



One-pot synthesis of diaryliodonium salts from arenes and aryl iodides with Oxone–sulfuric acid

Natalia Soldatova¹, Pavel Postnikov¹, Olga Kukurina¹, Viktor V. Zhdankin^{1,2}, Akira Yoshimura¹, Thomas Wirth^{*3} and Mekhman S. Yusubov^{*1}

Full Research Paper

Open Access

Address:

¹The Tomsk Polytechnic University, 634050 Tomsk, Russia,
²Department of Chemistry and Biochemistry, University of Minnesota,
Duluth MN 55812, USA and ³School of Chemistry, Cardiff University,
Park Place, Main Building, Cardiff CF10 3AT, UK

Email:

Thomas Wirth^{*} - wirth@cf.ac.uk; Mekhman S. Yusubov^{*} -
yusubov@tpu.ru

* Corresponding author

Keywords:

diaryliodonium salts; iodine; iodonium; oxidation; Oxone

Beilstein J. Org. Chem. **2018**, *14*, 849–855.

doi:10.3762/bjoc.14.70

Received: 18 February 2018

Accepted: 27 March 2018

Published: 12 April 2018

This article is part of the Thematic Series "Hypervalent iodine chemistry in organic synthesis".

Associate Editor: D. Y.-K. Chen

© 2018 Soldatova et al.; licensee Beilstein-Institut.

License and terms: see end of document.

Abstract

A facile synthesis of diaryliodonium salts utilizing Oxone as versatile and cheap oxidant has been developed. This method shows wide applicability and can be used for the preparation of iodonium salts containing electron-donating or electron-withdrawing groups in good yields. In addition, this procedure can be applied to the preparation of symmetric iodonium salts directly from arenes via a one-pot iodination–oxidation sequence.

Introduction

Diaryliodonium salts, which are also known as diaryl- λ^3 -iodanes, are widely considered to be an important and practically useful class of hypervalent iodine compounds [1-4]. Diaryliodonium salts have found broad synthetic application as electrophilic arylating reagents in reactions with various nucleophiles including electron-rich carbon-centered species [5-7]. The unique arylating reactivity of diaryliodonium salts has been demonstrated in many metal-catalyzed and also metal-free transformations [8-15].

The development of novel synthetic approaches to diaryliodonium salts based on the use of inexpensive, commercially available oxidants is an important and challenging goal. A vast majority of existing procedures involve the interaction of electrophilic hypervalent iodine(III) species with suitable arenes through ligand exchange processes [16-20]. The reactive hypervalent iodine(III) species can be used as stable reagents or can be generated in situ [21-25]. In particular, Olofsson and co-workers reported procedures based on the in situ generation

of reactive λ^3 -iodane species directly from arenes, which was a significant achievement in this field [26–29]. However, these now well-established processes involve oxidations using *m*CPBA in the presence of strong organic acids [30–35]. Therefore, the development of new, convenient and inexpensive methods utilizing readily available and easy-to-handle oxidants still remains a highly desirable goal.

Previously, we have published the utilization of Oxone[®] (2KHSO₅·KHSO₄·K₂SO₄) as a readily available and effective oxidant for the preparation of various hypervalent iodine compounds [36–42]. Oxone is used as an efficient oxidant for the direct conversion of substituted 2-iodobenzoic acids to arylbenziodoxoles [37,38], 2-iodobiphenyl to dibenziodolium compounds [39], iodoarenes to iodylbenzenes and [bis(trifluoroacetoxy)iodo]arenes [40,41], and for the preparation of diaryliodonium trifluoroacetates and triflates [42]. Yakura also used Oxone[®] as an oxidant for the generation of iodine(III) species in the oxidation of phenols [43]. In the present work, we report the development of a reliable and convenient procedure for the preparation of diaryliodonium bromides using Oxone in the presence of sulfuric acid.

