Diarylation of N- and O-nucleophiles through a metal-free cascade reaction

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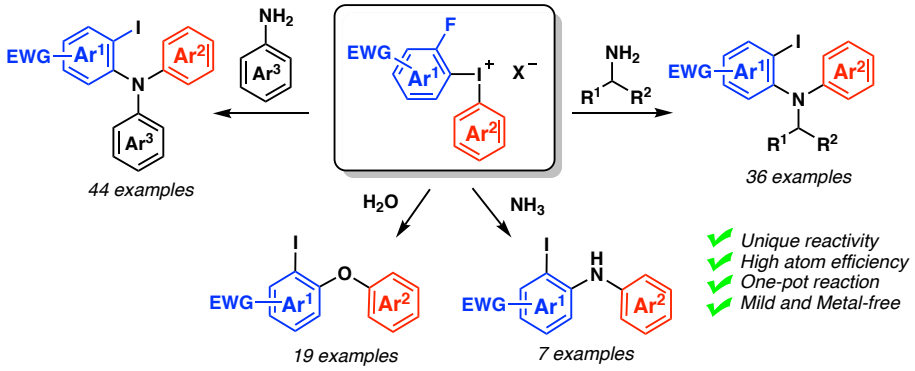
Abstract



The arylation of heteroatom nucleophiles is a central strategy to reach diarylated compounds that are key building blocks in agrochemicals, materials and pharmaceuticals. Nucleophilic aromatic substitution is a classical tool for such arylations, and hypervalent iodine-mediated arylations are modern alternatives to achieve a wider scope of products. Herein, we combine the benefits of those strategies to enable an atom-efficient and transition metal-free functionalization of N- and O-nucleophiles with two structurally different aryl groups, to provide di- and triarylamines and diaryl ethers in one single step (> 100 examples). The core of this strategy is the unique reactivity discovered with certain fluorinated diaryliodonium salts, which unveils novel reaction pathways in hypervalent iodine chemistry. The method is suitable for aliphatic amines, anilines, ammonia and even water and tolerates a wide variety of functional and protecting groups. Furthermore, the retained iodine substituent is easily accessible for derivatization of the products.

N- and O-arylated structural motifs are key building blocks in agrochemicals, materials and pharmaceuticals.[1-3] The arylation of heteroatom nucleophiles with an electrophilic arylation reagent is a central strategy to reach diarylated compound classes, such as diaryl ethers and diarylamines. Despite considerable progress in method development, the synthesis of highly functionalized di- or tri-arylated products is frequently a challenging endeavor, and methods for simultaneous introduction of two structurally different aryl groups are lacking.

Monoarylation of heteroatom nucleophiles can be achieved through the industrially important nucleophilic aromatic substitution (S_NAr) methodology, although the requirement for either highly reactive reagents with strong electron-withdrawing groups (EWG), harsh reaction conditions with strong bases or elevated temperatures limits the scope considerably (Figure 1**a**).[4] Transition metal-catalyzed arylations using established Buchwald-Hartwig,[5] Chan-Evans-Lam[6] or Ullman cross-couplings[7] with aryl halides or arylboronic acids is the most reliable entry to a wide scope of aryl ethers and arylamines, although complex ligands or excess reagents are sometimes required. State-of-the-art methodology involves C–H aminations[8] employing transition metal-catalyzed and/or photocatalytic reaction conditions.[9]

The increasing interest for sustainable, transition metal-free transformations has spurred the development of hypervalent iodine-mediated arylations, primarily using diaryliodonium salts (Ar_2IX).[10-13] These are easily available, bench-stable and non-hazardous reagents that have proven to be efficient electrophilic arylation agents with a variety of O- and N-nucleophiles.[11, 14-19] While reactions with diaryliodonium salts often proceed under mild conditions without excess reagents, they suffer from the fundamental drawback of poor atom economy, due to the stoichiometric formation of iodoarene side product (Figure 1**b**). Although this disadvantage can be overcome with cyclic diaryliodonium salts or intramolecular aryl migrations in iodonium ylides or iodonium salts,[20-22] limited structural diversity can be achieved in this fashion.

Diarylations can be accomplished through repeated use of the methods described above, or by combination of a metal-catalyzed Ar_2IX arylation with a cross-coupling of the resulting iodoarene.[23, 24] The latter strategy is established with cyclic diaryliodonium salts, where the second arylation occurs intramolecularly,[23-29] and sequential diarylation with acyclic Ar_2IX was recently demonstrated in a tandem C- and N-arylation of indoles.[17, 30-32] However, the atom efficiency in such tandem reactions only increases from 10-20% to 30-40% due to the loss of the heavy iodine atom.[23, 24]

We envisioned that a combination of the atom-efficient S_NAr methodology with the broad scope and mild conditions of Ar_2IX arylations would overcome the limitations of current diarylation methodologies and avoid the intrinsic formation of iodoarene waste. We hence designed a novel diaryliodonium reagent, carrying both a leaving group and a strong EWG in addition to the highly

electron-withdrawing iodonium moiety, to evaluate the strategy (Figure 1**c**). We speculated that the unusual structure of the iodonium reagent might enable initial S_NAr over the usual ligand coupling (LC) pathway,[11, 33] and deliver a unique iodine(III) intermediate that could undergo a subsequent aryl transfer to yield a diarylated product with the iodine substituent retained.

