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Carbocyclic Carbene Ligands Derived from Aromatic Nitrones: Formation and Catalytic Activity of Their Pd(II) Complexes

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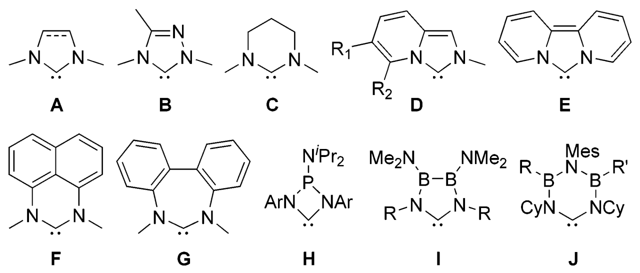
First introduced in 1995 by Herrmann[1] into the field of Pd-catalyzed cross-coupling reactions, N-heterocyclic carbenes (NHCs)[2] have become a paradigmatically new generation of strong σ donor ligands. NHCs are widely used in transition metal catalysis,[2,3] as exemplified by the development of highly active catalysts for olefin metathesis[4] and for room-temperature Suzuki coupling involving aryl chlorides.[5] Electronic and skeletal variation on the original Arduengo carbene **A**[2a,b] has led to the discovery of a number of diaminocarbene ligands such as **B**−**G**[6,7] (Chart 1). More recent additions to the list include cyclic diaminocarbenes **H**−**J** which are built on inorganic frameworks.[8]

Chart 1. Structural Motifs of NHCs



Compared to the aforementioned cyclic diaminocarbenes and other heterocyclic carbenes,[6] nucleophilic carbocyclic carbenes are much less well-known.[9,10] Analogous to the synthesis of NHCs, which can be obtained by deprotonation of azolium salts, carbocyclic carbenes could in principle be approached from their conjugate acids. Recently, the first isolated three-membered carbocyclic carbene of the type **K**, the bis(dialkylamino)cyclopropenylidene **1**, was synthesized by deprotonation of a cyclopropenium salt (Figure 1).[11] Stable transition metal complexes such as **2**[12] and **3**,[13] containing ligand **L** based on the aromatic tropylium system, have previously been synthesized and characterized. We were intrigued by the possibility of a six-membered congener of **L**, the anionic carbene **M**, as a new donor ligand. As depicted in Figure 1, carbene **M** represents an otherwise rarely considered resonance of the phenyl anion. As such, a benzene derivative could in principle serve as its precursor. We report here on our efforts toward the realization of this concept.

In contemplating a carbocyclic carbene based on the benzene skeleton, we took notice the formulistic distinction between a "phenylide" ligand and an *anionic carbene* ligand; the latter requires that the coordinating carbon atom serve as a neutral donor. We further reasoned that a stable cationic group such as an iminium group appended to the benzene ring would provide the required charge balance. Along this line of reasoning, we designed a bidentate ligand **N** featuring an anionic carbene attached to a nitrone group. The choice of this group is based on the anticipation that the iminium nitrogen would stabilize the charge on the phenyl ring and the anionic oxygen serve as a directing group for selective C−H activation via orthometalation.

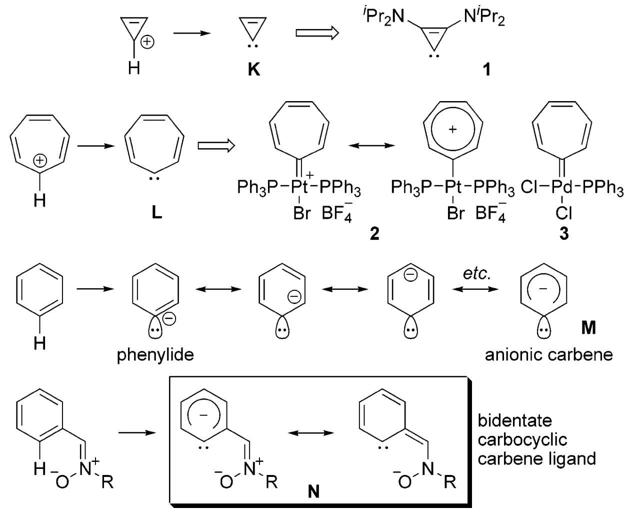
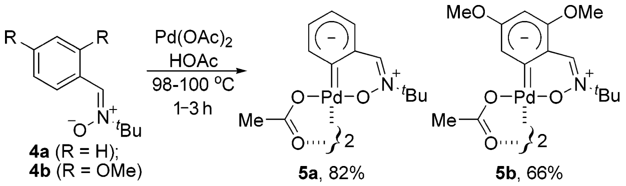