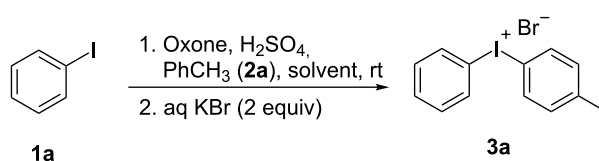
Results and Discussion

After having investigated previously described reaction conditions [37,38], initial optimization studies were performed using iodobenzene and toluene as reactants for the synthesis of diaryliodonium salt **3a** (Table 1). A simple mixing of the starting materials with finely ground Oxone and sulfuric acid leads to the formation of a very viscous and dark reaction mixture (Table 1, entry 1). Full conversion of the starting materials

could not be achieved even after 24 h stirring. The addition of aqueous KBr to the reaction mixture resulted in the formation of the desired bromide salt **3a** in 30% isolated yield. The addition of KBr is necessary as the high solubility of the diaryliodonium sulfonates does not allow their isolation from the reaction mixture. Dilution of the reaction mixture with dichloromethane did not increase the yield of the target product significantly (Table 1, entry 2). Moreover, we observed the formation of 4-iodobenzenesulfonic acid in both cases, probably due to the high concentration of sulfuric acid in the reaction mixture. Mixing dichloromethane with acetonitrile resulted in an increased yield of **3a** and a decreased amount of 4-iodobenzenesulfonic acid (Table 1, entry 3). When the reaction was carried out in pure acetonitrile, the iodonium salt **3a** was formed in 75% yield (Table 1, entry 4). The addition of 2 equivalents of Oxone increased the yield to 92% (Table 1, entry 5). Surprisingly, a smaller amount of toluene did not affect the yield (Table 1, entry 6). In order to avoid the formation of undesired 4-iodobenzenesulfonic acid, the reaction was carried out using smaller amounts of acid (Table 1, entries 7 and 8). That reaction proceeds smoothly with only 7.5 equivalents of sulfuric acid producing the target compound **3a** high yields. However, the use of 3.75 equivalents of sulfuric acid resulted in a significantly lower yield.

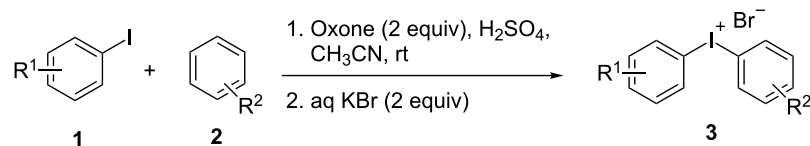
With the optimized procedure, the synthetic utility of this method using various aryl iodides and arenes was investigated (Table 2). Iodobenzene (**1a**) smoothly reacts with arenes containing electron-donating substituents to form the corresponding iodonium salts in high yields. 3-Trifluoromethyl iodobenzene (**1b**) exhibited higher reactivity, and iodonium salts have

Table 1: Optimization studies.^a



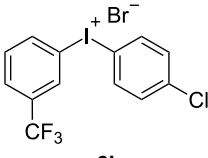
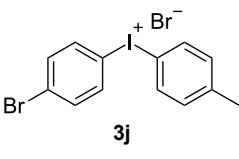
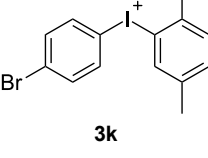
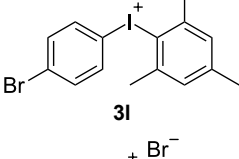
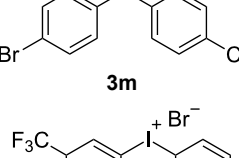
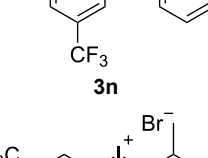
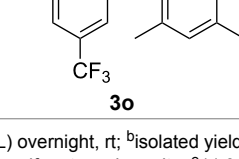
entry	solvent	toluene (equiv)	Oxone (equiv)	H ₂ SO ₄ (equiv)	yield ^b (%)
1	–	2.8	1.3	15	30 ^c
2	CH ₂ Cl ₂	2.8	1.3	15	40 ^c
3	CH ₂ Cl ₂ /MeCN	2.8	1.3	15	60 ^c
4	MeCN	2.8	1.3	15	75 ^c
5	MeCN	2.8	2	15	92 ^c
6	MeCN	1.2	2	15	88 ^c
7	MeCN	1.2	2	7.5	86
8	MeCN	1.2	2	3.75	53

^aReaction conditions: PhI (1 mmol), overnight, rt; ^bisolated yield; ^caccording to NMR data product contains up to 10% of (4-tolyl)phenyliodonium 4-iodobenzenesulfonate as an impurity.

