ORGANIC LETTERS

2013
Vol. 15, No. 5
1008–1011

Oxidative Diamination Promoted by Dinuclear Iodine(III) Reagents

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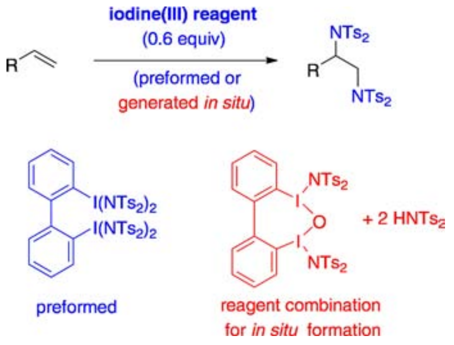
Received December 20, 2012

ABSTRACT



New dinuclear iodine(III) reagents for the intermolecular diamination of alkenes are reported. These are accessible through protolytic aminolysis events, which generate defined imido-iodine(III) groups.

The development of suitable hypervalent organoiodine(III) reactivity[1] has recently greatly enhanced the area of metal-free amination reactions. Several reports have detailed electrophilic, radical, or nucleophilic amination reactions based on these reagents.[2−6] Within this context, we have reported the synthesis, isolation, and structural characterization of defined reagents of the type $ArI[N(SO_2R)_2]_2$ **A** that show unprecedented reactivity in a series of different

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10.1021/ol3034884

oxidative amination reactions.[7] These compounds all derive from the general aryl iodine(III) theme. While this chemistry now appears to be well-understood, future developments require more diversification in structure. For example, a recent report on the C−H amination of arenes by Antonchick postulated the in situ formation of an I−N bond in the dinuclear reagent B (Figure 1).[8]

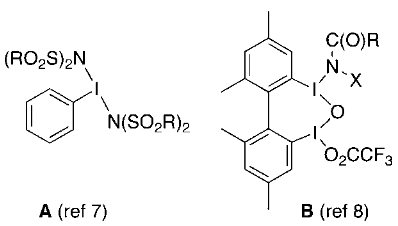
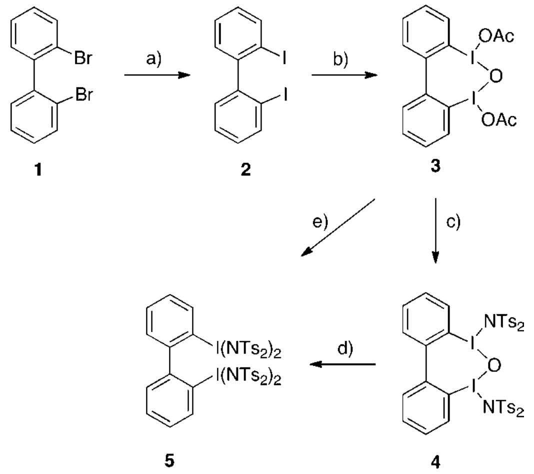


Figure 1. Hypervalent iodine reagents.

We here describe two new hypervalent iodine reagents based on the 2,2′-diiodo biaryl core that provide an efficient entry into metal-free diamination reactions.[9−12] Starting from 2,2′-dibromo biphenyl **1**, a halide exchange provides 2,2′-diiodo biphenyl **2**, which can be oxidized to the known μ-oxo bridged bisiodone(III) compound **3** (Scheme 1).[13]

Scheme 1. Synthesis of New Imido-Iodine(III) Compounds[a]



[a] (a) (1) *n*BuLi, Et_2O, −78 °C; (2) I_2, −78 °C to rt (91% over both steps). (b) Selectfluor, AcOH/CH_3CN, rt (90%). (c) $HNTs_2$ (2 equiv), $C_6H_5Cl/CHCl_3$, 50 °C (99%). (d) $HNTs_2$ (2 equiv), $C_6H_5Cl/CHCl_3$, rt (99%). (e) $HNTs_2$ (4 equiv), $C_6H_5Cl/CHCl_3$, rt (99%).

