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Preparation and Structure of Phenolic Aryliodonium Salts

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Phenol based aryliodonium salts were prepared by the reaction of [hydroxy(tosyloxy)iodo]arenes with arylsilyl ethers in the presence of trifluoromethanesulfonic acid. Structures of several aryliodonium salts with the hydroxy group in para-position of phenyl ring were established by single crystal X-ray crystallography. Under basic condition, 4-hydroxyphenyl(phenyl)iodonium salts form a dimeric hypervalent iodine(III) complex, oxyphenyl(phenyl)iodonium ylidic salt, the solid structure of which was confirmed by X-ray crystallography. Phenolic iodonium salts are potentially useful phenol transfer reagents in reactions with various anionic nucleophiles.

In recent years, organohypervalent iodine compounds have found a broad range of applications in organic chemistry because of their environmentally benign nature, oxidative ability similar to heavy metal oxidants, and the reactivity pattern similar to transition metals.[1-5] Diaryliodonium salts belong to a particularly important class of organohypervalent iodine(III) compounds, which have numerous synthetic applications under metal or metal-free conditions.[6-8] Symmetrical or unsymmetrical diaryliodonium salts are effective electrophilic arylating reagents whose reactions with various organic nucleophilic substrates involve oxidative transfer of aryl groups resulting in the formation of new aryl-carbon atom bonds, aryl-heteroatom bonds, and aryl-radioactive isotope bonds. Diaryliodonium salts can also serve as efficient benzyne precursors under appropriate conditions.[9-11] In particular, reactions of diaryliodonium salts with various substrates under strongly basic conditions produce the corresponding benzyne adducts.[12-14] Recently, diaryliodonium compounds with silyl or boron-containing substituents have been developed and used as efficient precursors to reactive species.[15-17] For example, Kitamura and co-workers reported the preparation and reactivity of [2,5-bis(trimethylsilyl)-4-(triflyloxy)phenyl](phenyl)iodonium triflate, which could be used as the 1,4-benzdiyne equivalent in the presence of fluoride source.[15] Legault group has reported zwitterionic iodonium trifluoroborates which react with phenols under basic condition forming the corresponding arylation products containing trifluoroborate group in the aryl group.[16] Our group has reported the preparation and structural investigation of novel benzyne precursors, pseudocyclic arylbenziodoxaborole triflates, which could react with various substrates in the presence of water to give the respective benzyne adducts in moderate to good yields.[17] Despite a significant current interest in functionalized diaryliodonium compounds, only few examples of phenol-derived aryliodonum salts have been reported.[18-22] Moreover, most of these examples deal with the *ortho*-hydroxy substituted diaryliodonium salts, which are important precursors to phenolic iodonium ylides. To the best of our knowledge, only single example of the *para*-hydroxy substituted diaryliodonium salt was reported in the literature,[18] and general synthetic procedures for the preparation of phenolic iodonum salts have been not established.

Herein, we report a straightforward one-pot synthesis and structural investigation of *para*-hydroxy substituted diaryliodonium salts, which can be prepared starting from the corresponding hypervalent iodine(III) reagents and triisopropylsiloxybenzene in the presence of trifluoromethanesulfonic acid. The obtained *para*-hydroxyphenyl(phenyl)iodonium bromide under basic conditions can be converted to a novel dimeric hypervalent iodine(III) complex, oxyphenyl(phenyl)iodonium ylidic salt, solid structure of which was confirmed by X-ray crystallography.