Table 2: Synthesis of diaryliodonium bromides.^a

R ¹ (1)	R ² (2)	product 3	yield ^b (%)
R ¹ = H (1a)	R ² = Me (2a)		86 ^c
R ¹ = H (1a)	R ² = H (2b)		74 ^{d,e,f}
R ¹ = H (1a)	R ² = 1,4-Me ₂ (2c)		75
R ¹ = H (1a)	R ² = 1,3,5-Me ₃ (2d)		75
R ¹ = 3-CF ₃ (1b)	R ² = H (2b)		85 ^{e,f}
R ¹ = 3-CF ₃ (1b)	R ² = Me (2a)		76 ^c
R ¹ = 3-CF ₃ (1b)	R ² = 1,4-Me ₂ (2c)		95
R ¹ = 3-CF ₃ (1b)	R ² = 1,3,5-Me ₃ (2d)		92

Table 2: Synthesis of diaryliodonium bromides.^a (continued)

R ¹ = 3-CF ₃ (1b)	R ² = Cl (2e)		51 ^{g,h}
R ¹ = 4-Br (1c)	R ² = Me (2a)		70 ^c
R ¹ = 4-Br (1c)	R ² = 1,4-Me ₂ (2c)		32
R ¹ = 4-Br (1c)	R ² = 1,3,5-Me ₃ (2d)		71
R ¹ = 4-Br (1c)	R ² = Cl (2e)		34 ^{g,h}
R ¹ = 3,5-(CF ₃) ₂ (1d)	R ² = H (2b)		35 ^{e,f}
R ¹ = 3,5-(CF ₃) ₂ (1d)	R ² = 1,3,5-Me ₃ (2d)		62

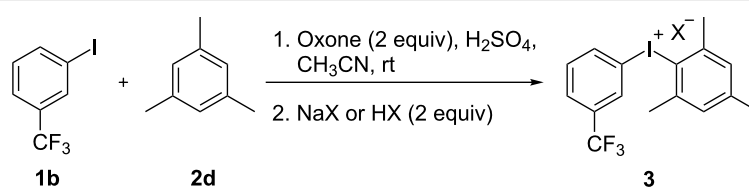
^aReaction conditions: **1** (1 mmol), **2** (1.1 mmol), H₂SO₄ (7.5 mmol), MeCN (2 mL) overnight, rt; ^bisolated yield; ^c1.2 mmol of **2a** was used; ^daccording to NMR data product contains an up to 1.5% of diphenyliodonium 4-iodobenzenesulfonate as impurity; ^e11.3 mmol of H₂SO₄ was used; ^f1.3 mmol of **2b** was used; ^g15 mmol of H₂SO₄ was used; ^h1.5 mmol of **2e** was used.

been isolated in higher yields. Moreover, iodoarene **1b** reacted with the moderately electron-poor chlorobenzene (**2e**) forming iodonium salt **3i** in 51% yield. In contrast, 4-bromoiodobenzene (**1c**) was less reactive and afforded iodonium salts **3j–m** in lower yields. Similar reactions of 3,5-bis(trifluoromethyl)iodobenzene (**1d**) with benzene and mesitylene formed the corresponding iodonium salts **3n** and **3o** in moderate yields.

With electron-deficient arenes **2** such as chlorobenzene (**2e**) and benzene, an excess of sulfuric acid and arene was used to

improve the yields. Subsequently it was shown that the addition of aqueous potassium bromide can be modified and other counter anions can be introduced to prepare different diaryliodonium salts. This has been demonstrated in the preparation of diaryliodonium salts using 1-iodo-3-trifluoromethylbenzene (**1b**) and mesitylene (**2d**) as model substrates (Table 3).

