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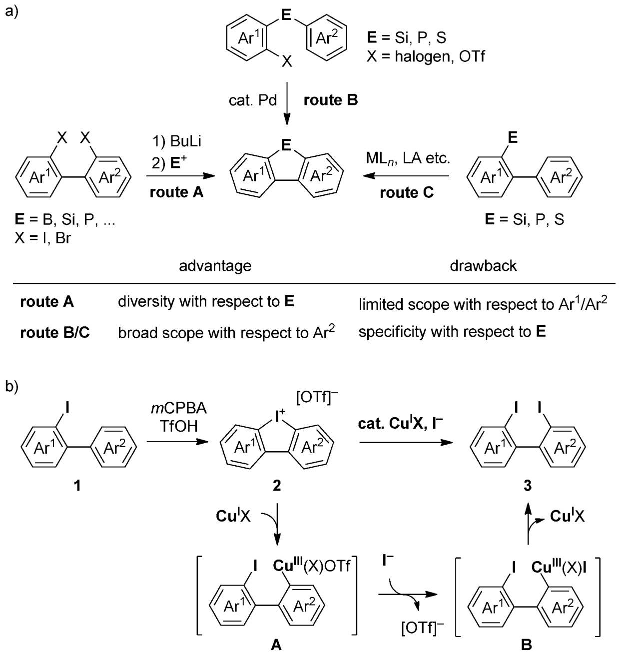
Conversion of 2-Iodobiaryls into 2,2′-Diiodobiaryls via Oxidation-Iodination Sequences: A Versatile Route to Ladder-Type Heterofluorenes**

*Bin Wu and Naohiko Yoshikai**

Abstract: *Even though 2,2′-diiodo- and 2,2′-dibromobiaryls represent accomplished precursors for heterofluorenes and other extended π-conjugated systems, their preparation still remains nontrivial when structural diversity of the biaryl backbone is required. Herein, we report a convenient method for the preparation of various 2,2′-diiodobiaryls from 2-iodobiaryls via cyclic diaryliodonium intermediates. An iodinative ring-opening of the diaryliodonium salts, mediated by a copper/diamine catalyst system, is able to afford the corresponding 2,2′-diiodobiaryls under mild conditions. The versatility of this two-step approach is demonstrated by the preparation of hitherto unexplored tetraiodoteraryls and their conversion into ladder-type π-conjugated systems.*

Heteroatom-bridged biaryls (heterofluorenes or dibenzoheteroles), containing Group 13–16 heteroatom elements, have garnered significant attention as building blocks of π-conjugated functional materials with optical and electronic applications.[1–4] Over the years, a variety of preparative methods for the synthesis of heterofluorenes have been established, especially well for the naturally occurring nitrogen- and oxygen-containing analogues (carbazoles and dibenzofurans).[5] But regardless, synthetic methods for the inclusion of other bridging heteroatoms in heterofluorenes still represent desirable research targets, as they provide a means to modulate the electronic nature of the π-conjugated systems.[6] The most frequently used precursors to such heterofluorenes are 2,2′-dihalobiaryls (X = Br or I), which are usually subjected to halogen–lithium exchange, followed by trapping with boron,[1a] silicon,[7] phosphorus,[8] or other heteroatom electrophiles (route A, Scheme 1 a).[9,10] Recently, approaches based on C–H functionalizations have emerged. For example, the Pd-catalyzed intramolecular C–X/C–H coupling of silicon-,[11] phosphorus-,[12] or sulfur-tethered[13] arenes allows the efficient preparation of the corresponding heterofluorenes (route B, Scheme 1 a). Alternatively, biaryls bearing appropriate *ortho*-substituents (Si, P, S) may undergo an intramolecular heteroatom–aryl bond formation, thus affording dibenzosiloles,[14] dibenzophospholes,[15] or dibenzothiophenes (route C, Scheme 1 a).[16] Even though each synthetic route has its own advantages, they also have individual drawbacks. Route A, for example, allows the conversion of common 2,2′-dihalobiaryl precursors into a variety of heterofluorenes, but the synthesis of a structurally diverse set of 2,2′-dihalobiaryls is laborious and nontrivial.[17] Routes B and C are suitable for the synthesis of specific heterofluorenes with various substituents, but are not a priori divergent with respect to the heteroatom. Consequently, a practical solution to enable diversity of both the central heteroatom and the peripheral substituents would be attractive.[18]



	advantage	drawback
route A	diversity with respect to **E**	limited scope with respect to Ar1/Ar2
route B/C	broad scope with respect to Ar2	specificity with respect to **E**

Scheme 1. a) Common synthetic approaches to heterofluorenes (routes A–C) and b) conversion of 2-iodobiaryls to 2,2′-diiodobiaryls through oxidation and iodinative ring-opening.