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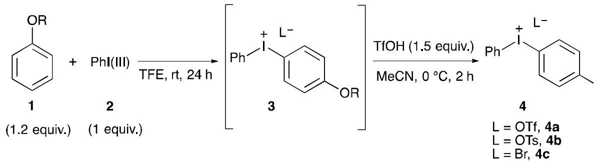
Our approach to the one-pot synthesis of hydroxyphenyl(aryl)iodonium salts is based on the reaction of various hypervalent iodine(III) reagents with phenyl silyl ethers involving the initial formation of silyloxyphenyl(aryl)iodonium salts followed by desilylation of intermediate product in the presence of trifluoromethanesulfonic acid (TfOH) to produce the desired hydroxyphenyl(aryl)iodonium salts. In our initial experiment, the reaction of Koser's reagent **2a** and triisopropylsiloxybenzene **1a** in 2,2,2-trifluoroethanol (TFE) gave the 4-triisopropylsiloxyphenyl(phenyl)iodonium tosylate **3a** (R = TIPS; L = OTs) in 87% yield (Table 1, entry 1). Without purification, the initial compound **3** was transformed to the desired 4-hydroxyphenyl(phenyl)iodonium triflate **4a** in 97% yield by treatment with TfOH in acetonitrile at 0 °C (entry 2). The structure of **4a** was confirmed by NMR, elemental analysis, and high-resolution ESI mass spectrometry. Reactions of other phenyl silyl ethers protected with *tert*-butyldimethylsilyl group (TBDMS) **1b** or *tert*-butyldiphenylsilyl group (TBDPS) **1c** under similar conditions gave the corresponding phenolic iodonium triflate **4a** in 65-83% yields (entries 3 and 4). However, the reaction of trimethylsiloxybenzene **1d** or phenol **1e** instead of **1a** using Koser's reagent **2a** did not afford the desired product (entries 5 and 6). Screening of other hypervalent iodine(III) reagents **2b-d** has indicated that the Koser's reagent **2a** and [bis(trifluoroacetoxy)iodo]benzene **2c** are the most effective reagents in this reaction (entries 2, 7-9). Since [hydroxy(tosyloxy)iodo]arenes are readily available and stable compounds, we decided to use these reagents in our following studies. The reaction in the presence of TfOH added from the beginning gave product **4a** in only 35% yield (entry 10). The tosylate product **4b** was obtained in 86% yield when *p*-toluenesulfonic acid was used instead of TfOH (entry 11). The triflate product **4a** could be further converted into the 4-hydroxyphenyl(phenyl)iodonium bromide **4c** by treatment with the aqueous potassium bromide solution at room temperature (entry 12). The bromide **4c** was recrystallized from methanol, and characterized by X-ray crystallography (Figure 1).

Table 1. Optimization of preparation of 4-hydroxyphenyl(phenyl)iodonium salts **4a**.[a]



Entry	**1**/R	**2**/PhI(III)	**4** (%)[b]
1	**1a**/TIPS	**2a**/PhI(OH)OTs	(**3a** 87%)[c]
2	**1a**	**2a**	**4a** 97%
3	**1b**/TBDMS	**2a**	**4a** 83%
4	**1c**/TBDPS	**2a**	**4a** 65%
5	**1d**/TMS	**2a**	–[d]
6	**1e**/H	**2a**	–[d]
7	**1a**	**2b**/PhI(OAc)$_2$,	**4a** 22%
8	**1a**	**2c**/PhI(OCOCF$_3$)$_2$	**4a** 96%
9	**1a**	**2d**/PhIO	**4a** 32%
10[e]	**1a**	**2a**	**4a** 35%
11[f]	**1a**	**2a**	**4b** 86%
12[g]	**1a**	**2a**	**4c** 83%

[a] All reactions were performed using substrate **1** (1.2 equiv.) and hypervalent iodine reagent **2** (1 equiv.) in 2,2,2-trifluoroethanol at room temperature for 24 hours. The reaction mixture was evaporated and then TfOH (1.5 equiv.) was added to the reaction mixture in acetonitrile solution and stirred at 0 °C for 2 hours. [b] Yields of isolated products. [c] No TfOH added in the reaction mixture and isolated as **3a** (R = TIPS; L = OTs). [d] Complex mixture. [e] TfOH (1.5 equiv.) was added from the beginning. [f] *p*-TsOH·H$_2$O (3.0 equiv.) was used instead of TfOH and stirred for 24 hours. [g] KBr (10.0 equiv.) was added to the reaction mixture and stirred for 2 hours.