In this article, we present the realization of this strategy, which enables an atom-efficient and metal-free functionalization of N- and O-nucleophiles with two different aryl groups in a single reaction (Figure 1**d**). Both aryl groups from the diaryliodonium salt are transferred to the nucleophile, with concomitant loss of the fluorine atom, through a unique pathway where the iodine(III) moiety and the EWG together activate the aryl group sufficiently to enable an S_NAr reaction under mild conditions. The diarylation of primary amines, ammonia and water delivers highly functionalized triarylamines, diarylamines and diaryl ethers, respectively, which can easily be further derivatized through the retained iodine substituent.

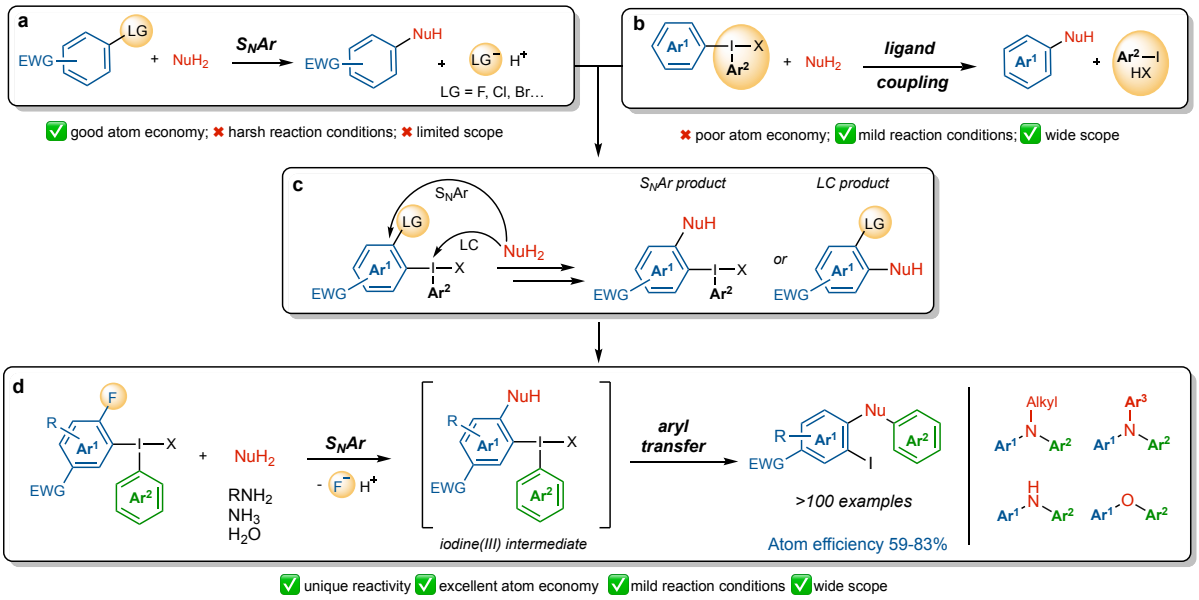


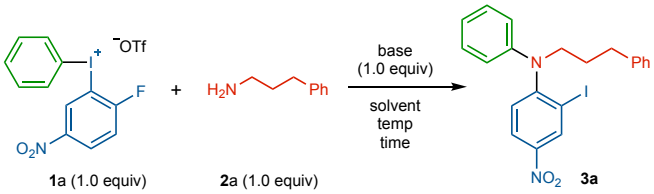
Fig. 1 |Transition meta-free mono- or di-arylation of heteroatom nucleophiles. a, Nucleophilic aromatic substitution. **b**, Arylation with diaryliodonium salt. **c**, Novel design to capture both types of arylation in the same reagent. **d**, This work: a one-pot, transition metal-free diarylation through an iodine(III) intermediate. EWG, electron-withdrawing group. LG, leaving group. Nu, nucleophile. X, trifluoromethylsulfonate (OTf), p-toluenesulfonate (OTs), or tetrafluoroborate (BF_4). LC, ligand coupling.

Results and Discussion

Diarylation of aliphatic amines. We selected diaryliodonium salt **1a** as model reagent, carrying a fluoride leaving group and a nitro group para to the fluoride to activate the S_NAr pathway (Table 1). To our delight, the desired reactivity was observed with aliphatic amine **2a** as nucleophile under our conditions for monoarylation of amines with diaryliodonium salts,[19] to yield diarylated product **3a**. An extensive screening of the reaction conditions was then performed (Table 1 and SI), and the

reaction proceeded well under basic conditions (entries 1-5). Sodium carbonate was used for further optimization since aryne formation can be avoided with weak inorganic bases.[34] A solvent screening showed that acetonitrile was comparable to toluene (entries 1, 6-10), with the benefit that reactions could be performed at significantly lower temperature in this solvent (entries 11-12). Interestingly, decent yields could be obtained even in water, showing the resilience of the method (entry 10). Further optimization at 50 °C revealed that the optimized conditions were MeCN, K_2CO_3 and 1.1 equiv. of **2a** at 50 °C (entry 13).

Table 1 | Selected optimization results for aliphatic amines.



1a (1.0 equiv) **2a** (1.0 equiv) **3a**

Entry	Solvent	Base	Temp (°C)	Time (h)	Yield (%)
1	toluene	Na_2CO_3	110	4	68
2	toluene	Et_3N	110	4	66
3	toluene	^{t}BuONa	110	4	42
4	toluene	NaOH	110	4	56
5	toluene	-	110	4	trace
6	MeCN	Na_2CO_3	110	4	70
7	THF	Na_2CO_3	110	4	24
8	CH_2Cl_2	Na_2CO_3	110	4	57
9	MeOH	Na_2CO_3	110	4	30
10	H_2O	Na_2CO_3	110	4	50
11	toluene	Na_2CO_3	90	4	55
12	MeCN	Na_2CO_3	90	4	73
13[a]	MeCN	K_2CO_3	50	7	92

The reactions were performed at 0.1 mmol scale with anhydrous and degassed solvent (0.2 M), isolated yields given.