This compound serves as the source for selective transformation into defined hypervalent imidoiodine(III) derivatives with I−N single bonds. For example, in the presence of 2 equiv of bistosylimide, **3** generates the new μ-oxo bridged symmetric bisimido compound **4**. The synthesis of **4** within a direct aminolysis of precursor **3** under preservation of the μ-oxo group is unprecedented. It confirms that the formation of postulated intermediates such as **B** from their respective oxygenated precursors is indeed a feasible process. The solid state structure of **4** is depicted in Figure 2.[14]

Aminolysis with a 4-fold excess of imine directly generates the deoxygenated compound **5** displaying two individual bisimidoiodine(III) groups. The same product is accessible through aminolysis of **4**. The isolation of **5** with its two bisimidoiodine(III) groups $ArI(NTs_2)_2$ confirms the general implication of the latter as the reactive reagents in metal-free oxidative diamination reactions.

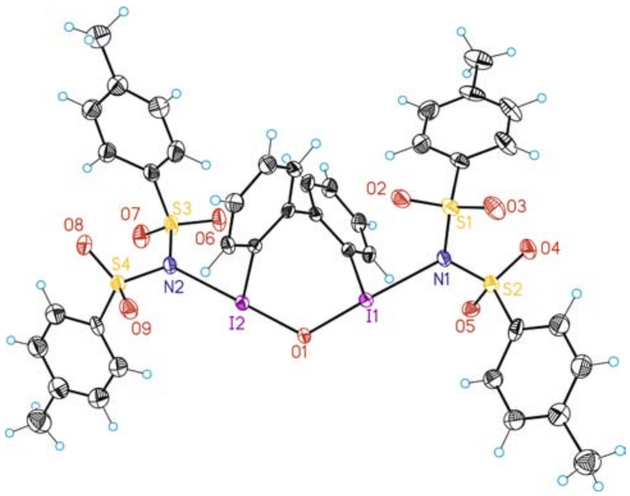


Figure 2. Solid state structure of **4**. Selected bond lengths (Å) and angles (deg): N1−I1, 2.421(3); N2−I2, 2.365(3); O1−I2−N2, 176.41(10); O1−I1−N1, 173.93(10).

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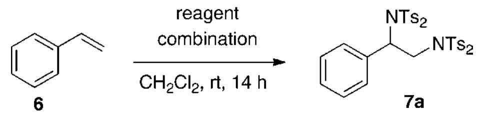
(14) See Supporting Information for details on the structural elucidation.

Table 1. Diamination of Styrene with Iodine(III) Reagents **3**, **4**, and **5**: Optimization[a]



entry	reagent combination	yield [%][b]
1	**3** (0.6 equiv) + $HNTs_2$ (1.2 equiv)	20[c]
2	**3** (1.2 equiv) + $HNTs_2$ (2.4 equiv)	43[c]
3	**3** (0.6 equiv) + $HNTs_2$ (2.4 equiv)	32[c]
4	**4** (0.6 equiv)	54
5	**4** (1.2 equiv)	88
6	**4** (0.6 equiv) + $HNTs_2$ (1.2 equiv)	74
7	**4** (0.6 equiv) + $HNTs_2$ (2.4 equiv)	74
8	**5** (0.6 equiv)	77
9	**5** (1.0 equiv)	92

[a] Reactions were performed on a 0.2−0.5 mmol scale. [b] Isolated yield of product after purification on silica gel. [c] Major amounts of unreacted styrene according to analysis by ^{1}H NMR of the crude reaction.