Herein, we disclose an expansion to route A for the synthesis of heterofluorenes enabled by the conversion of readily available 2-iodobiaryls (**1**) into the corresponding 2,2′-diiodobiaryls (**3**) in two steps through oxidation to cyclic diaryliodonium triflates (**2**),[19] followed by a copper/diamine-catalyzed iodinative ring-opening reaction (Scheme 1 b). Although conversion of **1** to **3** was previously achieved by the thermal decomposition of cyclic diaryliodonium iodide at

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[*] B. Wu, Prof. N. Yoshikai
Division of Chemistry and Biological Chemistry
School of Physical and Mathematical Sciences
Nanyang Technological University
Singapore 637371 (Singapore)
E-mail: nyoshikai@ntu.edu.sg

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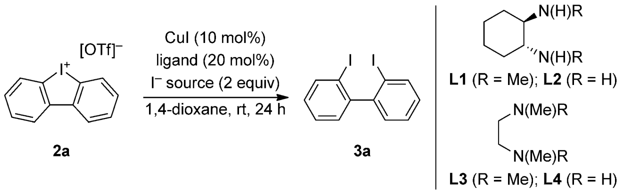
200–250 °C,[20] this classical method requires several steps under harsh conditions, and has hence found limited applications. In contrast, the present approach allows the facile preparation of a wide variety of 2,2′-diiodobiaryls, as well as the generation of hitherto unexplored tetraiodoteraryl derivatives, which may serve as versatile precursors for the construction of ladder-type π-conjugated systems.[6b]

The key to the present two-step preparation of 2,2′-diiodobiaryls is the iodinative ring-opening of the cyclic diaryliodonium salts. We envisioned that an oxidative addition of the aryl–I^{III} bond to a Cu^{I} catalyst should generate a 2-iodo-2′-cuprio(III)biaryl intermediate (**A**),[19a,21] which should subsequently be intercepted by an iodide anion (**B**) to furnish the desired 2,2′-diiodobiaryl through C–I bond-forming reductive elimination (Scheme 1 b). On the basis of this hypothesis, dibenzo[*b*,*d*]iodol-5-ium triflate (**2a**) was treated with tetrabutylammonium iodide in dioxane at room temperature in the presence of various copper catalysts (10 mol %; Table 1). Using CuI in the absence of any additives afforded 2,2′-diiodobiphenyl (**3a**) merely in low yield (10 %; entry 1, Table 1). However, using a combination of CuI and *N*,*N*′-dimethylcyclohexane-1,2-diamine (**L1**, 20 mol %)[22] resulted in the clean conversion of **2a** to **3a** in 95 % yield as determined by ^{1}H NMR spectroscopy (89 % yield of the isolated product; entry 2, Table 1). Other 1,2-diamine ligands (**L2**–**L4**, Table 1), 2,2′-bipyridine, and 1,10-phenanthroline also promoted the iodinative ring-opening, albeit in somewhat lower yields (57–83 %; entries 3–7, Table 1). As alternative sources of iodide, NaI and KI could be used instead of [(*n*Bu)$_4$N]I (entries 8 and 9, Table 1). Even though reduced loadings of CuI (5 mol %) and **L1** (10 mol %) resulted in significantly decreased yields (entry 10, Table 1), the reaction can be readily scaled up to 5 mmol (entry 11, Table 1). It is worth noting that the use of [(*n*Bu)$_4$N]Br instead of [(*n*Bu)$_4$N]I promoted the brominative ring-opening of **2a** to afford 2-iodo-2′-bromobiphenyl (53 % yield; data not shown).

