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Metal-Free Iodine-Catalyzed Direct Arylthiation of Substituted Anilines with Thiols

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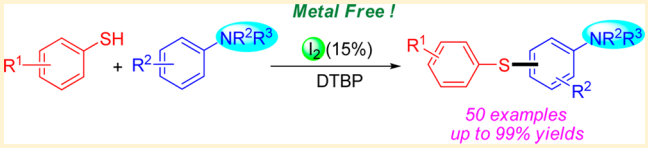
Supporting Information

ABSTRACT: Iodine-catalyzed direct arylthiation of substituted anilines for the synthesis of various diaryl sulfides has been developed under metal- and solvent-free conditions. The present method uses readily available thiols as the arylthiation reagents, and environmentally friendly and inexpensive I_2 as the catalyst. Importantly, no base or ligand was necessary. Such a simple, efficient, and economical transformation provides an attractive approach to various diaryl sulfides in good to excellent yields.



INTRODUCTION

Diaryl sulfides are ubiquitous in natural products, pharmacologically active compounds, and organic materials.[1] Therefore, the development of novel, practical, and highly efficient methods for the construction of diaryl sulfide motifs continues to stimulate a large number of research groups. The classical methods for the formation of diaryl sulfides traditionally involve two approaches. One is the transition-metal-catalyzed cross-couplings of disulfides or thiols with aryl halides, pseudo halides or arylboronic acids,[2] where transition-metal catalysts mainly focus on palladium,[3] copper,[4] iron,[5] nickel,[6] cobalt,[7] and rhodium[8] (Scheme 1, a). Another method typically relies on the coupling of sulfenyl chlorides with organozinc[9] or Grignard reagents[10] (Scheme 1, b). In recent years, seeking mild and selective methods for the direct functionalization of inert C−H bonds has received much more attention in organic chemistry.[11] Undoubtedly, direct arylthiation of C−H bonds is more economical and practical.[12] However, research surveys of this synthetic strategy for the preparation of diaryl sulfides are rather limited,[13] and in this respect, several examples using diaryl disulfides or 1-(substituted phenylthio)pyrrolidine-2,5-dione as the arylthiation reagents under Pd,[14] Cu,[15] and Fe[16] catalytic conditions have been reported (Scheme 1, c). Very recently, Fu and co-workers demonstrated an elegant work for the synthesis of diaryl sulfides via iron- or boron-catalyzed C−H arylthiation of phenols at room temperature.[17] Despite some great advantages, these reactions could encounter certain limitations, including readily unavailable precursors, harsh reaction conditions, and toxic metal salt catalysts. As a consequence, it remains a challenging, but very attractive, task to develop more efficient, economical, and practical synthesis methods for constructing the diaryl sulfide derivatives.

Recently, there are increasing demands in metal-free transformations owing to that trace-metal impurities might be avoided in the target molecules.[18] As a consequence, the development of a metal-free protocol for the C−S bond formation via direct aryl C−H bond functionalization appears desirable and synthetically attractive. On the other hand, molecular iodine as an inexpensive, green, and efficient reagent has been extensively used in organic transformations.[19] In 2012, Bolm and co-workers reported a facile procedure for the synthesis of thioethers via transition-metal-free thiolation of 1,3,4-oxadiazoles.[20] In 2013, Deng and co-workers described an iodine-promoted method for the synthesis of 2-arylsulfanylphenols under metal-free conditions.[21] In 2014, Huang' group reported the direct use of arylsulfonyl hydrazide as the arylthiation reagents for iodine-mediated thiolation of substituted naphthols and naphthylamines.[22] Herein, we report a