[a] Degassed, non-dried MeCN and **2a** (1.1 equiv.) used.

To demonstrate the versatility of the reaction, a wide variety of primary aliphatic amines were evaluated as nucleophiles in the reaction with model iodonium salt **1a** (Figure 2**a**). Unhindered amines provided diarylamines **3a**–**3c** in good to excellent yields also in large scale reactions. While sterically demanding amines were less efficient nucleophiles (*cf* **3c** vs **3d**), the method displays high functional group tolerance in the nucleophilic coupling partner **2**, including allylic, benzylic and heterocyclic moieties **3e**–**3j**. For example, the monocyclic monoterpenoid geranyl amine, which is an important starting point for the synthesis of natural products, was diarylated to provide **3e** in 81%

yield. The compatibility with more complex molecules was exemplified by diarylation of the ester-protected derivatives of glycine and the pharmaceutical Baclofen to yield **3k** and **3l**.

A library of novel diaryliodonium salts **1** was efficiently synthesized in one-pot reactions from the corresponding fluoroiodoarene and arene to evaluate the scope of aryl rings **b** and **c**.[35-37] Figure 2**b** displays reactions where the green aryl group is substituted with a wide range of functional groups, ranging from the electron-withdrawing groups CF_3 and OCF_3 (**3m**, **3n**) over halides (**3o**, **3p**) to electron-donating groups (EDG), including OPh and NHAc (**3q**–**3t**). To our delight, the sterically demanding mesityl (Mes) and triisopropylphenyl (TRIP) groups could be introduced to provide **3u** and **3v** in good to excellent yields. Arylations with such aryl groups are highly challenging,[38, 39] and Mes and TRIP are indeed used as non-transferrable groups in metal-catalyzed reactions with diaryliodonium salts.[40, 41] Also ester and thienyl groups were introduced in this position (**3w**, **3x**).

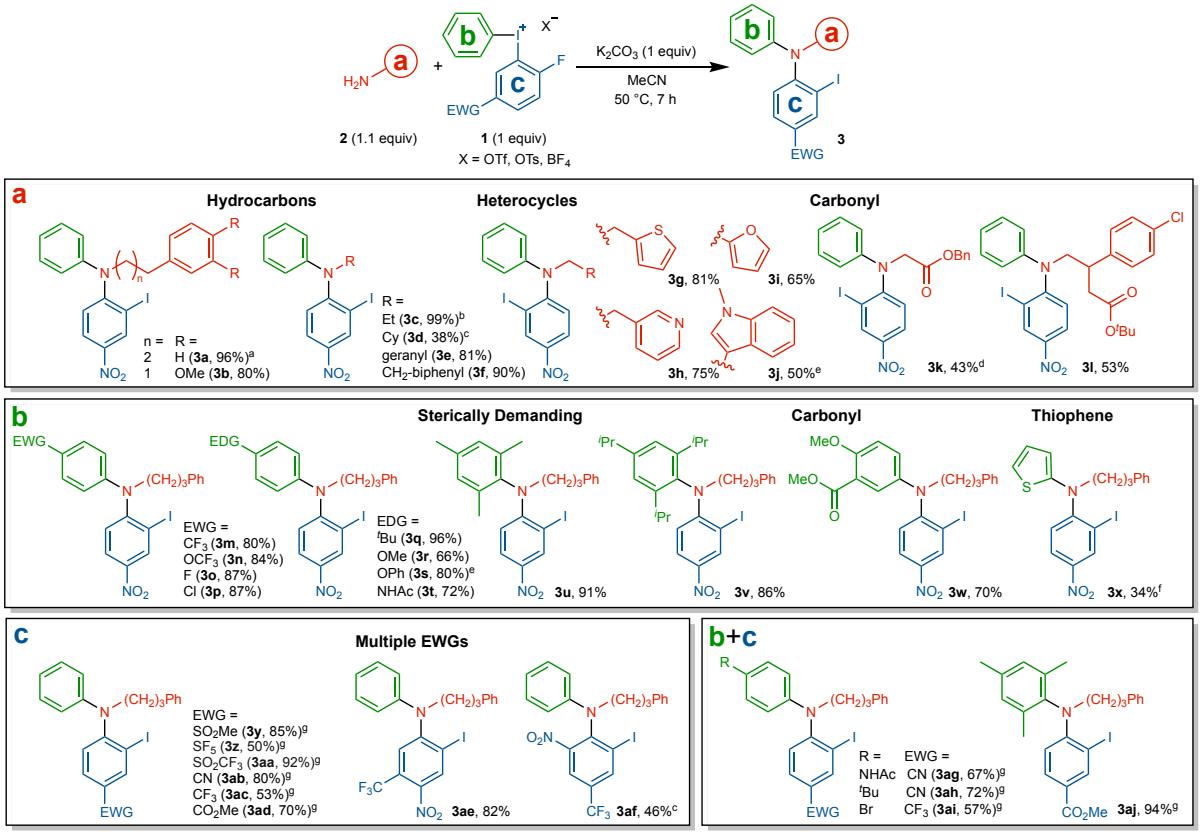


Fig. 2 | Reaction scope with diaryliodonium salts 1a–1y and aliphatic amines 2. Isolated yields. Sections **a**, **b**, **c** and **b+c** indicate which parts of products **3** that are varied. [a] 1 g scale of **1a.** [b] With $EtNH_2$ (5.0 equiv, 2.0 M in THF). [c] **2** (2.0 equiv) used. [d] **1a** (2.0 equiv) used. [e] In pyridine. [f] In toluene, 110 °C, 4 h. [g] At 90 °C, 15 h. Cy, cyclohexyl. EWG, electron-withdrawing group. EDG, electron-donating group.