The yield of the salts **3h** and **3p–s** do not depend on the nature of the anion and its source. Small differences in yield can be explained by different solubility of salts in aceto-

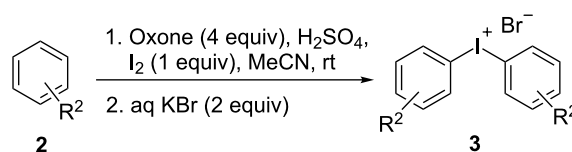
Table 3: Preparation of diaryliodonium salts with different anions.^a

NaX / HX	product	yield ^b (%)
NaBr	3h	92
TsOH	3p	82
TfOH	3q	89
NaBF ₄	3r	81
NaPF ₆	3s	80

^aReaction conditions: **1b** (1 mmol), **2d** (1.1 mmol), Oxone (1 mmol), H₂SO₄ (7.5 mmol), MeCN (2 mL), NaX or HX (2 mmol) overnight, rt; ^bisolated yield.

nitrile/water. Diaryliodonium bromides were isolated in higher yields because of the low solubility of these products (Table 3).

Finally, a one-step procedure for the preparation of symmetric iodonium salts directly from arenes via an in situ iodination was developed (Table 4). Arenes **2b–e** can be transformed to the

Table 4: Preparation of symmetric iodonium salts via a one-step iodination–oxidation procedure.^a

R ² (2)	product 3	yield ^b (%)
R ² = H (2b)		84 ^{c,d}
R ² = 1,4-Me ₂ (2c)		80
R ² = 1,3,5-Me ₃ (2d)		77
R ² = Cl (2e)		40 ^e

^aReaction conditions: ArH (2.2 mmol), Oxone (2 mmol), H₂SO₄ (7.5 mmol), MeCN (2 mL) overnight, rt; ^bisolated yield; ^caccording to NMR data the product contains up to 1.5% of diphenyliodonium 4-iodobenzenesulfonate as impurity; ^d11.3 mmol of H₂SO₄ and 2.6 mmol of **2b** were used; ^e15 mmol of H₂SO₄ and 3.0 mmol of **2e** were used.

symmetric iodonium salts **3b** and **3t–v** by the reaction with iodine, Oxone, and sulfuric acid. The attempted synthesis of the symmetric iodonium salt using toluene as substrate led to a regioisomeric mixture of products due to the low regioselectivity of iodination.

This procedure allowed the synthesis of iodonium salts with arenes containing electron-donating groups. Unfortunately, electron-poor arenes exhibited a lower reactivity and bis-(4-chlorophenyl)iodonium bromide have been isolated in only 40% yield. Nevertheless, the developed procedure is characterized by important advantages, such as simplicity, the use of inexpensive and available reagents, and typically good yields of iodonium salts. It is a versatile addition to the methodology toolbox for the preparation of diaryliodonium salts.

Conclusion

In conclusion, a new facile protocol for the preparation of diaryliodonium salts using cheap and readily available Oxone as an oxidant in the presence of sulfuric acid has been developed. The procedure allows the synthesis of a wide range of iodonium salts containing electron-donating and electron-withdrawing substituents. Particularly attractive is the possibility of the one-pot synthesis of symmetric bis-aryliodonium salts directly from arenes via an iodination–oxidation sequence.

Supporting Information

Supporting Information File 1

Experimental details and NMR spectra.

[<https://www.beilstein-journals.org/bjoc/content/supplementary/1860-5397-14-70-S1.pdf>]

Acknowledgements

This work was supported by the Russian Foundation for Basic Research (RFBR-mol_nr 17-33-50111), the Tomsk Polytechnic University Competitiveness Enhancement Program and the Royal Society (IE160304). We thank the EPSRC National Mass Spectrometry Facility, Swansea, for mass spectrometric data.