Scheme 1. Strategies for the Synthesis of Diaryl Sulfides

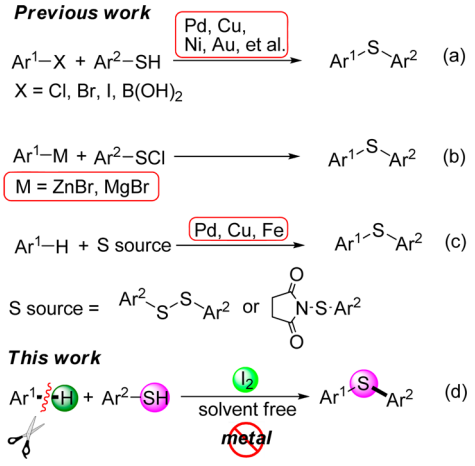


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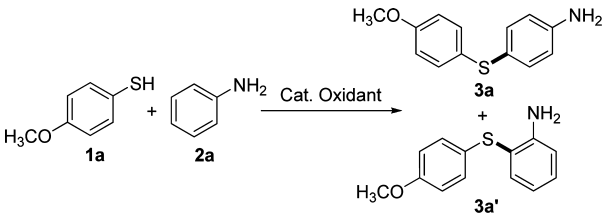
Table 1. I_2-Catalyzed Coupling Reaction of 4-Methoxybenzenethiol (1a) with Aniline (2a) Leading to 4-(4-Methoxyphenylthio)aniline (3a): Optimization of Conditions[a]



entry	catalyst	oxidant	temp. [°C]	yield (3a) [%][b]	yield (3a′) [%][b]
1	I_2	DTBP	90	51	10
2	$^nBu_4NI$	DTBP	90	trace	trace
3	KI	DTBP	90	trace	trace
4	NIS	DTBP	90	42	7
5	I_2	H_2O_2	90	47	9
6	I_2	TBHP	90	16	trace
7	I_2	DTBP	100	59	12
8	I_2	DTBP	110	66	14
9	**I_2**	**DTBP**	**120**	**75**	**11**
10	I_2	DTBP	120	68[c]	14
11	I_2	DTBP	120	56[d]	15
12	I_2	DTBP	130	75	10
13	I_2	DTBP	110	65[e]	11
14	none	DTBP	120	0	0

[a]Reaction conditions: 4-methoxybenzenethiol (**1a**) (0.5 mmol), aniline (**2a**) (1.0 mmol), catalyst (0.075 mmol), oxidant (2.5 mmol), reaction time (24 h) under nitrogen atmosphere. [b]Isolated yield. [c]In the presence of DTBP (3 equiv). [d]In the presence of DTBP (2 equiv). [e]In the presence of DTBP (8 equiv).

metal-free molecular iodine-catalyzed approach to diaryl sulfides containing amino groups from readily available thiols and substituted anilines under solvent free-conditions (Scheme 1, d).

RESULTS AND DISCUSSION

First, 4-methoxybenzenethiol (**1a**) and aniline (**2a**) were selected as the model substrates to optimize the reaction conditions, including the catalysts, oxidants, reaction temperatures, and the amounts of oxidant under a nitrogen atmosphere. As shown in Table 1, four catalysts, such as I_2, $^nBu_4NI$, KI, and NIS, were investigated at 90 °C by using 5.0 equiv of DTBP (di-*tert*-butyl peroxide) as the oxidant, and I_2 provided 4-(4-methoxyphenylthio)aniline (**3a**) in 51% yield with the corresponding *ortho*-substituted product (**3a′**) appearing in 10% yield (entries 1−4). We have compared different oxidants (compare entries 1, 5, and 6), and DTBP was superior to the other oxidants (entry 1). In addition, various temperatures were investigated (entries 7−9), and 120 °C was discovered to be more suitable for this transformation (entry 9). Elevating the reaction temperature did not enahance the yield (entry 12, Table 1). Besides that, different amounts of DTBP were used in the reactions (entries 9−11), and the 5 equiv of DTBP provided the highest yield (entry 9). Futhermore, 8 equiv of DTBP at 110 °C gave a 65% yield, indicating that the temperature is crucial for this reaction (entry 13, Table 1). Notably, no conversion was observed in the absence of iodine (entry 14). After the optimization process for catalysts, temperature, and oxidants, the various diaryl sulfide derivatives were synthesized under our standard conditions: 15 mol % I_2 as the catalyst, 5 equiv of DTBP as the oxidant under solvent-free conditions at 120 °C.

