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Introducing Axial Chirality into Mesoionic 4,4′-Bis(1,2,3-triazole) Dicarbenes

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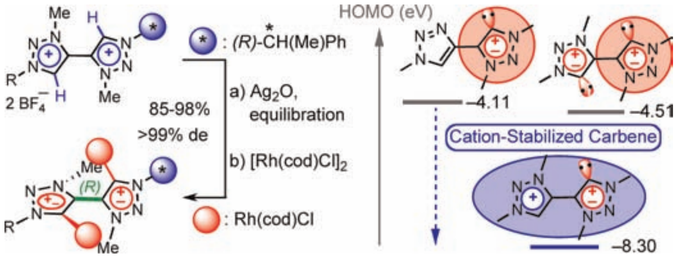
ABSTRACT



Mesoionic 4,4′-bis(1,2,3-triazole-5,5′-diylidene) Rh(I) complexes having a C2 chiral 4,4′-axis were accessed from 3-alkyltriazolium salts in virtually complete de. Their structure and configurational integrity were assessed by NMR spectroscopy, X-ray crystallography, and chiral HPLC. Computational analysis of the MICs involved in the reaction suggested the formation of a highly stable and unprecedented cation-carbene intermediate species, which could be evidenced experimentally by cyclic voltammetry analysis.

Mesoionic carbenes (MICs) constitute a novel, yet scarcely studied, class of divalent carbon species possessing unique electronic features and transition coordination ability.[1] Very recently, 1*H*-1,2,3-triazole-derived MICs[2] **1** (Scheme 1) have attracted special attention because of their high ligand donation ability and ease of preparation following "click" chemistry methodologies.[3] Introduction of chirality elements close to the carbene center in such MIC compounds is a particularly challenging problem, which was first addressed by Sankararaman et al.[4]

Inspired by noncarbene atropoisomeric 5,5′-bistriazoles **2** described by Burgess,[5] we envisioned the dicarbene

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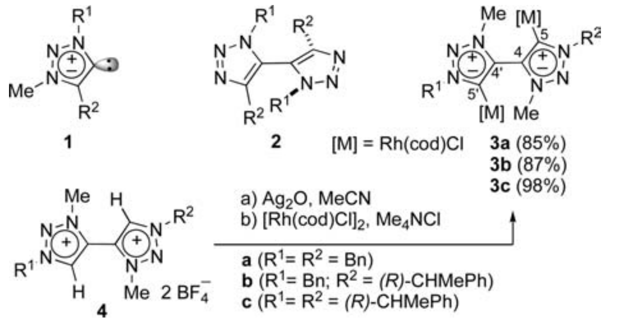
complexes **3** as candidates to display analogous axial chirality, provided that the very strong carbene–metal bonds in these MICs could hold configurational stability.[6] Herein we report the preparation and full structural analysis of the first enantiopure C2-type MIC dicarbenes **3** with a C4–C4′-chiral axis created during the metalation process.

Scheme 1. Mesoionic 1,2,3-Triazole-derived Carbenes **1** and Chiral 4,4′-Bis(1,2,3-triazole) Dicarbene Complexes **3**; Synthesis from 4,4′-Bis(1,2,3-triazolium) Salts **4a–c**[a]



[a] Cod = 1,5-cyclooctadienyl group.

In previous work to prepare 4,4′-bis(1*H*-1,2,3-triazole)s, we developed a fully site-controlled method to synthesize unsymmetrically substituted *N*-alkylated 4,4′-bis(1,2,3-triazolium) salts **4**,[7] which can be considered as the natural precursors of MICs **3**. Upon deprotonation/metalation of **4** with Ag$_2$O in acetonitrile, the intermediate silver dicarbene complexes were obtained quantitatively after 24 h at 80 °C.[8] ^{1}H NMR monitoring at the early stages of the reaction revealed a mixture of the two possible diastereomers around the C4–C4′ biaryl bond for the silver dicarbenes **3b–c** [M = Ag], although they experienced a thermodynamic equilibration to a single complex in each case (see Supporting Information (SI) Figures S3–S4). Subsequent transmetalation with [Rh(cod)Cl]$_2$ to afford the complexes **3** [M = Rh(cod)Cl] occurred with total axial configuration integrity, as judged from the single set of proton signals observed in the ^{1}H NMR spectra and the sharp double doublets for the benzylic diastereotopic protons in **3a** and **3b**. Characteristic ^{13}C NMR doublets of Rh(I) carbenes at $\delta \approx 170$ ppm ($^{1}J_{\mathrm{Rh-C}} \approx 46$ Hz) were also recorded. Compounds **3a–c** were completely stable to the air and moisture at room temperature.