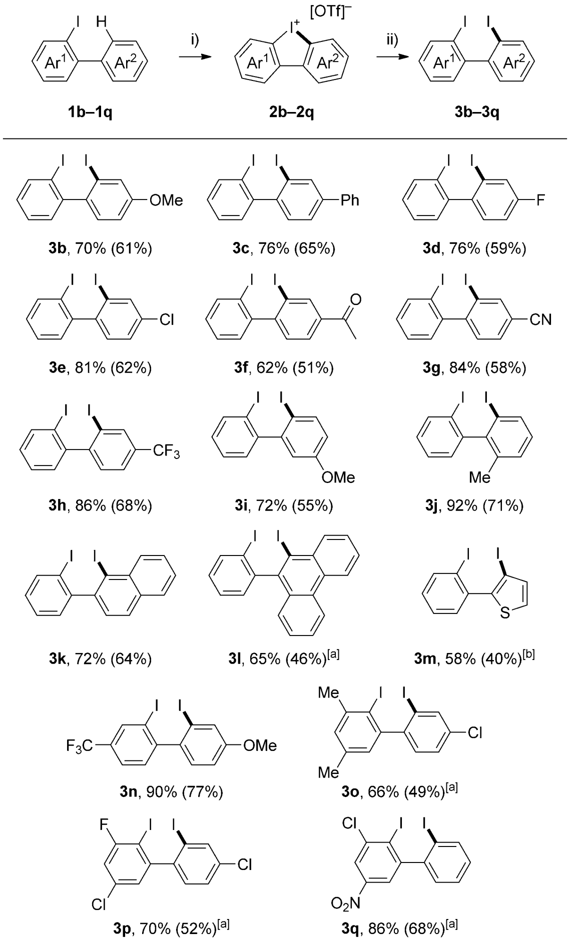
Table 1: Optimization of the reaction conditions for the iodinative ring-opening of cyclic diaryliodonium triflate **2a**.[a]



Entry	Ligand	I⁻ source	Yield [%][b]
1	none	[(*n*Bu)$_4$N]I	10
2	**L1**	[(*n*Bu)$_4$N]I	95 (89)
3	**L2**	[(*n*Bu)$_4$N]I	74
4	**L3**	[(*n*Bu)$_4$N]I	64
5	**L4**	[(*n*Bu)$_4$N]I	83
6	2,2′-bipyridyl	[(*n*Bu)$_4$N]I	57
7	1,10-phenanthroline	[(*n*Bu)$_4$N]I	66
8	**L1**	NaI	82
9	**L1**	KI	83
10[c]	**L1**	[(*n*Bu)$_4$N]I	20
11[d]	**L1**	[(*n*Bu)$_4$N]I	(84)

[a] Scale: 0.2 mmol. [b] Determined by ^{1}H NMR spectroscopy using 1,1,2,2-tetrachloroethane as an internal standard; yield of isolated product in parentheses. [c] Reduced loadings of CuI (5 mol %) and **L1** (10 mol %). [d] Scale: 5 mmol.

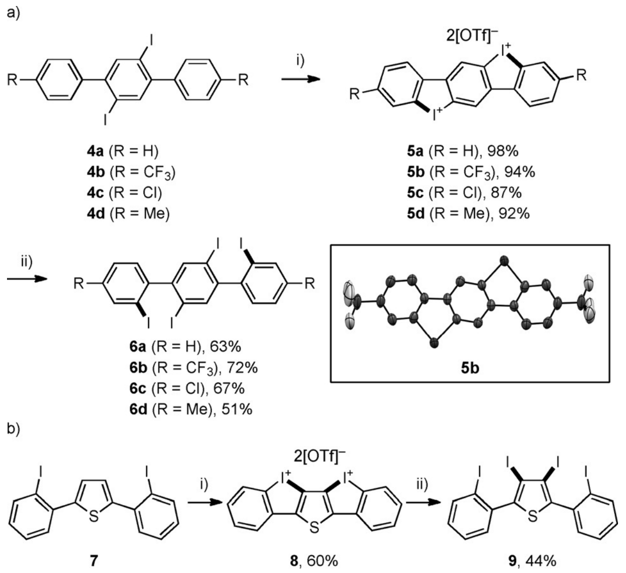
We next explored the scope of the iodinative ring-opening reaction (Scheme 2). Various 2-iodobiaryls (**1b**–**1q**) were readily oxidized using a mixture of *m*CPBA (1.5 equiv) and TfOH (3 equiv) in CH$_2$Cl$_2$ (room temperature, 1 h),[19,23] thus affording the corresponding cyclic diaryliodonium triflates (**2b**–**2q**). The subsequent iodinative ring-opening of **2b**–**2q** proceeded smoothly and generated the corresponding 2,2′-diiodobiaryls (**3b**–**3q**) in moderate to good yields (58–92 %), resulting in respectable combined yields (40–77 %) over both steps. The solubility of some iodonium triflates (**2l**, **2m**, **2o**–**2q**) was limited in dioxane, which required a modification of the reaction conditions (DMSO or DMF, *T* = 60 °C) to achieve the desired reaction. The method showed tolerance toward electron-donating methoxy groups (**3b**, **3i**, **3n**) as well as toward electron-withdrawing chloro (**3e**, **3o**–**3q**), acetyl (**3f**), cyano (**3g**), trifluoromethyl (**3h**, **3n**), and nitro (**3q**)