With the optimized conditions in hand, a variety of substituted thiols were employed for coupling with aniline derivatives (Tables 2−4). It was found that the moderate to excellent yields were obtained under the standard conditions. It should be pointed out that the reaction sites for the arythiation of aniline derivatives could depend on the position of the substituents of anilines. As shown in Table 2, the arythiation mainly occurred at the *para* site of the amino group in anilines, due to the *ortho* steric hindrance effects (Table 2, **3a**−**3d′**). When the amino group was substituted by other groups, such as methyl and amino, the arylthiation took place only at the *para* site of substituted amino groups in anilines (Table 2, **3e**−**3p**). Heteroaromatic thiol (i.e., thiophene-2-thiol) could be tolerated in this transformation, affording the desired products in 76% yield (Table 2, **3p**). Although aromatic thiols exhibited high reactivity, unfortunately, aliphatic ones were poor substrates (Table 2, **3n** and **3o**). Importantly, phenylhydrazine was a excellent substrate in the transformation and afforded the only *para*-substituted products (Table 2, **3k**−**3m**). Besides, the reaction could be performed only at the *para* site of amino when the amino *ortho* site was occupied by a substituent, as shown in Table 3. On the other hand, the reaction could occur at the amino *ortho* site when the amino *para* site was occupied (Table 4). For substituted thiols, the substrates containing electron-donating functional groups showed higher reactivity than the others (Table 2, **3a**, **3b**, **3k**, and **3m**; Table 3, **5a**, **5b**, **5f**, and **5g**; Table 4, **7c**, **7d**, **7e**, and **7f**). The catalytic efficiency was not affected by steric hindrance in thiols (Table 2, **3j** and **3l**; Table 3, **5d**; Table 4, **7b**, **7h**, and **7k**). Further, for substituted anilines, the substrates containing electron-donating groups showed higher reactivity than those with electron-withdrawing groups (Table 3, **5a**, **5e**, **5c**, and **5h**; Table 4, **7a**, **7g**, **7e**, and **7m**). Notablely, when naphthalen-2-amine was used as the substrate, the arylthiation reaction occurred on the *ortho*

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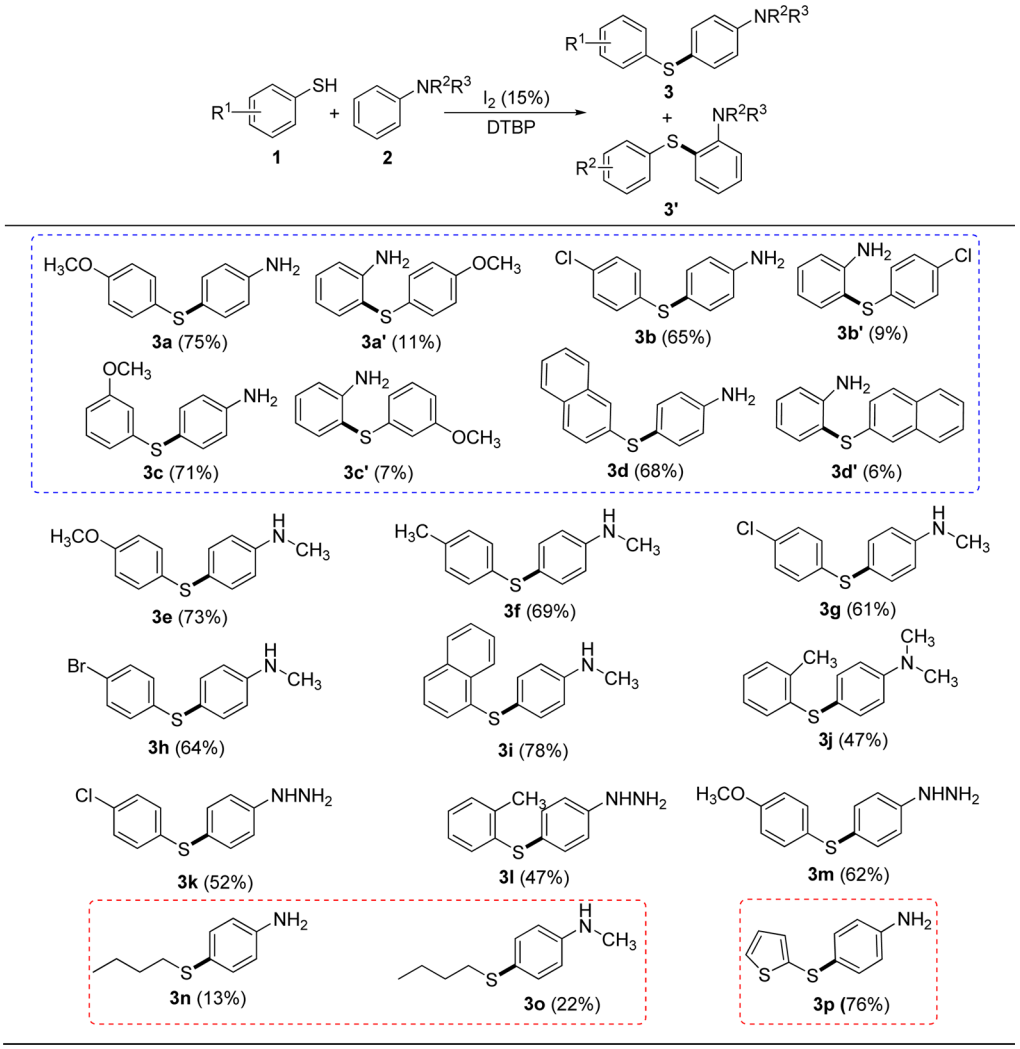
Table 2. I_2-Catalyzed Synthesis of Diaryl Sulfides from Phenylthiols (1) with Anilines (2)[a,b,c]