Finally, structural variations of the aryl ring **c** were investigated (Figure 2**c**). While the amine nucleophiles **2** were mostly limited by sterics and the structure of aryl groups **b** could be varied widely, electronic properties proved to play an important role in variations of aryl group **c**. The NO_2 substituent could efficiently be exchanged for other strong EWG, such as SO_2Me and SO_2CF_3 (**3y**–

3aa). Reagents with the weaker electron-withdrawing groups SF_5, CN, CF_3 and esters were also sufficiently reactive, providing products **3ab**–**3ad**. Iodonium salts with multiple electron-withdrawing groups could also be employed (**3ae** and **3af**). As illustrated in Figure 2**b**+**c** (bottom right), both aryl groups of reagent **1** can be varied simultaneously (**3ag**–**3aj**).

Diarylation of anilines. We wanted to extend the methodology to the diarylation of aniline nucleophiles as an efficient route to triarylamines, which have industrial relevance in functional materials including solar cells.[3, 42] The synthesis of triarylamines can be challenging, in particular when three structurally different aryl groups are to be introduced. Only traces of the desired triarylamines were obtained with anilines under the standard reaction conditions above, which was not surprising as anilines are less nucleophilic[43] and the nitrogen in the triarylamine product is sterically hindered. To our satisfaction, an efficient synthesis of triarylamines **5** could be achieved upon carefully reoptimized reaction conditions.[44] The reaction proceeded well in pyridine at 40 °C, with two equivalents of aniline instead of external base, and $MgSO_4$ as an additive. Under these reaction conditions, aniline could be diarylated with salt **1a** to give triarylamine **5a** in 80% yield at 2 g scale (Figure 3**a**).

The substrate scope of anilines **5** was investigated with model salt **1a** (Figure 3**a**). As substituents on the aniline widely alter the reactivity,[43] the reaction yield strongly correlated with the electronic properties of **4**. Alkylated anilines generally reacted smoothly to deliver triarylamines **5b**–**5e** in high yields, while steric interference decreased the arylation yield of *o*-methylated aniline (**5f**). Conjugated substituents were also tolerated (**5g, 5h**). Anilines with strong EDG such as *p*-OMe, *p*-SMe and *p*-NHAc delivered high to excellent yields of triarylamines **5i**–**5o** , also in the presence of halide substituents.

The arylation of anilines bearing only EWG, e.g., *m*-OMe (**5p**), halides (**5q**–**5t**) and carboxylic acid (**5u**) was more demanding. To our delight, good yields with such substrates could be obtained by increasing the nucleophile loading (**5p, 5r**–**5t**) or introducing an electron-donating substituent (**5j**–**5m**, **5v**). With this method, additional bromo- and iodo-substituents can be easily introduced into the products, which would be difficult with transition metal-catalyzed methods. Pleasingly, anilines with complex substituents were efficiently diarylated, and the high functional group tolerance was demonstrated by synthesis of triarylamines containing an imide (**5w**), heterocycles (**5x**–**5z**), a large π-system (**5aa**), an amino acid (**5ab**), a peptide (**5ac**), and a steroid (**5ad**).

