Organic LETTERS
Letter
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An Efficient Synthesis of Bis-1,3-(3′-aryl-*N*-heterocycl-1′-yl)arenes as CCC-NHC Pincer Ligand Precursors

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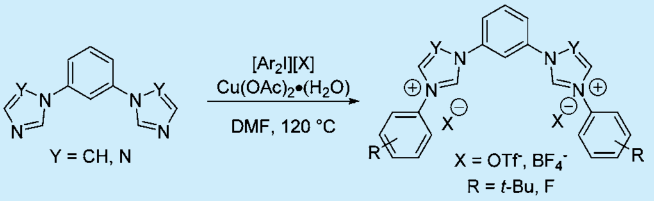
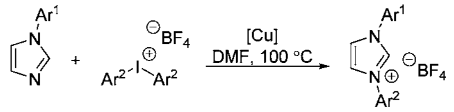
Supporting Information

ABSTRACT: A report that demonstrated an efficient methodology for the arylation of imidazoles has been extended to bis(*N*-heterocyclic) compounds. Using bis(aryl) iodonium salts provides high-yielding access to CCC-NHC ligand precursors in a single step. Examples of arylation using various iodonium salts are reported herein with an investigation into the factors governing their relative rate of reactivity. The metalation of one of these compounds using $Zr(NMe_2)_4$ and its subsequent treatment with $[Pt(COD)Cl_2]$ to yield a transmetalated product are reported.



The vast majority of reports for the synthesis of unsymmetrical *N*,*N*′-diaryl imidazolium salts follow Arduengo's original multistep aryl *N*-heterocyclic carbene (NHC) synthetic protocol.[1−4] After searching sometime for an efficient, direct synthesis to unsymmetrical *N*,*N*′-diaryl imidazolium salts we had exhausted all the known, direct methodologies. Fortunatley, Gao and You recently reported a methodology that utilizes hypervalent iodonium salts as electrophilic arylation reagents for this purpose (Scheme 1).[5]

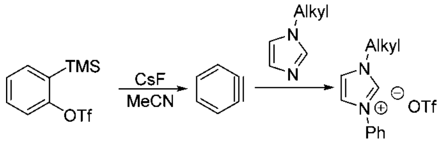
Scheme 1. Methodology of Gao and You (Ref 5)



Their report represents a significant advance for the synthesis of a wide range of unsymmetrical imidazolium salts as ionic liquids[6] or NHC precursors.[7] The extension of their methodology to di-imidazolium systems is reported herein and provides easy access to arylated CCC-NHC pincer ligand precursors.

Several methodologies for synthesizing unsymmetrical aryl imidazolium salts have been reported in the past decade.[8−14] As Yoshida and Kunai reported in 2002, nucleophilic attack on aryne intermediates by 1-alkyl imidazoles yielded 1-alkyl-3-aryl imidazolium salts (Scheme 2).[15] Unfortunately, our attempts to utilize this method for the arylation of 1,3-di-*N*-imidazolylbenzene, **1**, did not yield the desired bis-arylated product. Therefore, methods that afford bis-1,3-(3′-aryl-*N*-heterocycl-1′-yl)arenes were needed.

Scheme 2. Methodology of Yoshida and Kunai (Ref 15)



The capacity to generate bis-1,3-(3′-aryl-*N*-heterocycl-1′-yl)arenes will provide easy access to NHC based pincer ligand precursors. Recently, NHCs have been incorporated into tridentate meridional pincer ligands since they are stronger electron donors than phosphine analogues, which lends to higher activity for some complexes.[16−20] Since they were first reported by Shaw in 1976, pincer ligands have become an important moiety in transition metal complexes.[21−24] Furthermore, evidence from some catalytic systems suggest that the presence of an aryl substituent, in lieu of an alkyl substituent, improves pincer catalyst performance in dehydrogenation.[25]

The strategy presented by Gao and You was employed to produce bis(*N*,*N*′-diaryl *N*-heterocyclic) salts. Additionally, preliminary metalation of the bis-1,3-(3′-aryl-*N*-heterocycl-1′-yl)benzene ligand precursor with $Zr(NMe_2)_4$ and transmetalation using $[Pt(COD)Cl_2]$ are reported.