[a]Reaction conditions: substituted thiols (0.5 mmol), anilines (1.0 mmol), I_2 (0.075 mmol), DTBP (2.5 mmol). [b]Isolated yield. [c]Reaction time (24 h).

α-carbon of NH_2 due to the highest electron density of α-carbon (Table 4, **7o**−**7r**). In addition, the I_2-catalyzed reactions could tolerate some functional groups such as amino groups (Tables 2−4), hydrazine (products **3k**−**3m**), methyl ether (products **3m**, **5f**, and **7k**), C−Cl bond (products **3g**, **5g**, and **7g**), and C−Br bond (products **3h**, **5h**, and **7f**).

The arythiation reactions were investigated using different amounts of anilines. The results are shown in Scheme 2. Under the standard conditions, the control experiments with 4-chloroaniline **6b** alone gave the messy yields detected by TLC, indicating that 4-chloroaniline **6b** could be oxidized into other substances in this transformation [eq 1, Scheme 2]. Furthermore, different amounts of **6b** ranging from 0.5 to 3.0 mmol were applied in the reactions. The obtained yields increased as the **6b** amounts increased up to 1.5 mmol to reach the maximum [eq 2, Scheme 2]. 1.0 mmol of **6b** gave a slightly lower yield than 1.5 mmol of **6b**; however, it is economical and of practical application in the arythiation. Notably, the yields could decrease dramatically when the amount of **6b** was changed from 1.0 to 0.5 mmol. It is thereby thought that the aniline could be oxidized before it could react with the thiols under the given conditions, As a result, 2 equiv of aniline should be sufficient for this reaction, whereas the excess of the aniline might make up for the loss.

Further, we explored the synthetic applicability of the present method. The gram-scale reaction was performed between **1f** and **6b**, and the reaction afforded **7c** in 89% yield (Scheme 3). Therefore, this simple protocol could be served as an efficient and practical method for the synthesis of various diaryl sulfide derivatives containing amino groups.

Inspired by these excellent results above, we applied this I_2-catalyzed method to construct some potential medicinal agents. As shown in Scheme 4, coupling of 2,4-dichlorobenzenethiol (**1r**) with 3-chloroaniline (**8b**) provided **9a** in 92% yield under the standard conditions, which was used as inhibitors of LFA-1/CAM-1,[23] suggesting that the developed method would be applied in the medical industry.