The absolute configuration of the newly created C4–C4′ chiral axis for **3b–c** was unambiguously established as (*R*) for both compounds from the X-ray crystallograms (Figure 1, top). Their optical purities were further confirmed by chiral HPLC analysis (Figure 1, bottom), showing single peaks for enantiopure **3b–c** but two peaks for the racemic mixture **3a**. Optical rotations were also in full agreement with these data.

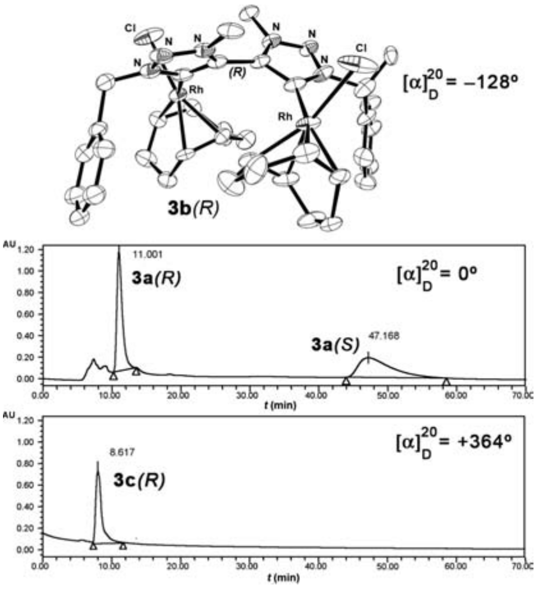


Figure 1. (Top) ORTEP plot of the X-ray crystal structure of the chiral carbene complex **3b**. (Bottom) Chiral stationary phase HPLC chromatograms of rhodium complexes **3a** (racemic) and **3c** (enantiopure).

In order to gain insight into the intermediate carbene species involved in the Ag-metalation reaction that could explain the efficient thermodynamic equilibration observed, *ab initio* calculations were conducted to estimate the protonation affinities (PA$_1$),[9] HOMO energies, and HOMO/LUMO gaps of carbenes **5–7** ($R^1 = R^2 =$ Me, Figure 2; SI Figure S17). In all instances, singlet carbenes were the more stable electronic configurations with large singlet–triplet band gaps[2b] (54–57 kcal·mol^{-1}). We found that neutral carbene **5** and dicarbene **7** gave protonation affinities in the range ~270–280 kcal·mol^{-1}, in line with previous results reported for monotriazole carbenes **1** and classical 1,3-imidazolium carbenes.[2b,c] In contrast, the cationic MIC **6** yielded dramatically low PA$_1$, HOMO energy, and HOMO/LUMO energy gap values, likely resulting from the strong stabilization of the carbene by the conjugated electrodeficient triazolium moiety.

Seeking an experimental confirmation of the anticipated stability of cation carbenes **6**, we studied the deprotonation reaction of bistriazolium dication salt **4a** under cathodic electroreduction conditions to generate the naked

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(8) This double metallation of 1,4-bis(1,2,3-triazolium) salts contrasted with the formation of 1,4-bidentated monometallated Rh(I) complexes upon deprotonation of the bistriazolium salts with NaOEt followed by trapping with [Rh(cod)(OEt)]$_2$, as reported recently by Bertrand et al.; see: Guisado-Barrios, G.; Bouffard, J.; Donnadieu, B.; Bertrand, G. *Organometallics* **2011**, *30*, 6017–6021.

