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COMMUNICATION

Chelation Assistance as a Tool for the Selective Preparation of an Imidazole-Based Mesoionic Palladium Carbene Complex

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A C(4)-bound palladium-N-heterocyclic carbene (4) was selectively obtained from the C(2)-unsubstituted imidazolium salt 3. The higher stability of the C(4) versus the C(2)-bound carbene complex due to pyridine chelation assistance allowed this mesoionic compound to be obtained.

Mesoionic carbenes (MICs) are a type of N-heterocyclic carbene (NHC) that require mesoionic resonance forms to represent their structure.[1] Most of these compounds are based on imidazol-4-ylidene (**A**) and 1,2,3-triazol-4-ylidene (**B**) (Figure 1) but other heterocycles have been shown to form MICs.[2] Generally, these kinds of compounds are bound to the transition metal through the carbene carbon.
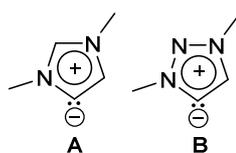
Figure 1. Mesoionic carbenes of imidazole and 1,2,3-triazole.

The pioneering work by Crabtree and co-workers in 2001[3] concerned the first MIC, which was a C(5)-bound imidazolylidene-iridium complex, and they named this new class of carbenes abnormal N-heterocyclic carbenes. In 2009 the Bertrand group isolated the first metal-free MIC[4] and in 2010 they proposed the term mesoionic carbene[1] for these compounds. Due to the strong σ electron-donating character of these compounds, which is higher than that of classical NHCs, this area of research has attracted a great deal of attention and numerous papers covering the synthesis, stability, electronic properties and applications of MICs have been published.[2] Imidazol-2-ylidenes are more stable than imidazol-4-ylidenes and classical

C(2)-bound NHCs are obtained in most cases. The selectivity in favor of the abnormal coordination seems to be related to steric control, the tether length (and thus the bite angle) and the nature of the anion of the imidazolium salt or the ligand on the metal. However, in most cases these compounds are obtained as mixtures with the normal NHC complexes. Oxidative addition of 4-iodoimidazolium[5] to Pd(0) exclusively afforded mesoionic carbene complexes. However, C(2) protection by bonding of an alkyl or aryl group is the most widely used method to prepare this kind of complex.[2] In this paper we describe how imidazole-based palladium-mesoionic carbene complexes can be selectively obtained by the assistance of pyridine chelation, without the need for C(2)-protection, by either direct metallation or by transmetallation from a C(2)-bound silver(I) carbene complex. To the best of our knowledge, this is the first study in which an imidazole-based abnormal carbene has been obtained by chelation assistance. A brief investigation of the catalytic activity of the resulting palladium complex is also presented.

We speculated that chelation assistance[2d,6] could govern the selectivity in obtaining C(4)- versus C(2)-bound NHC complexes. This hypothesis was tested by designing the pyridyl-imidazolium salt **3**. In this molecule both the C(2) and C(5) positions of imidazolium are able to form a carbene but only deprotonation of the C(5)-H can generate a complex stabilized by the chelate effect. The synthesis of **3** is shown in Scheme 1.
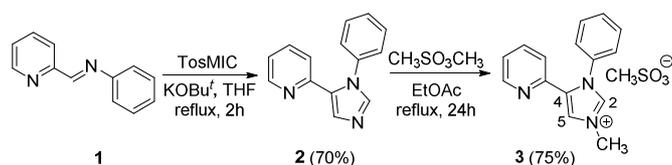
Scheme 1. Synthesis of 1-methyl-3-phenyl-4-(2-pyridyl)-1*H*-imidazolium methanesulfonate (**3**).

A base-induced 1,3-cycloaddition of tosylmethylisocyanide (TosMIC)[7] on the imine **1** afforded **2**. This compound was converted into pyridyl-imidazolium salt **3** by reaction with methyl methanesulfonate under reflux in EtOAc. The ^{1}H NMR spectrum of **3** shows the characteristic signals for the imidazolium ring [C(2)-H and C(5)-H at 9.61 and 8.39 ppm, respectively]. The MIC complex **4** [PdCl$_2$(κ^2-mppIm)] was prepared in good yield by reaction of **3** with [PdCl$_2$(CH$_3$CN)$_2$] under reflux in THF using Cs$_2$CO$_3$ as base (Scheme 2).
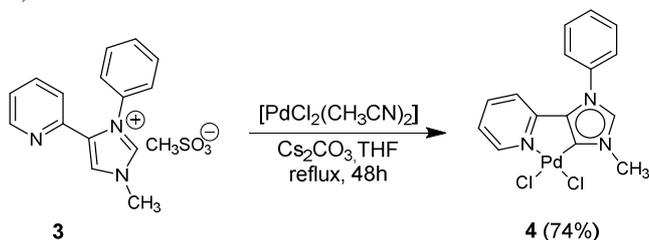
Scheme 2. Synthesis of [PdCl$_2$(κ^2-mppIm)] (**4**).