In order to explore the possible mechanism of I_2-catalyzed direct C−H arylthiation of substituted anilines, several control experiments were performed, as shown in Scheme 5. When 4-methylbenzenethiol (**1f**) was added independently under the standard conditions, 1,2-di-*p*-tolyldisulfane (**10**) was obtained in 97% yield. Furthermore, treatment of 1,2-di-*p*-tolyldisulfane (**10**) with 4-chloroaniline (**6b**) under the standard conditions

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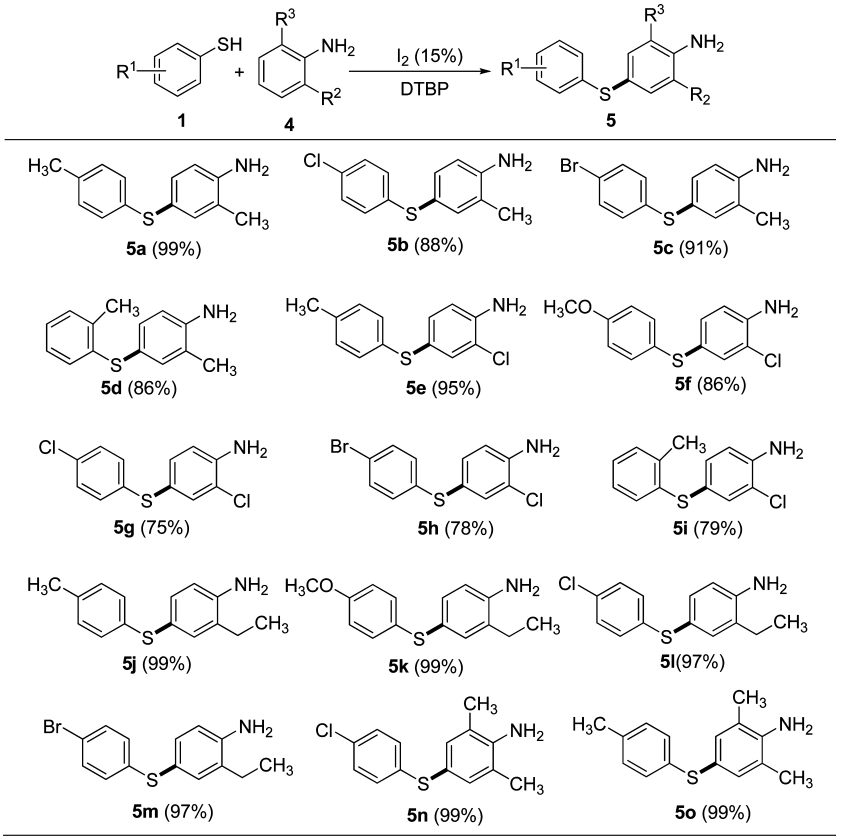
Table 3. I_2-Catalyzed Synthesis of Diaryl Sulfides from Coupling Phenylthiols (1) with *Ortho*-Substituted Anilines (4)[a,b,c]



[a]Reaction conditions: substituted thiols (0.5 mmol), *ortho*-substituted anilines (1.0 mmol), I_2 (0.075 mmol), DTBP (2.5 mmol). [b]Isolated yield. [c]Reaction time (24 h).

led to **7c** in 90% yield, indicating that 1,2-diphenyldisulfane might be intermediates for this transformation. Additionally, the reaction of 1,2-di-*p*-tolyldisulfane (**10**) with 4-chloroaniline (**6b**) was tested without iodine. As expected, no conversion was observed. To investigate the mechanism further, the reaction of 1,2-di-*p*-tolyldisulfane (**10**) with 4-chloroaniline (**6b**) was tested in the presence of 1 equiv of 2,2,6,6-tetramethylpiperidinyl-1-oxy (TEMPO), a classical radical inhibitor, the C−H arylthiation reaction was completely suppressed, indicating that the present reaction might involve a radical process.

On the basis of these preliminary results above and together with previous reports in the literature,[24] a possible mechanism for I_2-catalyzed synthesis of diaryl sulfide derivatives was proposed in Scheme 6. Initially, 4-methylbenzenethiol (**1f**) was oxidized to 1,2-di-*p*-tolyldisulfane (**10**) under the standard conditions. The reaction of **10** with I_2 formed 2 equiv of an electrophilic species *p*-MePhSI (**I**),[21] which attacked 4-chloroaniline (**6b**) to yield **II**. Then, the subsequent loss of HI resulted in the desirable product (**7c**). Finally, treatment of *t*-BuO· radical with HI led to the catalyst I_2. Further investigations on the more detailed mechanism are ongoing in our laboratory.