Scheme 2. Two-step conversion of 2-iodobiaryls to 2,2′-diiodobiaryls. Reaction conditions: i) *m*CPBA (1.5 equiv), TfOH (3 equiv), CH$_2$Cl$_2$, RT, 1 h; ii) CuI (10 mol %), **L1** (20 mol %), [(*n*Bu)$_4$N]I (2 equiv), dioxane, RT, 24 h. The yield refers to that of the second step, and the overall yield over two steps is shown in parentheses. [a] Reaction in DMSO at 60 °C. [b] Reaction in DMF at 60 °C. Tf = trifluoromethanesulfonyl,

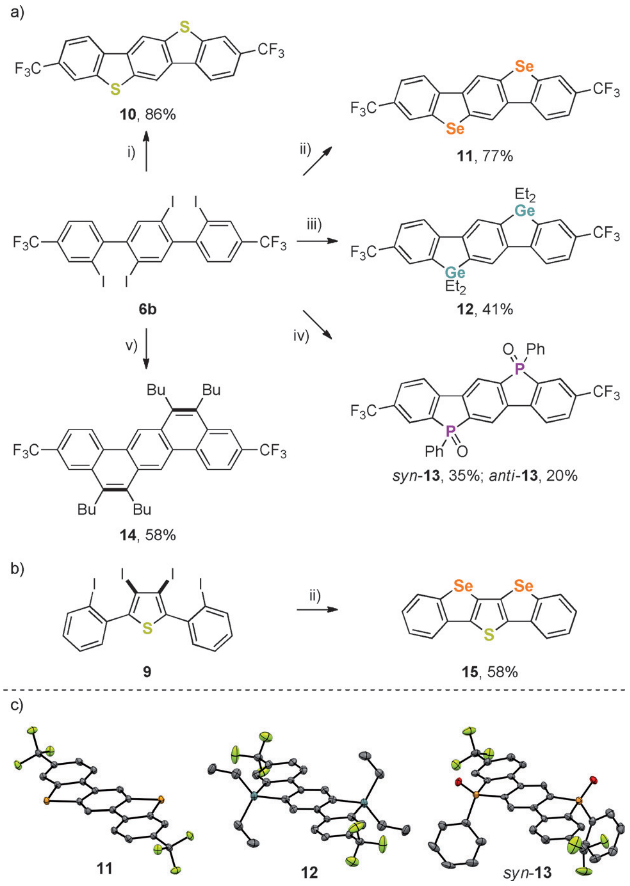
groups. Whereas iodination at the C3 position of thiophene was successfully achieved (**3m**), the attempted iodination at the C2 position of thiophene or the C3 position of indole failed due to decomposition of the starting material in the first step. Note that the regioselectivities of iodination in the products **3i** and **3k** were expected from previous studies by Wen et al.[19a]

We extended the present method to the conversion of diiodoteraryls into the corresponding tetraiodoteraryls (Scheme 3). The oxidation of 2′,5′-diiodo-*p*-terphenyl derivatives **4a–4d** proceeded cleanly to afford bis-iodonium triflates **5a–5d** in high yields (87–98%; Scheme 3a). The ladder-type structure of these bis-iodonium triflates was confirmed by X-ray crystallographic analysis of single crystals of **5b** (see inset in Scheme 3a).[24] A twofold iodinative ring-opening of **5a–5d** took place in acetonitrile at 60°C, affording the desired 2,2′,2′′,5′-tetraiodo-*p*-terphenyl derivatives **6a–6d** as light-sensitive solids in moderate to good yields (51–72%; Scheme 3a). Furthermore, 2,5-bis(2-iodophenyl)thiophene (**7**) was also amenable to a twofold oxidation/ring-opening, which resulted in the formation of 3,4-diiodo-2,5-bis(2-iodophenyl)thiophene (**9**) in moderate yield (44%; Scheme 3b).