Figure 1. Carbocyclic carbenes and carbene-containing metal complexes.

Scheme 1



When nitrone **4a** was allowed to react with Pd(OAc)$_2$ in acetic acid, Pd complex **5a** was isolated in 82% yield as an air-stable pale yellow solid (mp 213 °C) (Scheme 1). Both ^{1}H NMR and ^{13}C NMR data revealed **5a** to exist as a mixture of two diastereoisomers in a ratio of ca. 10:1. The major isomer was assigned as the C-2 symmetric dinuclear *transoid* form, **5a-I** (Figure 2). The bridging acetate groups in **5a-I** are diastereotopically equivalent (singlet at σ 2.12 ppm for ^{1}H and σ 180.7 ppm for ^{13}C). The minor isomer, the symmetric *cisoid* form, **5a-II**, has two diastereotopically different acetate groups (singlet at σ 2.01 and 2.15 ppm for ^{1}H, and σ 179.8 and 182.6 ppm for ^{13}C). In a similar manner, the

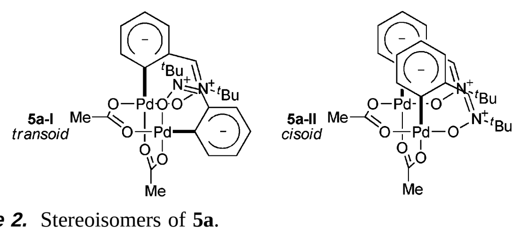


Figure 2. Stereoisomers of **5a**.

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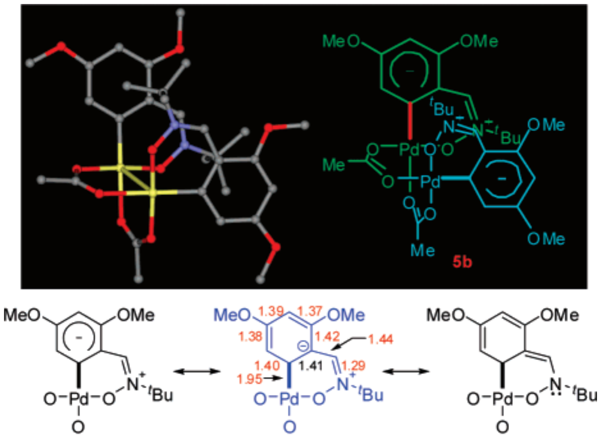
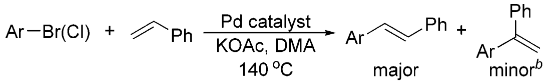
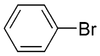
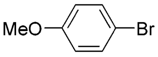
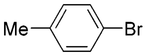
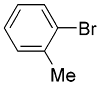
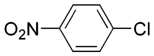


5b-A **5b-B** **5b-C**

Figure 3. X-ray crystal structure and selected bond lengths (Å) of **5b**.