ORCID® IDs

Pavel Postnikov - <http://orcid.org/0000-0001-9713-1290>

Olga Kukurina - <http://orcid.org/0000-0001-6017-5628>

Viktor V. Zhdankin - <http://orcid.org/0000-0002-0315-8861>

Akira Yoshimura - <http://orcid.org/0000-0002-2577-397X>

Thomas Wirth - <http://orcid.org/0000-0002-8990-0667>

Mekhman S. Yusubov - <http://orcid.org/0000-0001-9233-1824>

References

1. Yusubov, M. S.; Maskaev, A. V.; Zhdankin, V. V. *ARKIVOC* **2011**, i, 370–409. doi:10.3998/ark.5550190.0012.107
2. Zhdankin, V. V. *Hypervalent Iodine Chemistry*; Wiley: Chichester, 2014.
3. Yoshimura, A.; Zhdankin, V. V. *Chem. Rev.* **2016**, *116*, 3328–3435. doi:10.1021/acs.chemrev.5b00547
4. Wirth, T., Ed. *Hypervalent Iodine Chemistry in Topics in Current Chemistry*; Springer: Berlin, 2016; Vol. 373.
5. Merritt, E. A.; Olofsson, B. *Angew. Chem., Int. Ed.* **2009**, *48*, 9052–9070. doi:10.1002/anie.200904689
6. Aradi, K.; Tóth, B. L.; Tolnai, G. L.; Novák, Z. *Synlett* **2016**, *27*, 1456–1485. doi:10.1055/s-0035-1561369
7. Fañanás-Mastral, M. *Synthesis* **2017**, *49*, 1905–1930. doi:10.1055/s-0036-1589483
8. Gonda, Z.; Novák, Z. *Chem. – Eur. J.* **2015**, *21*, 16801–16806. doi:10.1002/chem.201502995
9. Dey, C.; Lindstedt, E.; Olofsson, B. *Org. Lett.* **2015**, *17*, 4554–4557. doi:10.1021/acs.orglett.5b02270
10. Tinnis, F.; Stridfeldt, E.; Lundberg, H.; Adolfsson, H.; Olofsson, B. *Org. Lett.* **2015**, *17*, 2688–2691. doi:10.1021/acs.orglett.5b01079
11. Cahard, E.; Male, H. P. J.; Tissot, M.; Gaunt, M. J. *J. Am. Chem. Soc.* **2015**, *137*, 7986–7989. doi:10.1021/jacs.5b03937
12. Modha, S. G.; Greaney, M. F. *J. Am. Chem. Soc.* **2015**, *137*, 1416–1419. doi:10.1021/ja5124754
13. Beaud, R.; Phipps, R. J.; Gaunt, M. J. *J. Am. Chem. Soc.* **2016**, *138*, 13183–13186. doi:10.1021/jacs.6b09334
14. Yin, K.; Zhang, R. *Org. Lett.* **2017**, *19*, 1530–1533. doi:10.1021/acs.orglett.7b00310
15. Seidl, T. L.; Stuart, D. R. *J. Org. Chem.* **2017**, *82*, 11765–11771. doi:10.1021/acs.joc.7b01599
16. Margida, A. J.; Koser, G. F. *J. Org. Chem.* **1984**, *49*, 3643–3646. doi:10.1021/jo00193a039
17. Kitamura, T.; Matsuyuki, J.-i.; Nagata, K.; Furuki, R.; Taniguchi, H. *Synthesis* **1992**, 945–946. doi:10.1055/s-1992-26272
18. Kitamura, T.; Matsuyuki, J.-i.; Taniguchi, H. *Synthesis* **1994**, 147–148. doi:10.1055/s-1994-25423
19. Pike, V. W.; Butt, F.; Shah, A.; Widdowson, D. A. *J. Chem. Soc., Perkin Trans. 1* **1999**, 245–248. doi:10.1039/a809349k
20. Carroll, M. A.; Pike, V. W.; Widdowson, D. A. *Tetrahedron Lett.* **2000**, *41*, 5393–5396. doi:10.1016/S0040-4039(00)00861-3
21. Kaźmierczak, P.; Skulski, L. *Synthesis* **1995**, 1027–1032. doi:10.1055/s-1995-4045
22. Kryśka, A.; Skulski, L. *Molecules* **2001**, *6*, 875–880. doi:10.3390/61100875
23. Hossain, M. D.; Kitamura, T. *Tetrahedron* **2006**, *62*, 6955–6960. doi:10.1016/j.tet.2006.04.073
24. Hossain, M. D.; Ikegami, Y.; Kitamura, T. *J. Org. Chem.* **2006**, *71*, 9903–9905. doi:10.1021/jo061889q
25. Dohi, T.; Yamaoka, N.; Itani, I.; Kita, Y. *Aust. J. Chem.* **2011**, *64*, 529–535. doi:10.1071/CH11057
26. Bielawski, M.; Zhu, M.; Olofsson, B. *Adv. Synth. Catal.* **2007**, *349*, 2610–2618. doi:10.1002/adsc.200700373
27. Bielawski, M.; Olofsson, B. *Chem. Commun.* **2007**, 2521–2523. doi:10.1039/b701864a
28. Bielawski, M.; Aili, D.; Olofsson, B. *J. Org. Chem.* **2008**, *73*, 4602–4607. doi:10.1021/jo8004974
29. Zhu, M.; Jalalian, N.; Olofsson, B. *Synlett* **2008**, 592–596. doi:10.1055/s-2008-1032050