Scheme 3. a) Conversion of 2′,5′-diiodo-*p*-terphenyl derivatives **4a–4d** to 2,2′,2′′,5′-tetraiodo-*p*-terphenyl derivatives **6a–6d**, and b) conversion of 2,5-bis(2-iodophenyl)thiophene **7** to 3,4-diiodo-2,5-bis(2-iodophenyl)thiophene **9**. Reaction conditions: i) *m*CPBA (3 equiv), TfOH (6 equiv), CH_2Cl_2, RT, 2 h; ii) CuI (20 mol%), **L1** (40 mol%), $[(n\mathrm{Bu})_4\mathrm{N}]\mathrm{I}$ (4 equiv), MeCN, 60°C, 24 h. Inset: ORTEP drawing of **5b** (thermal ellipsoids set at 50% probability), whereby hydrogen atoms, counteranions, and solvent molecules were omitted for clarity.

The diiodobiaryl and tetraiodoteraryl derivatives synthesized by the present method should be able to serve as versatile starting materials for the synthesis of heterofluorenes and other extended π-conjugated systems. This idea was validated by conversion of tetraiodoteraryls **6b** and **9** into various ladder-type π-conjugated systems (Scheme 4a,b). Exposure of **6b** to a catalytic amount of CuI, sulfur powder, and K_2CO_3 in DMF[25] resulted in a fourfold C−S bond formation to afford benzo[1,2-*b*:4,5-*b*′]bis[*b*]benzothiophene[26] **10** in 86% yield. A similar Cu-catalyzed method using selenium and (*N*-methyl-2-pyrrolidone) (NMP) instead of sulfur and DMF[18a] allowed conversion of **6b** and **9** into benzo[1,2-*b*:4,5-*b*′]bis[*b*]benzoselenophene[26a] (**11**) and dibenzo[*d*,*d*′]thieno[3,2-*b*;4,5-*b*′]diselenophene (**15**). These results suggest great promise for a catalyst system based on copper and elemental sulfur/selenium to prepare dibenzothiophenes and dibenzoselenophenes directly from 2,2′-diiodobiaryls.[27] A twofold iodine–lithium exchange/electrophilic trapping sequence proved effective for the preparation of germanium- and phosphoryl-bridged *p*-teraryls **12** and **13**,[15a,28] respectively. The latter product was obtained as a separable mixture of *syn*- and *anti*-isomers. Besides the heteroatom-bridged *p*-teraryls, the Pd-catalyzed reaction of **6b** with 5-decyne, using Wu's conditions,[29] resulted in a twofold annulation to afford benzo[*k*]tetraphene derivative **14**. Single-crystal X-ray diffraction analysis was performed for all of these ladder-type products except *anti*-**13**, which invariably demonstrated high levels of coplanarity of their



Scheme 4. Conversion of tetraiodoteraryl **6b** into ladder-type π-conjugated systems. a,b) Reaction conditions: i) CuI (20 mol%), sulfur powder, K_2CO_3, DMF, 90°C; ii) CuI (20 mol%), selenium powder, K_2CO_3, NMP, 120°C; iii) 1) *n*BuLi, THF, −78°C; 2) Et_2GeCl_2, −78°C to RT; iv) 1) *n*BuLi, THF, −78°C; 2) $PhPCl_2$, −78°C to RT; 3) H_2O_2; v) $Pd(OAc)_2$ (20 mol%), IPr·HCl (10 mol%), $P(t\mathrm{Bu})_3\cdot HBF_4$ (10 mol%), AgOAc, *p*-xylene, 130°C. c) ORTEP drawings of **11**, **12**, and *syn*-**13** (thermal ellipsoids at 50% probability; hydrogen atoms and solvent molecules were omitted for clarity).

skeletons in the solid state (see Scheme 4 c for **11**, **12**, and *syn*-**13**, and the Supporting Information for further details).[24]

In summary, we have developed a convenient two-step method for the preparation of 2,2′-diiodobiaryls from readily accessible 2-iodobiaryls through oxidative cyclization/Cu-catalyzed iodinative ring-opening sequences. Even though cyclic diaryliodonium intermediates have previously been reported to serve as direct precursors to carbazoles and some other bridged biaryl compounds,[19,30] the method presented herein should substantially enhance their utility for the synthesis of a wide range of heterofluorenes. Indeed, the versatility of this method has been demonstrated by the preparation of novel tetraiodoteraryls and their conversion into various ladder-type π-conjugated systems. Furthermore, the present method may also be useful for the diversification of Kita's 2,2′-diiodobiaryl-based organocatalysts for oxidation reactions.[31]

Keywords: biaryls · copper · diaryliodonium salts · heterofluorenes · iodination

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