The new compounds are active reagents for the intermolecular diamination of alkenes or suitable precursors to these reagents. As demonstrated for the diamination of styrene, both an in situ reagent formation from **3** or **4** as well as use of preformed **4** or **5** lead to chemoselective diamination in all cases (Table 1). For example, treatment of styrene in dichloromethane solution with 0.6 equiv of reagent **3** (1.2 equiv of I(III)) and 1.2 equiv of bistosylimide already leads to formation of 20% diamination product **7a** (entry 1). Doubling the reagent amount to 1.2 equiv gives a 43% isolated yield (entry 2), while doubling the relative amount of imide provides an increase in yield to 32% (entry 3). Use of preformed imido compounds resulted in superior performances. For example, a diamination with 0.6 equiv of **4** led to a yield of 54% (out of a maximum 60% yield, entry 4), while an excess of iodine(III) in the same reaction provided an 88% yield (entry 5). These observations demonstrate that efficient diamination can already be accomplished with reagent **4**. We rationalize this behavior by the assumption of an intramolecular rearrangement of **4**. Upon dissociation of bistosylimide, the resulting cationic intermediate **4**′ undergoes opening of the μ-oxo bridge to form a iodoso group and the reactive $ArI(NTs_2)_2$ unit[7] that initiates the diamination reaction (Scheme 2).

Scheme 2. Proposed Formation of $ArI(NTs_2)_2$ Reagent **4**″ from **4**

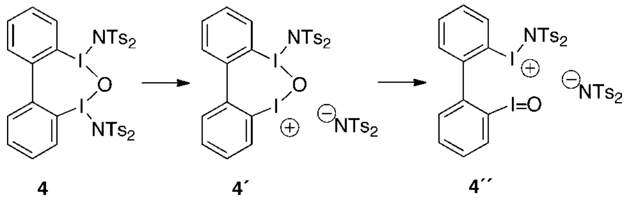
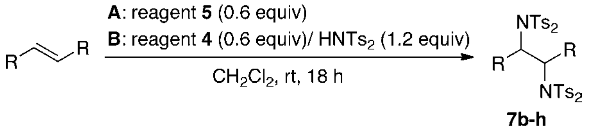
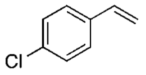
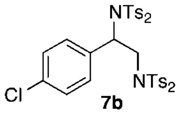
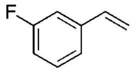
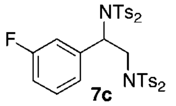
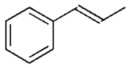
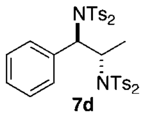
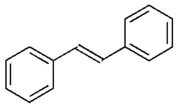
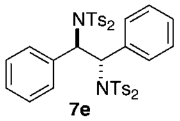
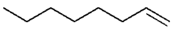
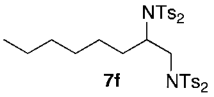
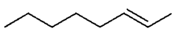
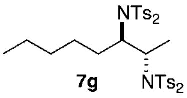
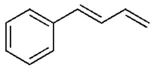
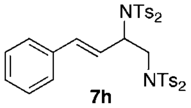
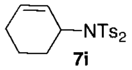


Table 2. Diamination of Alkenes with Iodine(III) Reagents **4/2HNTs₂** or **5**[a]



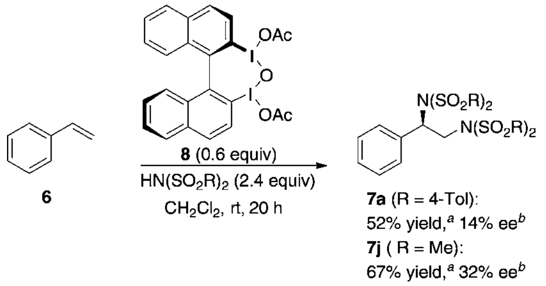
entry	substrate	procedure	product	yield [%][b]
1		A	 **7b**	77
2		A	 **7c**	67
3[c]		B	 **7d**	64
4[c]		B	 **7e**	43
5		A	 **7f**	80
6		A	 **7g**	72
7		A	 **7h**	71
8		A	 **7i**	62

[a] Reaction conditions: alkene (0.5 mmol), oxidant **5** (0.6 mmol), or combinations of reagents **3** or **4** as indicated, CH_2Cl_2, rt, 18 h. [b] Isolated yield of product after purification on silica gel. [c] Reaction at 50 °C.