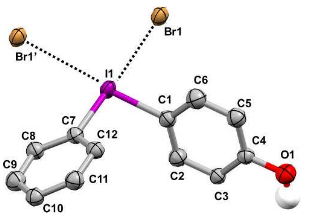
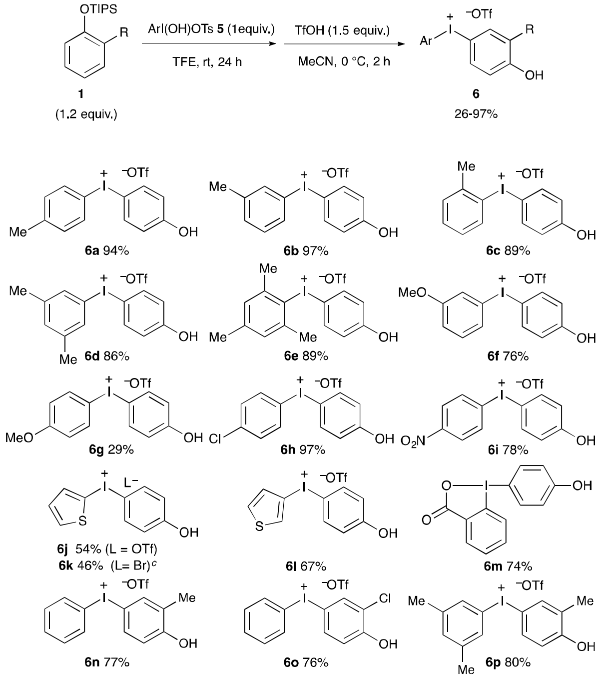


Figure 1. X-ray crystal structure of compound **4c**. All non-oxygen hydrogen atoms were removed for clarity. Ellipsoids drawn to the 50% probability level. Selected bond lengths and angles: I(1)-C(1) 2.094(13); I(1)-C(7) 2.137(11); I(1)-Br(1) 3.277(2); O(1)-C(4) 1.379(15); I(1)-Br(1') 3.280(1); C(1)-I(1)-C(7) 92.7(4); C(1)-I(1)-Br(1) 86.8(3); Br(1)-I(1)-Br(1') 89.9(1); Br(1')-I(1)-C(7) 90.5(2). Br(1') is located in the neighboring asymmetric unit (Figure S1).

According to the X-ray crystallography data, compound **4c** has a pseudo-square-planar coordination formed by two covalent iodine-carbon bonds and two close contact bromide anions, with one of the bromide anions in the neighboring asymmetric unit (Br1'). The I•••Br non-covalent intermolecular interaction distances were 3.277(2) and 3.280(1) with angles nearly 90° between the iodine atom and the four contacts (Figure S1). Additionally, a least-squares plane fit through I1, C1, C7, Br1 and Br1' resulted in a root-mean square deviation of 0.029 Å. The bond angles and bond distances of C–I–C are similar to the previously reported structure of diaryliodonium salts.[23] The bond distance between oxygen and carbon atoms falls within the typical range for a phenolic C–O bond length.