This compound was isolated as an air- and moisture-stable yellow solid that was soluble in DMSO and DMA but only sparingly soluble in acetonitrile and nitromethane. Compound **4** was not soluble in less polar solvents such as THF or CH$_2$Cl$_2$ and this behavior is consistent with that of similar compounds.[8] Having established that 1-alkyl-3-arylimidazolium exclusively yielded C(2)-bound NHC-Pd complexes,[9] the formation of the MIC complex **4** confirmed our initial hypothesis that abnormal Pd-carbenes can be obtained by chelation assistance.

The structure of compound **4** was unequivocally confirmed by X-ray diffraction and NMR experiments. Single crystals were grown by cooling a hot saturated acetonitrile solution. The molecular structure of compound **4** is shown in Figure 2.
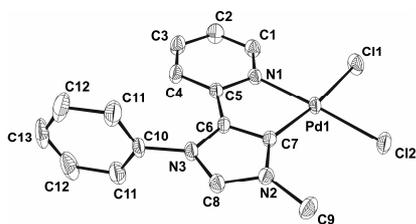
Figure 2. ORTEP view of **4** with 30% probability ellipsoids. Hydrogen atoms are omitted for clarity.

The palladium center is coordinated by a C^4,N-bidentate pyridyl-imidazol-4-ylidene ligand and two chlorides, which define a distorted squared-planar geometry with a C7-Pd1-N1 bite angle of 80.1(2)°. The Pd1-C7 bond length [1.972(3) Å] is similar to those found in related five- and six-membered MIC and classical NHC palladacyclic complexes.[8,10] This fact suggests that the bond length is not affected by the nature of the carbene, halide or chelate bite angle (see ESI for further discussion).

Palladium-MIC complex formation was evidenced in solution by the upfield shift of the C(2)-H imidazole proton signal (9.23 ppm) from the salt **3** in the ^{1}H NMR spectrum and the absence of the signal due to C(4)-H. This assignment was confirmed by NOESY experiments, which unambiguously showed the proximity of the *ortho*-phenyl protons to C(2)-H of the imidazole ring. Coordination by the pyridine nitrogen is supported by the displacements observed for the signals due to C(6)-H and C(3)-H in this ring. C(6)-H was observed as a very broad singlet that was shifted downfield to 9.32

ppm, in a similar way to those in related compounds,[5] and C(3)-H was shifted upfield by nearly 0.70 ppm from the expected value[8] and appears as a doublet centered at 6.35 ppm. These results suggest an arrangement with a five-membered metallacycle involving the palladium, carbene and pyridine. The metallacycle is perpendicular to the phenyl ring and C(3)-H of the pyridine ring is within the shielding region of the phenyl ring, a situation that is consistent with a CH/π interaction between C(3)-H of the pyridine and the phenyl ring – as observed in the solid state. The ^{13}C NMR signal for C(4)-Pd was not observed, as described by Albrecht for similar MICs.[8] MIC-Pd **4** was the only compound obtained despite the low steric bulk of the wingtip group bound to N(3) and the high acidity of C(2)-H. The formation of this complex probably occurs in a stepwise manner.[2d] Initial coordination of the basic pyridine provides the necessary electron density at the central metal to allow subsequent oxidative addition of the imidazolium C(5)-H bond.

In order to confirm the assistance of pyridine in the formation of **4**, we considered the reaction of the salt **3** with Ag$_2$O, a metal that usually shows a linear geometry[11] and cannot form a chelate. This reaction was performed under reflux in acetonitrile and the polymer {[μ-N,N'-Ag(MsO)$_2$][μ-C,C'-Ag(mppIm)$_2$]}$_n$ (**5**) was obtained in 80% yield (Scheme 3).
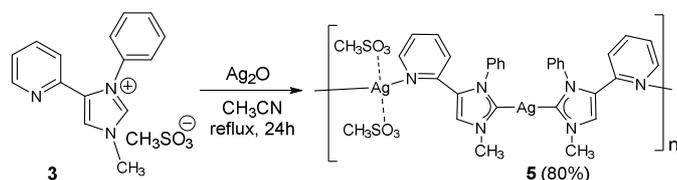
Scheme 3. Synthesis of the polymer {[μ-N,N'-Ag(MsO)$_2$][μ-C,C'-Ag(mppIm)$_2$]}$_n$ (**5**)

Single crystals of **5** were grown by slow evaporation of the solvent from a THF solution. The ORTEP diagram is shown in Figure 3. The structure revealed that compound **5** is a C(2)-bound Pd-NHC polymer.
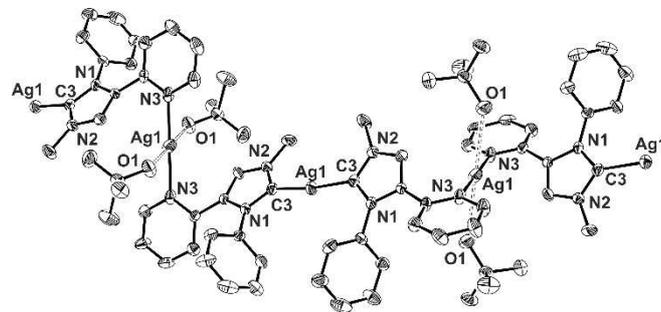
Figure 3. ORTEP view of compound **5** with 30% probability ellipsoids. Hydrogen atoms are omitted for clarity.

