

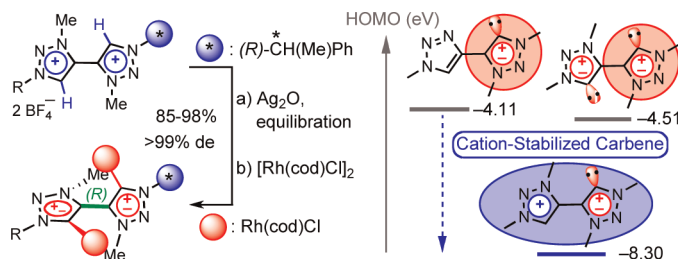
Introducing Axial Chirality into Mesoionic  
4,4'-Bis(1,2,3-triazole) DicarbenesJesus M. Aizpurua,<sup>\*,†</sup> Maialen Sagartzazu-Aizpurua,<sup>†</sup> Zaira Monasterio,<sup>†</sup> Itxaso Azcune,<sup>†</sup> Claudio Mendicute,<sup>†</sup> Jose I. Miranda,<sup>†</sup> Eva García-Lecina,<sup>‡</sup> Ainhoa Altube,<sup>‡</sup> and Raluca M. Fratila<sup>§</sup>

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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.<sup>1</sup> Very recently, 1*H*-1,2,3-triazole-derived MICs<sup>2</sup> **1** (Scheme 1) have attracted special attention because of their

high ligand donation ability and ease of preparation following “click” chemistry methodologies.<sup>3</sup> 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.<sup>4</sup>

Inspired by noncarbene atropoisomeric 5,5'-bistriazoles **2** described by Burgess,<sup>5</sup> we envisioned the dicarbene

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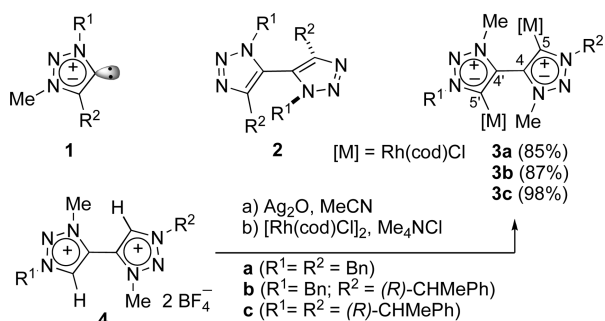
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complexes **3** as candidates to display analogous axial chirality, provided that the very strong carbene–metal bonds in these MICs could hold configurational stability.<sup>6</sup> Herein we report the preparation and full structural analysis of the first enantiopure C2-type MIC dicarbene **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**<sup>a</sup>



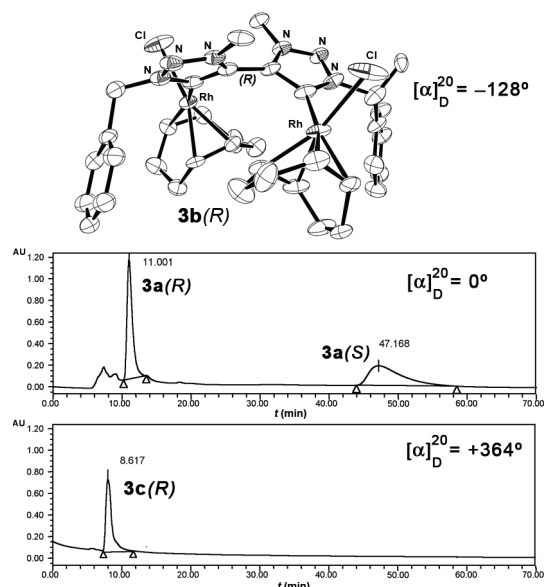
<sup>a</sup> Cod = 1,5-cyclooctadienyl group.

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**,<sup>7</sup> which can be considered as the natural precursors of MICs **3**. Upon deprotonation/metalation of **4** with Ag<sub>2</sub>O in acetonitrile, the intermediate silver dicarbene complexes were obtained quantitatively after 24 h at 80 °C.<sup>8</sup> <sup>1</sup>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 dicarbene complexes **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]<sub>2</sub> 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 <sup>1</sup>H NMR spectra and the sharp double doublets for the benzylic diastereotopic protons in **3a** and **3b**. Characteristic <sup>13</sup>C NMR doublets of Rh(I) carbenes at δ ≈ 170 ppm (<sup>1</sup>J<sub>Rh–C</sub> ≈ 46 Hz) were also recorded. Compounds **3a–c** were completely stable to the air and moisture at room temperature.

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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)]<sub>2</sub>, as reported recently by Bertrand et al.; see: Guisado-Barrios, G.; Bouffard, J.; Donnadiu, B.; Bertrand, G. *Organometallics* **2011**, *30*, 6017–6021.

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<sub>1</sub>),<sup>9</sup> HOMO energies, and HOMO/LUMO gaps of carbenes **5–7** (R<sup>1</sup> = R<sup>2</sup> = Me, Figure 2; SI Figure S17). In all instances, singlet carbenes were the more stable electronic configurations with large singlet–triplet band gaps<sup>2b</sup> (54–57 kcal·mol<sup>-1</sup>). We found that neutral carbene **5** and dicarbene **7** gave protonation affinities in the range ~270–280 kcal·mol<sup>-1</sup>, in line with previous results reported for monotriazole carbenes **1** and classical 1,3-imidazolium carbenes.<sup>2b,c</sup> In contrast, the cationic MIC **6** yielded dramatically low PA<sub>1</sub>, 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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	5	6	7
PA <sub>1</sub>	280.0	181.1	269.7
HOMO	-4.11	-8.30	-4.51
HOMO/LUMO <sub>gap</sub>	54.5	42.4	57.3

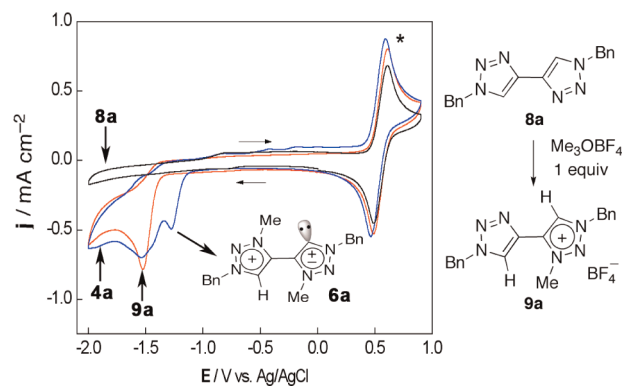
**Figure 2.** PA<sub>1</sub> protonation affinities (kcal·mol<sup>-1</sup>), HOMO energies (eV), and HOMO/LUMO gap (kcal·mol<sup>-1</sup>) for bis(1,2,3-triazole) carbenes **5–7** (R<sup>1</sup> = R<sup>2</sup> = Me) calculated with Gaussian09 optimized energies and BP86/def2-SVP gradients.

carbenes (Figure 3).<sup>10</sup> 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 electro-reduction 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

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

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.<sup>11</sup>

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**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.