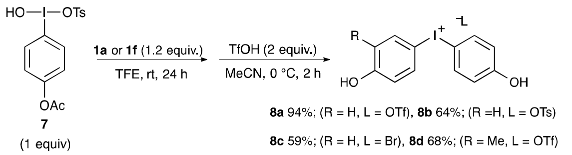
At the next step, we investigated the preparation of various substituted 4-hydroxyphenyl(aryl)iodonium triflates **6** from the corresponding [hydroxy(tosyloxy)iodo]arenes **5** under optimized conditions. In general, the reaction of reagents **5** bearing electron-withdrawing or electron-donating substituents in *para*-position with phenyl silyl ether **1a** gave the corresponding 4-hydroxyphenyl(aryl)iodonium triflates **6a-i** in moderate to good yields. In the reaction of sterically hindered *ortho*-substituted [hydroxy(tosyloxy)iodo]arenes **5c,e** with **1a**, the desired products **6c,e** were also obtained in good yields. However, the reaction of *para*-methoxy substituted reagent **5g** afforded product **6g** only in 29% yield probably because this reagent was a relatively unstable compound that decomposed during the reaction.[24] In the reaction of 2-thienyl **(5j)** or 3-thienyl **(5k)** Koser's type reagents with **1a**, the respective phenolic (thienyl)iodonium triflates **6j,k** were obtained in moderate yields. The bromide salt of **6k** was also prepared in 46% yield. The structures of phenolic (thienyl)iodonium salts **6j-l** were established by X-ray crystallography (see supporting information). Molecular arrangements in these structures are similar to the previously reported aryl(thienyl)iodonium salts.[25,26] The reaction of pseudocyclic Koser's reagent, 2-[hydroxy(tosyloxy)]iodobenzoic acid **5l**, with **1a** under the same conditions gave the corresponding 1-(4-hydroxyphenyl)-benziodoxole 6**m** in 74% yield. Compound **6m** was recrystallized from methanol and characterized by X-ray crystallography (see supporting information). The reaction of substituted aryl silyl ether **1f** or **1g** with **2a** or **3e** gave the corresponding phenolic iodonium triflates 6**n-p** in good yields.

Table 2. Preparation of 4-hydroxyphenyl(aryl)iodonium salts **6a-o**.[a,b]



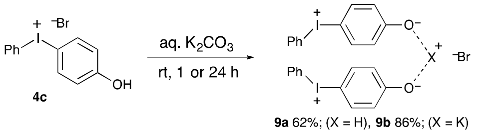
[a] All reactions were performed using substrate **1** (1.2 equiv.) and hypervalent iodine reagent **3** (1 equiv.) in 2,2,2-trifluoroethanol at room temperature for 24 hours. The reaction mixture was evaporated and then TfOH (1.5 equiv.) was added to the reaction mixture in acetonitrile solution and stirred at 0 °C for 2 hours. [b] Yields of isolated products. [c] KBr (10.0 equiv.) was added to the reaction mixture and stirred for 2 hours.

Furthermore, we investigated the preparation of symmetrical diphenolic iodonium salts, from 4-acetoxy[hydroxy(tosyloxy)iodo]benzene **7** with triisopropylsiloxybenzene **1a** (Scheme 1). The reaction of reagent **7** with **1a** under similar conditions afforded 4,4'-di(hydroxyphenyl)iodonium triflate **8a** in 94% yield. Other diphenolic iodonium derivatives, tosylate **8b** or bromide **8c**, could be produced in moderate yields via ligand exchange reaction. Under same conditions, asymmetrical compound **8d** was prepared in 68% from **7** with **1f**.



Scheme 1. Preparation of 4,4'-di(hydroxyphenyl)iodonium salts **8a-d**.

Phenolic (aryl)iodonium salts have the acidic hydroxyl group on the aromatic ring. Previously, several research groups reported that *ortho*-phenolic iodonium salts could be converted to the corresponding aryliodonium ylides under basic conditions.[19,21] Thus, we investigated the preparation of aryliodonim ylide from phenolic salt **4c** under basic conditions. The reaction of 4-hydroxyphenyl(phenyl)iodonium bromide **4c** with aqueous potassium carbonate at room temperature for 1 hour afforded the dimeric oxyphenyl(phenyl)iodonium ylide–HBr complex **9a** in 62% yield (Scheme 2). The reaction mixture was stirred for 24 hours to give the respective potassium bromide complex **9b** in 86% yield. However, reaction of triflate **4a**, tosylate **4b**, or symmetrical diphenolic iodonium salts **7** under similar conditions did not produce the respective product. The composition of compounds **9** was confirmed by elemental analysis. The solid structure of **9a** was established by X-ray crystallography (Figure 2).



Scheme 2. Preparation of dimeric oxyphenyl(phenyl)iodonium ylides **9a,b**.

