 999 (12), 898 (4), 867 (18), 722 (1), 550 (4), 518 (40), Anal. Found: C, 69.08; H, 8.20; N, 8.55; $C_{76}H_{106}N_8O_{12}$ requires: C, 68.96; H, 8.07; N, 8.47.
13. Compound **9a**: Gold-shining microcrystals, UV/vis (CH_2Cl_2): λ_{max} (lg ε) = 623 (4.6), 594 (4.5), ^{1}H NMR (250 MHz, CD_2Cl_2): $\delta = 7.46$ (4H, d, $J = 7.9$ Hz, Ar–H), 7.16 (4H, d, $J = 7.3$ Hz, Ar–H), 7.04 (4H, m, Ar–H), 6.86 (4H, m, Ar–H), 4.21 (8H, t, $J = 7.9$ Hz, N–CH_2), 3.07 (8H, t, $J = 7.9$ Hz, CH_2), ^{13}C NMR (22,63 MHz, CD_2Cl_2): $\delta = 155.1$, 150.6, 144.1, 132.0, 126.5, 124.1, 121.9, 113.1, 51.8, 28.9, MS (DCI, H_2O) *m*/*z* (Int): 601 (M^++1, 13), 510 (12), 391 (100), 338 (10), 261 (9), 221 (36), 165 (40), 120 (65); Anal. Found: C, 75.88; H, 5.33; N, 18.76; $C_{38}H_{32}N_8$ requires: C, 75.98; H, 5.37; N, 18.65.
Compound **9b**: Blue powder, UV/vis (acetone): $\lambda_{max} = 608$, 557 nm.
Compound **9c**: Green powder, UV/vis (acetone): $\lambda_{max} = 690$, 628, 550 nm.
Compound **9d**: Dark green oil, UV/vis (acetone): $\lambda_{max} = 719$, 680, 650 nm, ^{1}H NMR (250 MHz, $CDCl_3$): $\delta = 3.68$ (16H, t, $J = 6.6$ Hz, N–CH_2), 1.0–1.3 (96H, m), 0.81 (24H, t, $J = 5.9$ Hz, CH_3).