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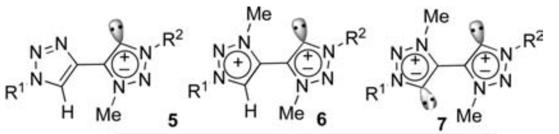

	5	6	7
PA_1	280.0	181.1	269.7
HOMO	−4.11	−8.30	−4.51
$HOMO/LUMO_{gap}$	54.5	42.4	57.3

Figure 2. PA_1 protonation affinities (kcal·mol^{-1}), HOMO energies (eV), and HOMO/LUMO gap (kcal·mol^{-1}) for bis(1,2,3-triazole) carbenes **5**–**7** (R^1 = R^2 = Me) calculated with Gaussian09 optimized energies and BP86/def2-SVP gradients.

carbenes (Figure 3).[10] The monoalkylated triazolium salt **9a** and the parent bistriazole **8a** were analyzed by cyclic voltammetry (CV) for comparison purposes. Unlike **8a**, which shows no electrochemical activity in the potential window studied, a well-defined cathodic peak was measured at −1.6 V for monocation **9a**, denoting the electroreduction to the neutral carbene **5a** (see SI Figure S18). In contrast, the bis(triazolium) salt **4a** showed two different reduction potentials, consistent with the stepwise formation of the stabilized cation carbene **6a** at a lower reduction potential (−1.3 V) and the neutral dicarbene **7a** at −1.6 V.

In conclusion, we have demonstrated that mesoionic dicarbenes derived from 4,4′-bis(1,2,3-triazolium) salts can be endowed with axial chirality at one bond distance from the carbene center by promoting a double metalation reaction at positions C5 and C5′. When the starting bistriazoles bear stereogenic groups at positions N1 and/or N1′ a perfect stereoinduction assisted by thermodynamic equilibration can be achieved at the newly created C4–C4′ chiral axis. The metalation reaction occurs through a cation-carbene intermediate, strongly stabilized by conjugative effects. This species has been identified by cyclic voltammetry in the first example of an electrogenerated mesoionic carbene. It can be expected that these novel chiral carbene ligands could be structurally tuned to meet interesting applications in the field of asymmetric catalysis.[11]

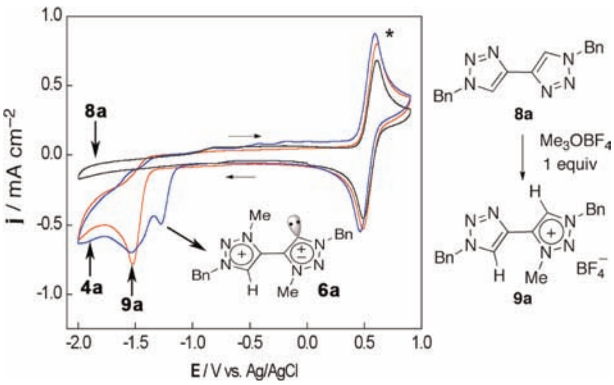

Figure 3. Cyclic voltammograms of 4,4′-bis(1,2,3-triazole) derivatives **4a**, **9a**, and **8a**. Conditions: 25 °C, 2 × 10^{-3} M in DMF/TBAFP(10^{-1} M), referenced to Ag/AgCl, using ferrocene/ferrocenium (Fc/Fc^+) redox couple ($E°$ = 0.508 V vs Ag/AgCl, labeled with an asterisk). TBAFP = tetrabutylammonium hexafluorophosphate.

Acknowledgment. This work was supported by the Ministerio de Ciencia e Innovación (MICINN, Spain) (Project: CTQ2010-21625-C02-01), UPV/EHU, and Gobierno Vasco (ETORTEK-nanoIKER IE-11/304). We thank SGIker UPV/EHU for NMR and X-ray crystallography facilities. Grants from Gobierno Vasco to M.S.A. and UPV/EHU to Z.M. are acknowledged.

Supporting Information Available. Preparation procedures and full characterization data for compounds **3a**–**c**, **4a**–**c**, and **9a**. NMR spectra of **3a**–**c**. Cyclic voltammogram analysis data. Gaussian output data of structures **5**–**7**. CIF files of **3a**–**c**. This material is available free of charge via the Internet at http://pubs.acs.org.

The authors declare no competing financial interest.

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