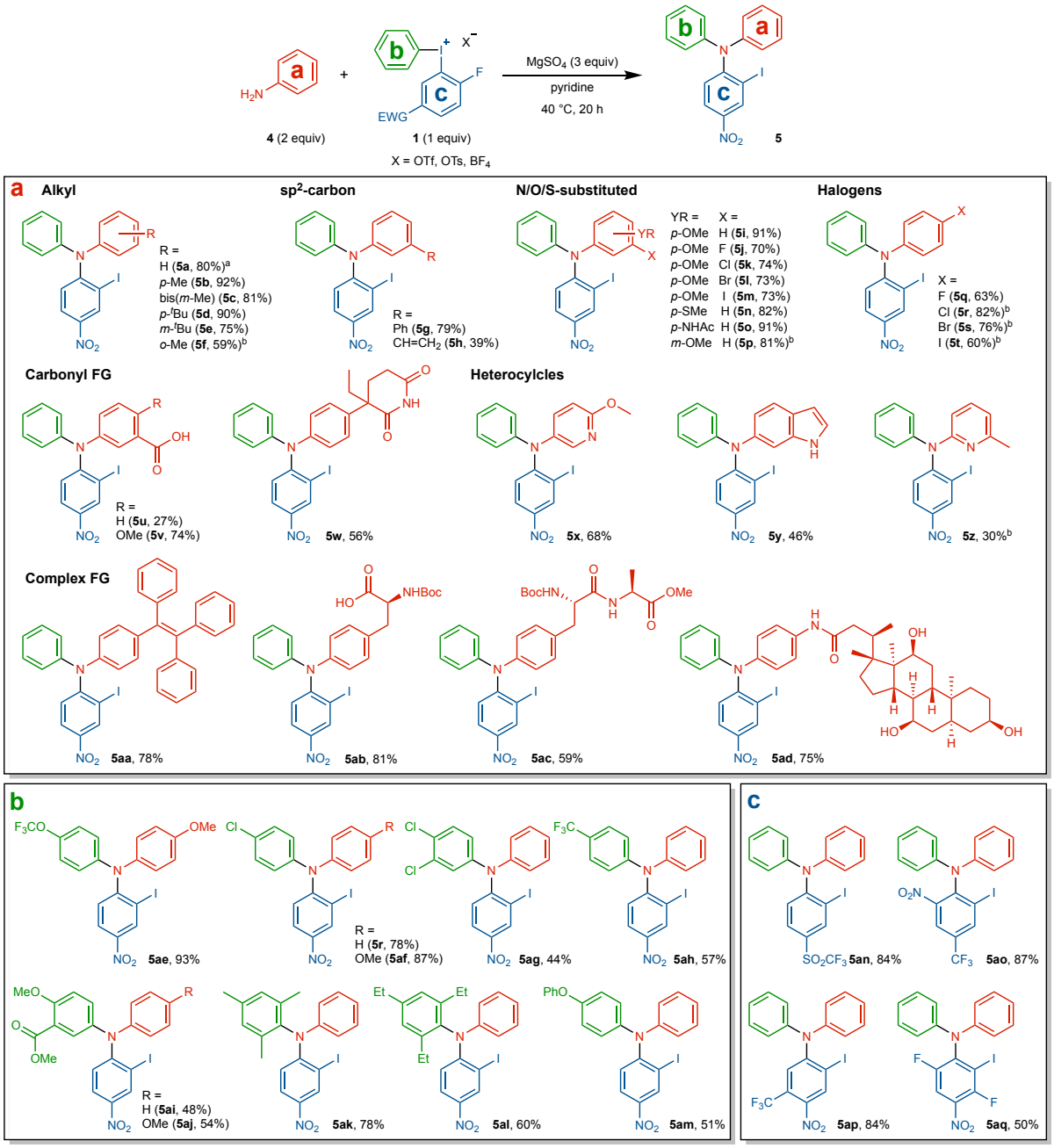


Fig. 3 | Reaction scope with anilines 4. Isolated yields**.** Sections **a**, **b** and **c** indicate which parts of products **5** that are varied. [a] 6 mmol (2 g) scale of **4a**. [b] Aniline **4** (5 equiv) used. Boc, *tert*-Butyloxycarbonyl.

The scope of diaryliodonium salts **1** was evaluated next, and aryl group **b** was modified with a wide variety of functional groups (Figure 3**b**). Both EWG (**5ae**–**5ah**) and EDG (**5ai**–**5am**) were well tolerated, and in this fashion, chloro-substituted triarylamine **5r** was formed in good yield without need for increased nucleophile amounts (*vide supra*). Astonishingly, the introduction of mesityl and triethylphenyl groups was feasible with anilines, resulting in the highly sterically encumbered triarylamines **5ak** and **5al**. Products with such excessively crowded nitrogen centers are very uncommon in literature.

The F-containing aryl group **c** proved to be less variable compared to reactions with aliphatic amines, and strong electron-withdrawing groups were required to compensate for the low nucleophilicity of the aniline (Figure 3**c**). The nitro group could be exchanged with, SO_2CF_3 (**5an**), whereas CF_3, CN, and CO_2Me gave no reactivity. Further structural diversity was enabled through insertion of additional EWG in other positions of group **c**, thus delivering products **5ao**–**5aq**. Interestingly, the reaction remained completely regioselective upon the addition of further fluorine atoms to this aryl ring, delivering **5aq** as the sole product with the other fluorine atoms untouched.

Diarylation of ammonia and water. Diarylamines and diaryl ethers are essential building blocks in agrochemicals, pharmaceuticals and optical materials.[1, 2] An extension of our methodology to nucleophiles such as ammonia and water would give access to these compound classes from very simple substrates in a highly atom efficient and straightforward manner. Simultaneous introduction of two different aryl groups to such nucleophiles is unprecedented.[45]

The synthesis of diaryl ethers from water proved to be efficient after minor changes to the reaction conditions (Figure 4). It was crucial to use precisely one equivalent of water to obtain high yields, and the conditions were further improved by changing the base to Cs_2CO_3 and the solvent to EtOAc.[44] Under these conditions, diaryl ether **6a** could be obtained in 97% yield. Analogous to our results with other nucleophiles, a variety of substituents were tolerated in diaryliodonium salts **1**. Diaryl ethers were formed in good to excellent yields from salts **1** with EDGs (**6b**–**6d**), EWGs, (**6e**–**6j**), sterically demanding groups (**6k**, **6l**) or a carbonyl group (**6m**) in the aryl ring **b** (Figure 4**b**, left). As depicted in Figure 4**c** (left), the EWG on the aryl ring **c** could be varied in a similar fashion to the reactions with aliphatic amines, giving products **6o**–**6s**. Transfer of electron-rich aryl groups can be challenging due to their reduced reactivity in metal-free ligand coupling pathways.[46] This trend was observed with some of the electron-rich salts, which were low yielding under the optimized conditions. Fortunately, this obstacle was overcome by raising the reaction temperature to 70 °C, which resulted in good to excellent yields of diaryl ethers **6b** and **6d**. Increased temperature was also beneficial in the synthesis of **6g**, **6i**, **6m**, **6o-6p** and **6s** to compensate for the lower reactivity of those iodonium salts.