In conclusion, a novel and efficient method has been developed for the synthesis of diaryl sulfide derivatives containing amino groups via the I_2-catalyzed direct arylthiation of substituted anilines under solvent-free condtions. A series of diaryl sulfide derivatives could be efficiently obtained in moderate to excellent yields. This method can enjoy the following advantages: (a) commercially available and nontoxic molecular iodine as the catalyst; (b) solvent-free conditions; (c) no addition of any ligand, base, or additive; and (d) easy workup procedure. The developed synthesis approach would extend the scope of synthetic methods for diverse diaryl sulfides in the academic and industrial fields. Further investigation on the practical application of this method is in progress.

EXPERIMENTAL SECTION

General. All commercially available reagent grade chemicals were purchased from chemical suppliers and used as received without further purification. ^{1}H NMR and ^{13}C NMR spectra were recorded in $CDCl_3$ on a 400 MHz spectrometer with TMS as internal standard (400 MHz ^{1}H, 100 MHz ^{13}C) at room temperature, the chemical shifts (δ) were expressed in ppm, and *J* values were given in Hz. The following abbreviations are used to indicate the multiplicity: singlet (s), doublet (d), triplet (t), quartet (q) and multiplet (m). Column chromatography was performed on silica gel (200−300 mesh). Mass analyses and HRMS were obtained by ESI on a TOF mass analyzer.

General Experimental Procedures. A 25 mL Schlenk tube equipped with a magnetic stirring bar was charged with I_2 (19 mg, 0.075 mmol), substituted various thiols (**1**) (0.5 mmol), and anilines or phenylhydrazine (1.0 mmol). The tube was evacuated twice and backfilled with nitrogen, and DTBP (2.5 mmol) was added into the tube. The tube was sealed, and then the mixture was allowed to stir under a nitrogen atmosphere at 120 °C for 24 h. After completion of the reaction, the resulting solution was cooled down to room temperature, and the solvent was removed with the aid of a rotary evaporator. The desired product was obtained by column chromatography on silica gel using petroleum ether/ethyl acetate as eluent.

*4-(4-Methoxyphenylthio)aniline (**3a**).*[25] Compound **3a** was obtained in 75% yield (87 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (50:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.25 (d, 2H, *J* = 2.4 Hz), 7.23 (d, 2H, *J* = 2.4 Hz), 6.83