Table 1. The Heck Reaction of Aryl Halides Catalyzed by Pd(II) Complexes **5a** and **5b**



Ar–Br(Cl)	catalyst (mol %)	time (h)	% yield[a] (TON)	
			with **5a**	with **5b**
	8×10^{-4}	24	87 (108,750)	95 (118,750)
	2×10^{-4}	48	81 (405,000)	93 (465,000)
	8×10^{-5}	48	74 (925,000)	**89 (1,112,500)**
	8×10^{-5}	165	**88 (1,100,000)**	**94 (1,175,000)**
	8×10^{-4}	20	86 (107,500)	90 (112,500)
	4×10^{-4}	48	60 (150,000)	83 (207,000)
	8×10^{-5}	48	43 (537,000)	45 (562,500)
	8×10^{-5}	169	**64 (800,000)**	**75 (937,500)**
	8×10^{-5}	48 (at 160 °C)		**66 (825,000)**
	8×10^{-4}	24	-	93 (116,250)
	8×10^{-5}	48	-	64 (800,000)
	8×10^{-5}	168	-	**85 (1,062,500)**
	8×10^{-4}	24	-	53 (66,250)
	8×10^{-4}	48	-	79 (98,750)
	8×10^{-4}	168	-	**90 (112,500)**
	0.1	21	35 (350)	54 (540)

[a] Isolated yield based on the average of two parallel runs. [b] Up to 10% of the minor isomers was detected by ^1H NMR spectroscopy.

dimethoxy analogue **5b** was synthesized and isolated as a 5:1 isomeric mixture with the *transoid* isomer being the major component.

Crystallization of **5b** from C_6D_6 yielded yellow crystals suitable for X-ray structure determination. As shown in Figure 3, **5b** crystallizes as a single diastereomer, the *transoid* acetato-bridged form. Several structural features revealed by the bond parameters are noteworthy. The nitrogen atoms adopt a nearly planar geometry. The bond lengths at the benzylic carbon (C–C, 1.44 Å; C=N, 1.29 Å) are highly indicative of the zwitterionic iminium resonance form **5b-A**, the charge delocalized sum of individual resonance structures such as **5b-B**. Contribution from the enamine form **5b-C**, an *o*-metallaquinodimethane structure, if any, must be minimal. Additionally, the elongated C–C bonds (1.41 and 1.42 Å) at the carbon *ipso* to the benzylic position and the noticeable bond alternation on the rest of the benzene ring point to the significance of structure **5b-B** as a major contributor.

A preliminary test of their catalytic activity revealed that these Pd complexes are extremely efficient precatalysts for the Heck reaction (Table 1). The coupling of unactivated and deactivated aryl bromides with styrene could be achieved with TON greater than 1 000 0000. The catalysts were active at extremely low loading and remained active over a long period of reaction time, attesting to their excellent stability under the conditions employed. The unprecedented efficiency of **5a** and **5b** may be attributed to the anionic nature of the carbene ligand. The electron-donating methoxy groups in **5b** make it significantly more reactive than **5a**, pointing to the possibility of electronic and steric tuning on the carbene ligand to further increase the activity of the resulting metal catalysts.

In conclusion, we have shown that highly active and catalytically useful Pd complexes can be conveniently assembled from readily available ligand precursors. The concept of using an *anionic carbocyclic carbene* as ancillary ligand for palladium as demonstrated here opens a new opportunity for the development of structurally novel carbene ligands for transition metal catalysis.

Supporting Information Available: Experimental details and spectroscopic and X-ray data of compounds **5a** and **5b**. This material is available free of charge via the Internet at http://pubs.acs.org.