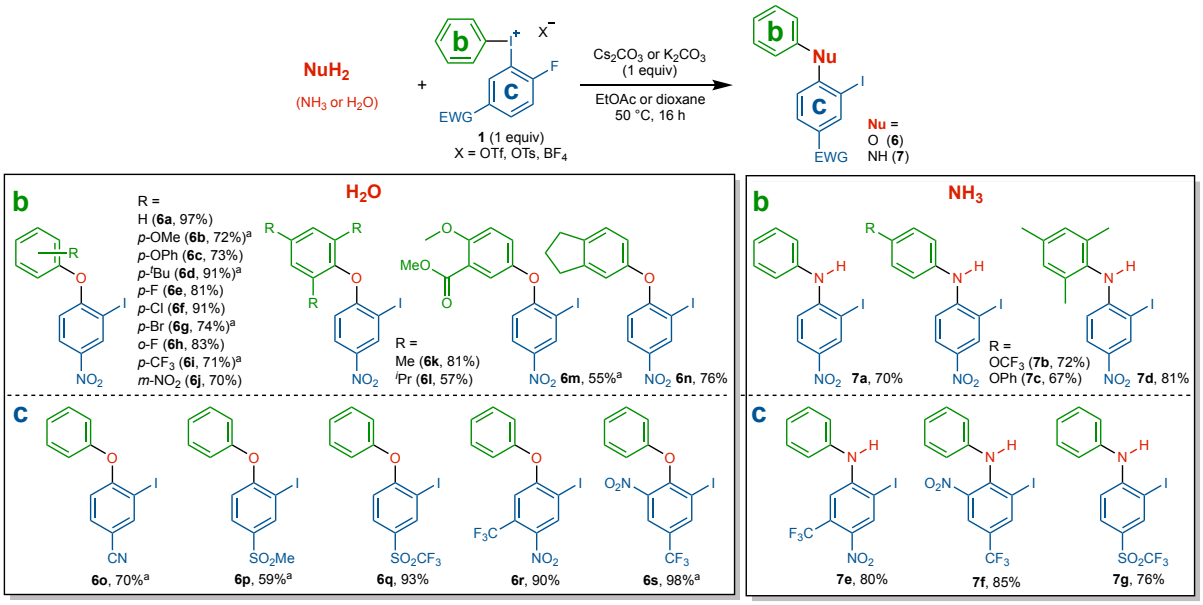


Fig. 4 | Reaction scope with NH_3 and H_2O. Isolated yields. Reactions with water (1 equiv) were performed in EtOAc with Cs_2CO_3 as base. Reactions with ammonia (5.0 equiv, 0.4 M in anhydrous dioxane) were performed with K_2CO_3 as base. Sections **b** and **c** indicate which parts of products **6** and **7** that are varied. [a] At 70 °C.

The synthesis of diarylamines from ammonia was challenging due to the efficient formation of diaryl ethers **6**, and reactions with aqueous ammonia delivered a complex product mixture. While initial reactions with NH_3 in dioxane solution delivered diaryl ether **6** as the main product, selective formation of product **7a** in 70% yield was achieved under strictly anhydrous conditions.[44] Figures 4**b**-**c** (right) illustrate a small scope evaluation, following the same trends as found for the other nucleophiles. The green aryl ring **b** could be modified with various substituents (**7b**–**7d**), whereas the F-containing aryl ring **c** needs a strong EWG for the reaction to proceed (**7e**–**7g**).

Mechanistic Studies. The mechanistic hypothesis depicted in Figure 5**a** involves initial S_NAr to give Meisenheimer complex **I** and the novel iodine(III) intermediate **II**, followed by an intramolecular aryl transfer to yield **III**. Such reactivity between diaryliodonium salts and nucleophiles is unreported, as literature reactions beyond ligand exchanges always result in reduction of the iodine(III) species to the corresponding iodine(I) compound.[11] In fact, metal-free arylations with diaryliodonium salts generally proceed through a ligand coupling pathway *via* T-shaped Nu-I intermediate **IV** (Figure 5**b**).[11, 33] The high reactivity in such transformations is explained by the electrophilicity of the iodine(III) atom and the potent leaving group ability of the hypervalent iodine functionality I^+–Ph.[47] Direct S_NAr attack on the carbon bound to the iodine(III) moiety has been investigated as a potential alternative pathway, but DFT calculations only favored S_NAr under special circumstances.[48]

A series of experiments was performed to distinguish the proposed pathway in Figure 5**a** from the alternative pathway shown in Figure 5**b**. The latter is based on well-established reactivity, where a chemoselective ligand coupling could result in arylated product **V** and fluoroiodoarene **VI**, followed

by an intermolecular S_NAr to form product **III**. To support the mechanism in Figure 5**a**, the reaction of water with iodonium salt **1a** was analyzed for possible intermediates under slightly modified reaction conditions, which enabled the isolation of the corresponding hydroxy-substituted iodonium salt **8** in 94% yield (Figure 5**c**). Importantly, this species could be converted to product **6a** in 53% yield upon heating. The second arylation step was evaluated through a crossover experiment to elucidate whether this step is intra- or inter-molecular. Indeed, a one-pot reaction with iodonium salts **1d** and **1q** only resulted in the products from intramolecular aryl transfer (Figure 5**d**).

The second pathway could be excluded as no S_NAr reactivity could be detected between the fluoroiodoarene **VI** (Figure 2**b**) and the phenylated derivative of **2a** (cf **V** in Figure 2**b**) under our reaction conditions.[44] Furthermore, the chemoselectivity in monoarylation of aliphatic amines was found to favor transfer of the electron-deficient aryl group when non-fluorinated diaryliodonium salts were used,[44] which means that **V** would not be the preferred product from **IV**.[19] Based on the experimental results, we conclude that the reaction proceeds through the pathway depicted in Figure 5**a**. To the best of our knowledge, such reactivity has never been reported with diaryliodonium salts.