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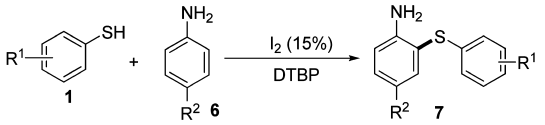
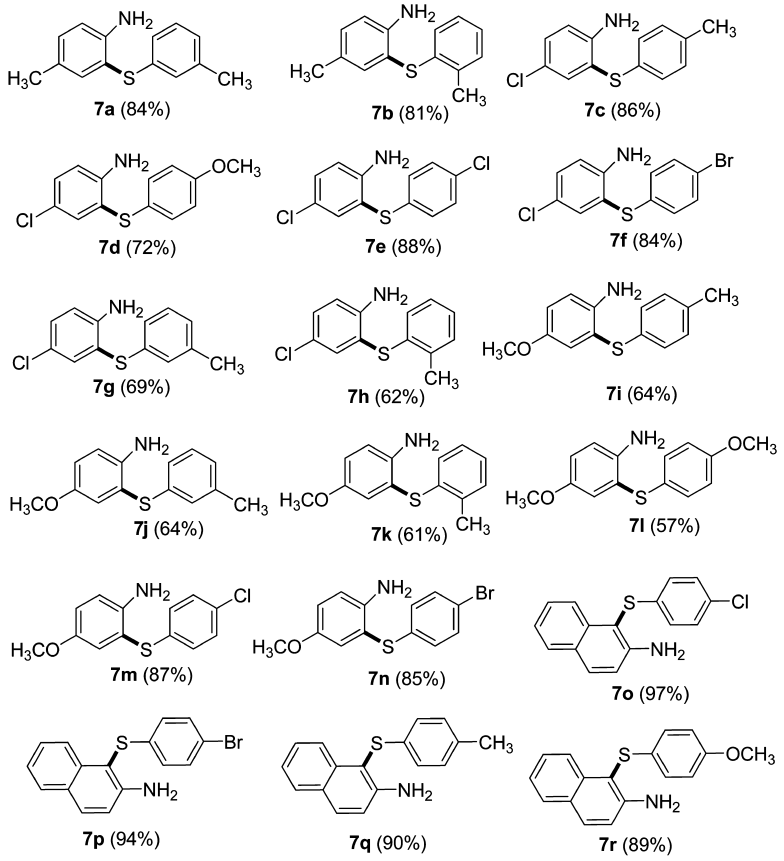
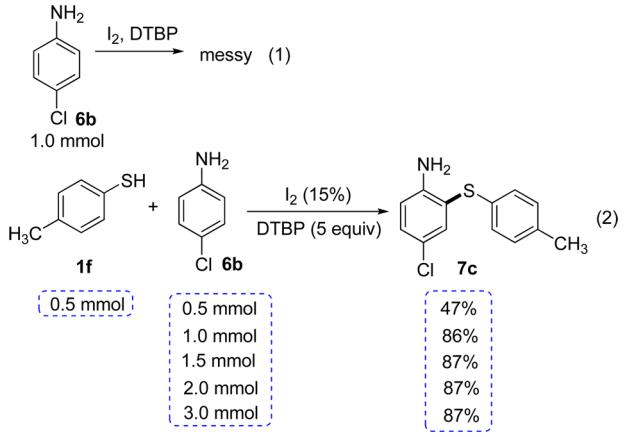
Table 4. I_2-Catalyzed Synthesis of Diaryl Sulfides from Coupling Phenylthiols (1) with *Para*-Substituted Anilines (6)[a,b,c]



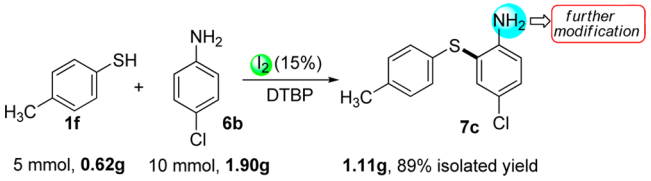


[a]Reaction conditions: substituted thiols (0.5 mmol), *para*-substituted anilines (1.0 mmol), I_2 (0.075 mmol), DTBP (2.5 mmol). [b]Isolated yield. [c]Reaction time (24 h).

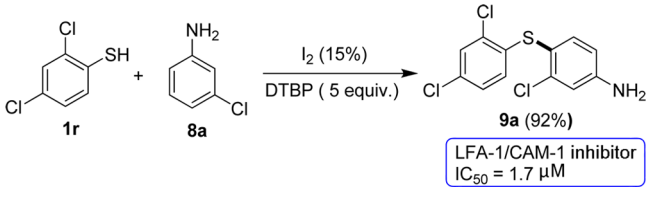
Scheme 2. Investigation of the Amount of Anilines in the Present Method



Scheme 3. Synthesis of 7c on Gram Scale



Scheme 4. Synthesis of 3-Chloro-4-(2,4-dichlorophenylthio)aniline (9a) under the Standard Conditions



(d, 2H, J = 8.0 Hz), 6.65 (d, 2H, J = 8.0 Hz), 3.80 (s, 3H), 3.75 (s, br, 2H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 158.5, 146.2, 133.9, 131.5, 128.9, 123.6, 115.8, 114.7, 55.4; HRMS m/z calcd. for $C_{13}H_{13}NOS$ [M + H]$^+$: 232.0796, found: 232.0785.