All bis-imidazole and bis-triazole starting materials were synthesized according to previous methodology.[8] Preliminary arylation experiments of **1** with bis(phenyl)iodonium tetrafluoroborate catalyzed with $Cu(OAc)_2{\cdot}H_2O$ or CuO in d_6-DMSO were monitored by ^1H NMR spectroscopy, which indicated that the reaction was successful in yielding the desired product and complete in 2 h. Attempts to scale up the reaction with reagent grade DMSO were unsuccessful, as arylated DMSO was the only product observed. This side product was attributed to trace amounts of DMS; thus, DMF was chosen as the solvent for scaled-up arylations. These reactions were

Received: March 10, 2014
Published: April 15, 2014

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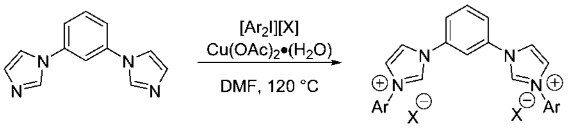
monitored by mass spectrometry, and at 2 h the reaction was complete. A mass spectrum of **2** contained a peak at m/z 451 that corresponded to ($[M-BF_4]^+$, calcd for $C_{24}H_{20}BF_4N_4^+$ 451), and the ^1H NMR spectrum contained an imidazolium proton resonance at δ 10.35.

To examine the effects of electron withdrawing or donating groups and steric congestion, the arylation of **1** was attempted with bis conjugated-aryl iodonium salts (Scheme 3). For the preparation of **3**, **1** was reacted with bis(4-*tert*-butylphenyl)iodonium salt and monitored via thin layer chromatography (TLC). After 20 h, the reagents had been converted to product as shown by TLC. Product **3** was isolated, and the ^1H NMR spectrum contained an imidazolium proton resonance at δ 10.43. Next, **4** was prepared from the reaction of **1** with bis(4-fluorophenyl)iodonium salt, and within 20 h the reagents had again been converted into product as shown by TLC. Compound **4** was isolated, and the ^1H NMR spectrum contained a resonance at δ 10.47. The preparation of **3** and **4** indicated that electron withdrawing and donating groups do not significantly impact the conversion of reactants to products. However, the increased reaction time is indicative of the transformation regiospecificity being similar to that observed by Gao and You, in which sterics are the governing factor in the reaction rate.[5]

Scheme 3. Isolated Yields of Varying Bis(imidazolium) Salts



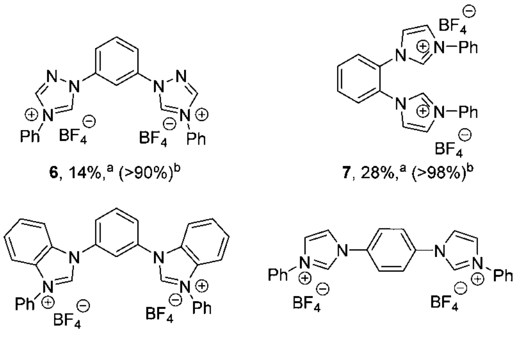
1

2: Ar = phenyl, X = BF_4, 2 h, 100%
3: Ar = *p*-t-butylphenyl, X = OTf, 20 h, 70%
4: Ar = *p*-fluorophenyl, X = OTf, 20 h, 67%
5: Ar = *o*-trifluoromethylphenyl, X = OTf, 23 h, 0%

Because it had been shown that when unsymmetrical iodonium salts are employed for arylation, the least substituted aryl group is selectively transferred;[26] [3-(trifluoromethyl)-phenyl](2,4,6-trimethylphenyl)iodonium salt was reacted with **1** to further investigate the impact of steric congestion. TLC was used to monitor the reaction, and after 23 h, starting material was no longer present. However, **5** was not observed as the product upon isolation. Further studies are underway to probe the reactivity of unsymmetrical iodonium salts.