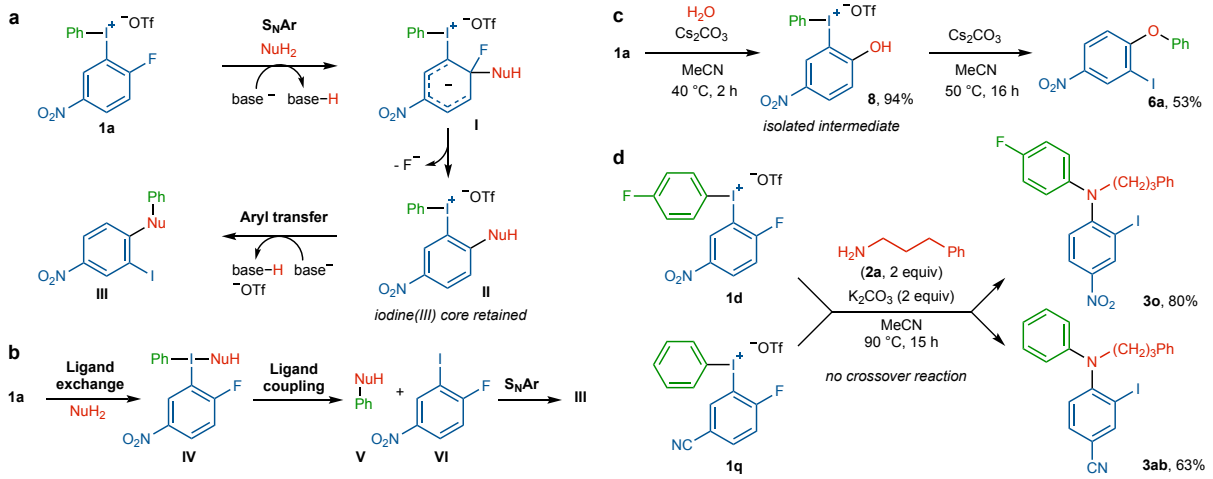


Fig. 5 | Mechanistic studies. a, Proposed mechanism for the diarylation. **b**, Alternative mechanistic pathway. **c**, Isolation of the S_NAr product. **d**, Cross-over experiment.

Product derivatizations. The diarylated products all contain an *ortho*-iodo substituent, which could provide an excellent opportunity for derivatization to further increase the structural complexity of the molecules. While aryl iodides generally display high reactivity in cross-coupling reactions, the considerable steric hindrance from the adjacent substituents could pose a problem in the derivatization. With inspiration from Wang and coworkers,[21] we performed a series of functionalizations of amines **3a** and **5a**. To our delight, amine **3a** was efficiently derivatized with Suzuki-Miyaura, Sonogashira, Heck, and Buchwald-Hartwig couplings to provide **9a**–**9d** in good to excellent yields (Figure 6). Furthermore, intramolecular CH-arylations of amines **3a** and **5a** delivered

carbazoles **9e**–**f**, and cross-couplings with triarylamine **5a** resulted in arylated products **9g**-**9h**. The results highlight that the *ortho*-iodide is easily accessible and that both the iodinated di- and triarylamines are viable building blocks for further transformations.