Compound **5** is a linear polymer that extends in the [–1 0 1] direction. In the repeat unit (RU) of the polymer two moieties can be distinguished. One is a slightly distorted linear complex with a silver cation (Ag1) coordinated by two imidazole-2-ylidenes in a 'head-to-head' orientation ([μ-C,C'-Ag(mppIm)$_2$]) with a *syn* arrangement. The C3-Ag1-C3 angle of 172.0(4)° and the C3-Ag1 bond length of 2.084(7) Å are similar to those in a related silver NHC polymer.[12] The other moiety consists of a second silver cation (Ag2) associated with two methanesulfonate groups ([μ-N,N'-Ag(MsO)$_2$]) and this is coordinated by two monomers through the pyridine nitrogen (N3). Ag2 has a linear geometry (excluding the Ag···O interactions), the N3-Ag2-N3 angle is 180.0° and the N3-Ag2 bond length is 2.183(5)

Å. The polymer has a zwitterionic character and the Ag(NHC)$_2^+$ moiety balances its charge with the Ag(MsO)$_2^-$ anion.

The absence of a resonance at *ca*. 9 ppm and the presence of a single peak at 8.05 ppm due to C(5)-H in the ^{1}H NMR spectrum are consistent with a C(2)-bound NHC. The structure was confirmed by the ^{13}C NMR spectrum. The presence of a single signal at 183.4 ppm due to Ag-C is consistent with data for other related systems.[10a,b] [13]C-[107]Ag and [13]C-[109]Ag coupling was not observed due to the fluxional behavior of the complex.[11] The mass spectrum (MALDI-TOF) contained fragmentation peaks of the RU. The most important signals are two peaks (m/z = 577.1 and 579.1) that are consistent with the isotopic distribution of [μ-C,C′-Ag[107](mppIm)$_2^+$] and [μ-C,C′-Ag[109](mppIm)$_2^+$].

Transmetallation from silver-N-heterocyclic carbenes has played an important role in the development of other C(2)- and C(4)-bound imidazole-based metal-carbene systems.[2a-f,11] However, to achieve metallation with Ag$_2$O in the C(4)-position it is necessary to protect the C(2)-positions with aryl substituents. Under these conditions this position is unable to take part in further transformations. It would be desirable to obtain transition metal MIC complexes by transmetallation without C(2)-protection. We speculated that compound **5** could form MICs complexes from the C(2)-bound system. In order to test our hypothesis we attempted the reaction of **5**, generated *in situ*, with PdCl$_2$ and chloride or bromide salts under different conditions in terms of solvent and temperature. When the reaction was performed under reflux in acetonitrile in the presence of tetrabutylammonium chloride, MIC **4** was isolated in 40% overall yield from **3** (Scheme 4). At room temperature complex mixtures of compounds were obtained in all cases. In these mixtures evidence for the Pd-MIC complex was not observed by NMR but the formation of C(2) bound Pd-NHCs was confirmed. This fact indicates that the C(2) bound NHC is the kinetically controlled product and Pd-MIC **4** is the thermodynamic product.
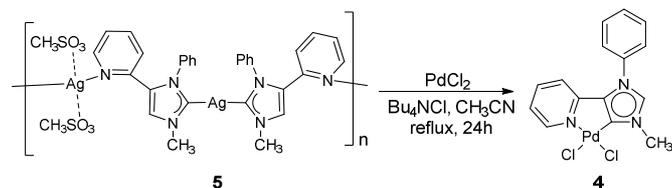
Scheme 4. Transmetallation from **5**

These kinds of compounds are mainly applied as catalysts for organic reactions. A catalytic study of MIC-Pd **4** in order to compare it with similar compounds is undergoing in our laboratories and will be reported in due course.

Conclusions

In summary, it has been demonstrated that imidazole-based MICs can be selectively obtained by pyridyl chelation assistance. 5-(2-Pyridyl)imidazolium salt **3** afforded an imidazol-4-ylidene system (**4**) with a metal that can form chelate complexes, namely Pd, but imidazol-2-ylidene **5** is obtained with a metal that forms linear complexes, i.e., Ag. The latter compound can be converted into imidazol-4-ylidene-palladium(II) by transmetallation with PdCl$_2$ under reflux in acetonitrile, but at room temperature imidazol-2-ylidene-palladium(II) systems are obtained. Imidazol-4-ylidene-palladium(II) is probably the thermodynamically controlled product and imidazol-2-ylidene-palladium(II) is the kinetic product.

Notes and references

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† Electronic Supplementary Information (ESI) available: Preparative and crystallographic data. See DOI: 10.1039/c000000x/

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