Once the synthesis and isolation of **2**, **3**, and **4** had been optimized, the aim became to define the scope of this methodology within bis(*N*-heterocyclic) systems (Figure 1). Arylation products **6**, **7**, **8**, and **9** were obtained using the reaction conditions shown in Scheme 3, and each reaction was run in an NMR tube using d_6-DMSO as the solvent. ^1H NMR spectroscopy was utilized to determine conversion. The bis(*N*-heterocyclic) compounds were converted into *N,N′*-diaryl *N*-heterocyclic salts within 16 h, and although isolation of the desired products proved challenging, isolated yields were obtained, thus supporting the application of this methodology to other bis(*N*-heterocyclic) systems. The ^1H NMR spectrum of each contained the expected imidazolium proton resonance in the downfield region (**6**, δ 11.68; **7**, δ 10.27; **8**, δ 10.74; **9**, δ 10.47).

Now that arylated CCC-NHC pincer precursors were available, metalation became a priority. Attempts to metalate **2** with $Zr(NMe_2)_4$ proved to be challenging, which was attributed to the insolubility of **2**. Therefore, **3** was utilized since it contained *tert*-butyl groups that improved solubility. Compound **3** was successfully metalated with excess $Zr(NMe_2)_4$ as shown by ^1H NMR spectroscopy. Metalation occurred within 30 min using methylene chloride as the solvent as indicated by the loss of an imidazolium proton resonance, δ 10.43, in the ^1H NMR spectrum. Additionally, the ^{13}C NMR spectrum contained a signal at δ 190.19 that corresponded to an NHC carbon bound to Zr.[27] Addition of $[Pt(COD)Cl_2]$ yielded an air-stable CCC-NHC pincer complex, **10** (Scheme 4), and the crude ^1H NMR spectrum continued to show a loss of three aromatic protons compared to salt **3**. Furthermore, the ^{13}C NMR spectrum contained a carbon−metal bond resonance shift from δ 190.19 to δ 170.43, which signifies an NHC carbon bound to Pt.[28]

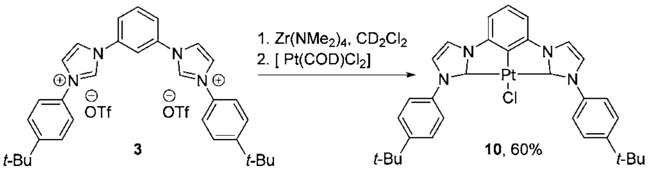


6, 14%,[a] (>90%)[b] **7**, 28%,[a] (>98%)[b]

8, 28%,[a] (>90%)[b] **9**, 86%,[a] (>90%)[b]

Figure 1. Scope of *N*-heterocycle reactivity with $[Ph_2I]^+[BF_4]^-$. [a] Isolated yields. [b] Conversion.

Scheme 4. Synthesis of Pt CCC-NHC Pincer Complex



3 **10**, 60%

In conclusion, a variety of bis(*N,N′*-diaryl *N*-heterocyclic) salts have been synthesized utilizing a methodology recently reported by Gao and You.[5] This extension provides efficient access to potential ionic liquids and pincer ligand precursors. Additionally, metalation of **3** with $Zr(NMe_2)_4$ and transmetalation using $[Pt(COD)Cl_2]$ yielded a Pt CCC-NHC pincer complex, **10**, in a total of three isolation steps starting with 1,3-dibromobenzene. This synthetic transformation represents an important step forward in efficient access to diaryl imidazolium salts.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

Selected key spectroscopic data. This material is available free of charge via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

ACKNOWLEDGMENTS

Mississippi State University (MSU) is gratefully acknowledged for financial support. Wesley D. Clark (MSU), Henry U. Valle (MSU), and Griffin A. Burk (MSU) are thanked for their donation of 1,2-bis(imidazol-1′-yl) benzene, 1,3-bis(triazol-1′-yl) benzene, and 1,4-bis(imidazol-1′-yl) benzene as starting materials.

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