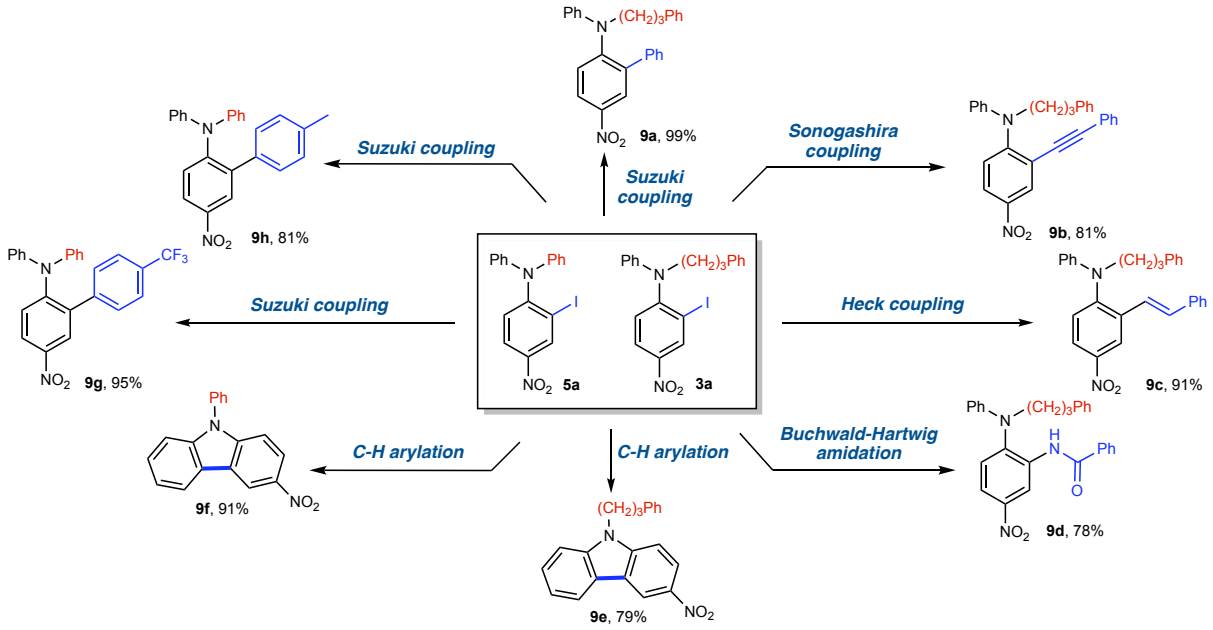


Fig. 6 | Functionalization of tertiary amines 3a and 5a. Isolated yields. **9a**: $Pd(PPh_3)_4$, K_2CO_3, DMF, 100 °C, 15 h. **9b**: $Pd(PPh_3)_4$, CuI, NEt_3, 100 °C, 15 h. **9c**: $Pd(OAc)_2$, PPh_3, NEt_3, 100 °C, 48 h. **9d**: CuI, DACH, K_3PO_4, dioxane, 100 °C, 48 h. **9e**: $Pd(OAc)_2$, $PCy_3{\cdot}HBF_4$, K_2CO_3, 130 °C, 15 h. **9f**: $Pd(OAc)_2$, K_2CO_3, DMSO, 100 °C, 15 h. **9g**: $Pd_2(dba)_3$, SPhos, Na_2CO_3, toluene/THF/H_2O (2:2:1), 90 °C, 16 h. **9h**: $Pd(PPh_3)_4$, K_2CO_3, DMF, 100 °C, 16 h. DACH = *trans*-1,2-diaminocyclohexane; Cy = cyclohexyl; dba = dibenzylideneacetone; SPhos = 2-dicyclohexylphosphino-2,6-dimethoxybiphenyl.

Conclusion

We have developed an efficient and transition metal-free diarylation cascade of various N-nucleophiles and water. The reaction relies on the unique reactivity of novel *ortho*-fluorinated diaryliodonium salts with an additional electron-withdrawing group. These electron-deficient substrates enable S_NAr-reactions to proceed under very mild reaction conditions, outcompeting the ligand coupling pathway that is normally observed with diaryliodonium salts. The intermediate S_NAr products retain the iodine(III) oxidation state, which has never been reported previously. An intramolecular aryl transfer completes the diarylations sequence, yielding the corresponding diarylamines, triarylamines or diaryl ethers with excellent atom efficiency. The mild reaction conditions enable the use of a large variety of different functional groups, resulting in impressive synthetic flexibility with up to three structurally different aryl groups. Furthermore, the simple reaction setup and avoidance of toxic or expensive reagents/catalysts grants utility of the methodology outside of advanced organic chemistry laboratories.

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Methods

Diarylation of aliphatic amines: Diaryliodonium salt **1** (0.1 mmol, 1.0 equiv) and K_2CO_3 (0.1 mmol, 1.0 equiv) were added to an oven-dried microwave vial. The vial was sealed with a cap and the atmosphere was exchanged to argon. Degassed MeCN (0.5 mL) was added, followed by subsequent addition of freshly distilled amine **2** (0.11 mmol, 1.1 equiv). The vial was transferred to a pre-heated oil bath, and the reaction was stirred at 50-90 °C for 7-16 hours depending on the reactivity of salt **1**. The crude mixture was directly subjected to the silica gel column chromatography, without prior workup, and eluted with pentane:Et_2O or pentane:EtOAc to yield tertiary diarylamine **3**.

Diarylation of anilines: Diaryliodonium salt **1** (0.1 mmol, 1.0 equiv) and $MgSO_4$ (0.3 mmol, 3.0 equiv) were added to a flask followed by addition of freshly distilled pyridine (0.25 – 0.5 ml). The flask was transferred to a preheated oil bath at 40 °C. The resulting suspension was vigorously stirred while the recently distilled or sublimated aniline **4** (0.2 mmol, 2.0 equiv) was added, and the mixture was

stirred for 20 h under air atmosphere. The solvent was removed *in vacuo*, and the residue was filtered through a plug of silica with pentane:Et_2O as eluent to yield triarylamine **5**.

Diarylation of water: Diaryliodonium salt **1** (0.2 mmol, 1.0 equiv) and Cs_2CO_3 (0.2 mmol, 1.0 equiv) were added to an oven-dried microwave vial. The vial was sealed with a cap and the atmosphere was exchanged to argon. EtOAc (0.5-1.0 mL) was added to the vial followed by subsequent addition of the water (0.2 mmol, 1.0 equiv). *NOTE:* Care should be taken to not add excess of water since this reduces the yield of the reaction significantly. The reaction mixture was transferred to a pre-heated oil bath, and stirred at 50 °C for 16 hours. The products were isolated by column chromatography with pentane:Et_2O or pentane:EtOAc as eluents, without prior work up, to yield diaryl ether **6**.

Diarylation of ammonia: Diaryliodonium salt **1** (0.16 mmol, 1.0 equiv) and K_2CO_3 (0.16 mmol, 1.0 equiv) were added to an oven-dried microwave vial. The vial was sealed with a cap and the atmosphere was exchanged to argon. Ammonia obtained as a 0.4 M solution in anhydrous dioxane (2.0 mL, 0.8 mmol, 5.0 equiv) was added to the vial with a syringe. The reaction mixture was transferred to a pre-heated oil bath where it was stirred at 50 °C for 16 hours. The crude mixture was directly subjected to silica gel column chromatography, without prior workup. The products were eluted with pentane:Et2O or pentane:EtOAc to yield diarylamine **7**.

Data availability

The data that support the findings of this study are available in the Supplementary Information (experimental procedures and characterization data).

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Author contributions

E.L. performed the optimization and scope of the aliphatic amines, ammonia and the diaryl ethers. D.B. performed the optimization and scope of the aromatic amines. G.K. participated in the initial studies with the aliphatic amines. N.P. discovered the reaction with aliphatic amines. B.O. designed and supervised the project. E.L., D.B. and B.O. participated in writing of the manuscript and SI.

Competing interests

The authors declare no competing interests.