References

(1) Herrmann, W. A.; Elison, M.; Fischer, J.; Köcher, C.; Artus, G. R. J. *Angew. Chem., Int. Ed. Engl.* **1995**, *34*, 2371.
(2) (a) Arduengo, A. J., III. *Acc. Chem. Res.* **1999**, *32*, 913. (b) Bourissou, D.; Guerret, O.; Gabbaï, F. P.; Bertrand, G. *Chem. Rev.* **2000**, *100*, 39.
(3) (a) Herrmann, W. A. *Angew. Chem., Int. Ed.* **2002**, *41*, 1290. (b) Peris, E.; Crabtree, R. H. *Coord. Chem. Rev.* **2004**, *248*, 2239. (c) Scott, N. M.; Nolan, S. P. *Eur. J. Inorg. Chem.* **2005**, 1815.
(4) Trnka, T. M.; Grubbs, R. H. *Acc. Chem. Res.* **2001**, *34*, 18.
(5) Marion, N.; Navarro, O.; Mei, J.; Stevens, E. D.; Scott, N. M., III; Nolan, S. P. *J. Am. Chem. Soc.* **2006**, *128*, 4102.
(6) Hahn, F. E. *Angew. Chem., Int. Ed.* **2006**, *45*, 1348.
(7) (a) Enders, D.; Breuer, K.; Raabe, G.; Runsink, J.; Teles, J. H.; Melder, J.-P.; Ebel, K.; Brode, S. *Angew. Chem., Int. Ed. Engl.* **1995**, *34*, 1021. (b) Alder, R. W.; Blake, M. E.; Bortolotti, C.; Bufali, S.; Butts, C. P.; Linehan, E.; Oliva, J. M.; Orpen, A. G.; Quayle, M. J. *Chem. Commun.* **1999**, 241. (c) Alcarazo, M.; Roseblade, S. J.; Cowley, A. R.; Fernandez, R.; Brown, J. M.; Lassaletta, J. M. *J. Am. Chem. Soc.* **2005**, *127*, 3290. (d) Weiss, R.; Reichel, S.; Handke, M.; Hampel, F. *Angew. Chem., Int. Ed.* **1998**, *37*, 344. (e) Bazinet, P.; Yap, G. P. A.; Richeson, D. S. *J. Am. Chem. Soc.* **2003**, *125*, 13314. (f) Grady, M. J. W.; Guzei, I. A.; Gandhi, B. A.; Bunel, E. E.; Stahl, S. S. *Angew. Chem., Int. Ed.* **2005**, *44*, 5269.
(8) (a) Despagnet-Ayoub, E.; Grubbs, R. H. *J. Am. Chem. Soc.* **2004**, *126*, 10198. (b) Krahulic, K. E.; Enright, G. D.; Parvez, M.; Roesler, R. *J. Am. Chem. Soc.* **2005**, *127*, 4142. (c) Prasang, C.; Donnadieu, B.; Bertrand, G. *J. Am. Chem. Soc.* **2005**, *127*, 10182.
(9) Kassaee, M. S.; Nimlos, M. R.; Downie, K. E.; Waali, E. E. *Tetrahedron* **1985**, *41*, 1579.
(10) Although cyclic alkylidenes including indenylidenes and fluorenylidenes are more commonly found in Schrock-type carbene complexes, they are not generally used as ancillary ligands in transition metal catalysis due to poor stability. For examples, see: (a) Dörwald, F. G. *Metal Carbenes in Organic Synthesis*; Wiley-VCH: Weinheim, Germany, 1999. (b) Bryan, J. C.; Mayer, J. M. *J. Am. Chem. Soc.* **1990**, *112*, 2298. (c) Schrock, R. R.; Seidel, S. W.; Mösch-Zanetti, N. C.; Dobbs, D. A.; Shih, K.-Y.; Davis, W. M. *Organometallics* **1997**, *16*, 5195. (d) Jafarpour, L.; Schanz, J.-J.; Stevens, E. D.; Nolan, S. P. *Organometallics* **1999**, *18*, 5416. (e) Fürstner, A.; Davies, P. W.; Lehmann, C. W. *Organometallics* **2005**, *24*, 4065. (f) Pfeiffer, J.; Dötz, K. H. *Angew. Chem., Int. Ed. Engl.* **1997**, *36*, 2828.
(11) Lavallo, V.; Canac, Y.; Donnadie, B.; Schoeller, W. W.; Bertrand, G. *Science* **2006**, *312*, 722.
(12) (a) Lu, Z.; Abboud, K. A.; Jones, W. M. *J. Am. Chem. Soc.* **1992**, *114*, 10991. (b) Lu, Z.; Jones, W. M.; Winchester, W. R. *Organometallics* **1993**, *12*, 1344.
(13) Herrmann, W. A.; Ofele, K.; Schneider, S. K.; Herdtweck, E.; Hoffmann, S. D. *Angew. Chem., Int. Ed.* **2006**, *45*, 3859–3862.

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