30. Jalalian, N.; Olofsson, B. *Tetrahedron* **2010**, *66*, 5793–5800. doi:10.1016/j.tet.2010.05.004
31. Seidl, T. L.; Sundalam, S. K.; McCullough, B.; Stuart, D. R. *J. Org. Chem.* **2016**, *81*, 1998–2009. doi:10.1021/acs.joc.5b02833
32. Lindstedt, E.; Reitti, M.; Olofsson, B. *J. Org. Chem.* **2017**, *82*, 11909–11914. doi:10.1021/acs.joc.7b01652
33. Carreras, V.; Sandtorv, A. H.; Stuart, D. R. *J. Org. Chem.* **2017**, *82*, 1279–1284. doi:10.1021/acs.joc.6b02811
34. Gemoets, H. P. L.; Laudadio, G.; Verstraete, K.; Hessel, V.; Noël, T. *Angew. Chem., Int. Ed.* **2017**, *56*, 7161–7165. doi:10.1002/anie.201703369
35. Laudadio, G.; Gemoets, H. P. L.; Hessel, V.; Noël, T. *J. Org. Chem.* **2017**, *82*, 11735–11741. doi:10.1021/acs.joc.7b01346
36. Frigerio, M.; Santagostino, M.; Sputore, S. *J. Org. Chem.* **1999**, *64*, 4537–4538. doi:10.1021/jo9824596
37. Yusubov, M. S.; Yusubova, R. Y.; Nemykin, V. N.; Zhdankin, V. V. *J. Org. Chem.* **2013**, *78*, 3767–3773. doi:10.1021/jo400212u
38. Yusubov, M. S.; Soldatova, N. S.; Postnikov, P. S.; Valiev, R. R.; Svitich, D. Y.; Yusubova, R. Y.; Yoshimura, A.; Wirth, T.; Zhdankin, V. V. *Eur. J. Org. Chem.* **2018**, 640–647. doi:10.1002/ejoc.201701595
39. Postnikov, P. S.; Guseynikova, O. A.; Yusubov, M. S.; Yoshimura, A.; Nemykin, V. N.; Zhdankin, V. V. *J. Org. Chem.* **2015**, *80*, 5783–5788. doi:10.1021/acs.joc.5b00741
40. Zagulyaeva, A. A.; Yusubov, M. S.; Zhdankin, V. V. *J. Org. Chem.* **2010**, *75*, 2119–2122. doi:10.1021/jo902733f
41. Soldatova, N.; Postnikov, P.; Troyan, A. A.; Yoshimura, A.; Yusubov, M. S.; Zhdankin, V. V. *Tetrahedron Lett.* **2016**, *57*, 4254–4256. doi:10.1016/j.tetlet.2016.08.038
42. Soldatova, N. S.; Postnikov, P. S.; Kukurina, O. S.; Zhdankin, V. V.; Yoshimura, A.; Wirth, T.; Yusubov, M. S. *ChemistryOpen* **2017**, *6*, 18–20. doi:10.1002/open.201600129
43. Yakura, T.; Omoto, M.; Yamauchi, Y.; Tian, Y.; Ozono, A. *Tetrahedron* **2010**, *66*, 5833–5840. doi:10.1016/j.tet.2010.04.124

License and Terms

This is an Open Access article under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

The license is subject to the *Beilstein Journal of Organic Chemistry* terms and conditions: (<https://www.beilstein-journals.org/bjoc>)

The definitive version of this article is the electronic one which can be found at:
[doi:10.3762/bjoc.14.70](https://doi.org/10.3762/bjoc.14.70)