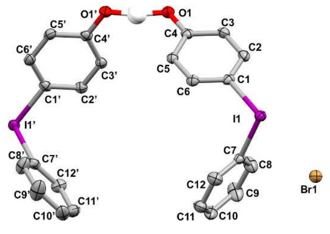
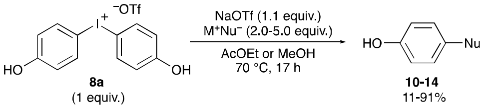


Figure 2. X-ray crystal structure of compound **9a**. Non-oxygen hydrogen atoms were removed for clarity. Ellipsoids drawn to the 50% probability level. Selected bond lengths and angles: I(1)-C(1) 2.108(2); I(1)-C(7) 2.106(2); I(1)-Br(1) 3.3076(3); O(1')-I(1) 2.760(2); C(1)-I(1)-C(7) 93.33(8); C(1)-I(1)-O(1') 85.93(6); C(7)-I(1)-Br(1) 81.84(6); O(1')-I(1)-Br(1) 98.71(3). O(1') is located in the neighboring asymmetric unit (Figure S6).

According to the X-ray crystallography data, compound **9a** has a pseudo-square-planar coordination formed by two covalent I–C bonds and two non-covalent intermolecular interactions: an I•••Br interation at 3.3076(3) Å atom and an I•••O interaction from a neighboring asymmetric unit at 2.760(2) Å (Figure S6). The C–I–C bond angle is close to the expected T-sharped geometry of diaryliodonium salts or iodonium zwitterion compounds.

Finally, we investigated the reactivity of a phenolic iodonium salt as a phenol transfer reagent. Previously, Olofsson and co-workers reported that the reaction of sodium nitrite with diaryliodonium salts under weakly basic conditions afforded the respective nitroarenes in good yields.[27] Thus, we tested the reactivity of the phenolic (aryl)iodonium salt as a phenol transfer reagent (Scheme 3). The reaction of sodium nitrite with **8a** in the presence of NaOTf gave *para*-nitrophenol **10** in 46% yield. Reactions of other anionic nucleophiles with **8a** under similar conditions gave respective compounds **11-14** in low to good yield. The obtained azide **11** is potentially useful as a click chemistry synthone.[28,29]



10 46%; (M^+Nu^- = $NaNO_2$), **11** 56%; (M^+Nu^- = NaN_3), **12** 47%; (M^+Nu^- = KSCN)

13 91%; (M^+Nu^- = KSeCN), **14** 11% (M^+Nu^- = $NaSO_2Ph$)

Scheme 3. Phenolation reactions of various nucleophiles using **8a**.

In summary, we have reported a practical one-pot synthetic procedure for the preparation of 4-hydroxyphenyl(aryl)iodonium salts from triisopropylsiloxybenzene using hydroxy(tosyloxy)iodoarenes in the presence of TfOH. Several solid-state structures of these products were established by X-ray crystallography. These phenolic diaryliodonium salts are potentially important precursors of novel hypervalent iodine(III) ylidic compounds. In particular, treatment of 4-hydroxyphenyl(phenyl)iodonium salts under basic conditions converts them to dimeric oxyphenyl(phenyl)iodonium ylidic salts. We have also demonstrated that the symmetrical bis(phenolic)iodonium salt is a potentially useful electrophilic phenol transfer reagent.

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Conflicts of interest

There are no conflicts to declare.

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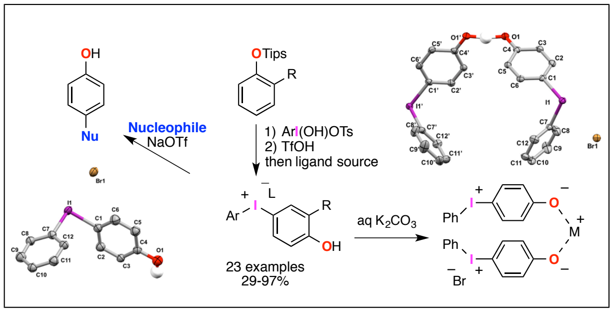

para-hydroxy- and oxy-phenyl(aryl)iodonium salts were prepared and structurally characterized by X-ray crystallography.