That an $ArI(NTs_2)_2$ moiety indeed constitutes the reactive iodine(III) reagent was concluded from the observation that treatment of **4** with an additional amount of bistosylimide results in formation of **7a** in 74% yield (Table 1, entry 6), while further addition of imide does not affect the yield (entry 7). The results from entries 3 and 6 suggest compound **5** as the reactive reagent in the diamination of styrene, and indeed, oxidation with preformed reagent **5** gives diamine **7a** in 77% isolated yield (entry 8). This yield can be increased to an excellent 92% using an excess of reagent **5** (entry 9).

Inspection of the reaction progress over time for a diamination of styrene with **5** as the reagent reveals a significant decrease in relative rate taking place after around 50% conversion, which was estimated to be in the range of a 6-fold overall drop.[14] This rate decrease suggests that the reaction is faster for oxidation with **5** than for the resulting intermediate mixed species bearing an iodine(I) and an iodine(III) group, which may be the result of a diminished

Scheme 3. Enantioselective Diamination of Styrene[a]



[a] Isolated yield of product after purification on silica gel. [b] Value determined by HPLC on a chiral stationary phase.

electrophilic character for the remaining iodine(III) group. Still, the reaction with 0.6 equiv of **5** reaches yields that are comparable to diamination with stoichiometric amounts of the so far best reagent $PhI(NTs_2)_2$.[7] However, it must be noted that significantly longer reaction times are required in the present cases.

Diamination reactions of alkenes using reagents **4** and **5** proceed with excellent results for a variety of different alkenes. Table 2 shows representative examples. These include styrenes as the priviledged substrates in such oxidations (entries 1, 2).[4a,b] In contrast to para- and meta-substitution, ortho-substituents such as methyl or fluoro were found to be incompatible with the present protocol. This is probably the consequence of the enhanced size of reagent **5**. Internal alkenes such as β-methyl styrene and stilbene work well (entries 3, 4) as do aliphatic alkenes such as 1- and 2-octene (entries 5, 6).[4b] New reagent **5** also promotes diamination of 1-phenyl butadiene (entry 7),[4c] while cyclohexene gives selective allylic amination (62% isolated yield).[4d]

In addition to diamination with **3**/$4HNTs_2$, a diamination starting from the related binaphthyl derivative **8** allowed for the exploration of the present type of reagents in enantioselective diamination of styrene (Scheme 3).[4a] Hence, in situ protolytic aminolysis of **8** by 4 equiv of bissulfonimide generates an active reagent that has so far escaped isolation but is considered to be the analogue of **5**. This chiral reagent is capable of inducing enantioselectivity in the diamination of styrene. Values of 14 and 32% ee were observed depending on the respective nitrogen source. Although the obtained enantioselectivities are not yet high, the reaction nevertheless demonstrates that the axially chiral binaphthyl scaffold is capable of inducing enantioselectivity.

In summary, we have described the synthesis of new dinuclear iodine(III) compounds with a defined structure and have explored their reactivity in intermolecular diamination reactions of alkenes. The reactivity of these new reagents is high and should result in the development of new efficient amination reactions. It bears significant potential for the development of enantioselective transformations as well.

Acknowledgment. C.R. gratefully acknowledges the Alexander von Humboldt Foundation for a postdoctoral fellowship (2010/2011). This work was supported by the ICIQ Foundation and by the Spanish Ministerio de Economía y Competitividad (CTQ2011-25027).

Supporting Information Available. Experimental procedures and characterization data including CIF file on the X-ray crystallographic analysis of compound **4**. This material is available free of charge via the Internet at http://pubs.acs.org.

The authors declare no competing financial interest.