*2-(4-Methoxyphenylthio)aniline (**3a′**).*[26] Compound **3a′** was obtained in 11% yield (13 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (50:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.44 (d, 1H, J = 8.0 Hz), 7.21 (t, 1H, J = 8.0 Hz), 7.16

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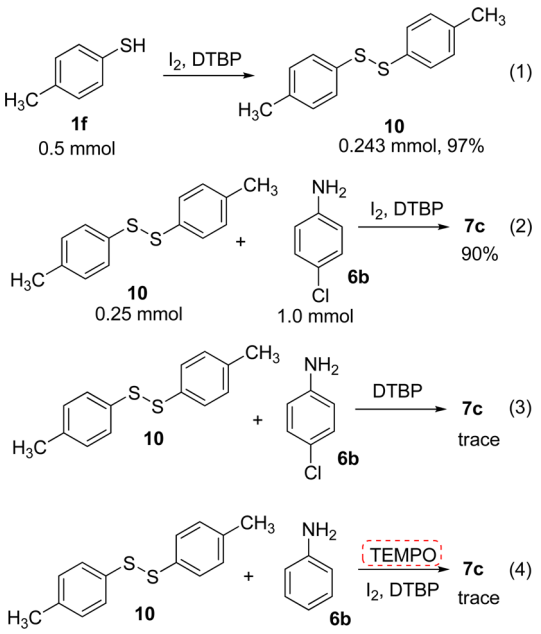
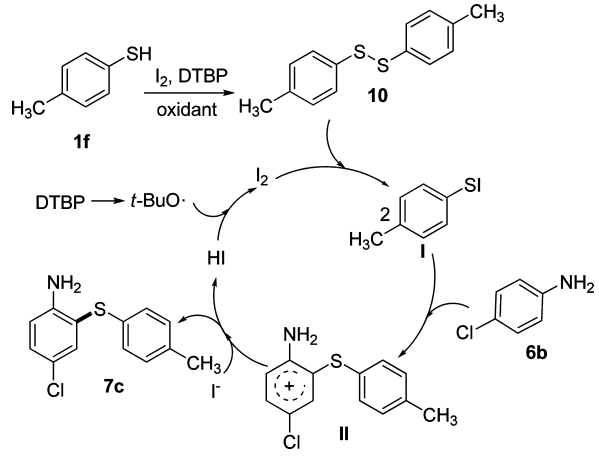
Scheme 5. Control Experiments



Scheme 6. A Proposed Mechanism for the Direct Transformation



(d, 2H, J = 8.0 Hz), 6.83 (d, 2H, J = 8.0 Hz), 6.79–6.74 (m, 2H), 4.29 (s, br, 2H), 3.79 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 158.4, 148.1, 136.3, 130.4, 129.7, 126.9, 118.7, 116.8, 115.4, 114.8, 55.4; HRMS m/z calcd. for $C_{13}H_{13}NOS$ $[M + H]^+$: 232.0796, found: 232.0785.

*4-(4-Chlorophenylthio)aniline (**3b**).*[27] Compound **3b** was obtained in 65% yield (77 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (50:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.32 (d, 2H, J = 8.0 Hz), 7.20 (d, 2H, J = 8.0 Hz), 7.06 (d, 2H, J = 8.0 Hz), 6.70 (d, 2H, J = 8.0 Hz), 3.87 (s, br, 2H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 158.5, 146.2, 133.9, 131.5, 128.9, 123.6, 115.8, 114.7; HRMS m/z calcd. for $C_{12}H_{10}ClNS$ $[M + H]^+$: 236.0301, found: 236.0312.

*2-(4-Chlorophenylthio)aniline (**3b′**).*[26] Compound **3b′** was obtained in 9% yield (11 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (50:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.47 (d, 2H, J = 8.0 Hz), 7.28 (t, 1H, J = 8.0 Hz), 7.21 (d, 2H, J = 8.0 Hz), 7.02 (d, 2H, J = 8.0 Hz), 6.83–6.77 (m, 2H), 4.32 (s, br, 2H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 148.8, 137.5, 135.5, 131.5, 131.3, 129.1, 127.7, 118.9, 115.5, 113.8; HRMS m/z calcd. for $C_{12}H_{10}ClNS$ $[M + H]^+$: 236.0301, found: 236.0312.

*4-(3-Methoxyphenylthio)aniline (**3c**).*[28] Compound **3c** was obtained in 71% yield (82 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (50:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.35 (d, 2H, J = 8.0 Hz), 7.15 (t, 1H, J = 8.0 Hz), 6.74–6.66 (m, 5H), 3.88 (s, br, 2H), 3.75 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 159.9, 147.2, 141.3, 136.4, 129.6, 119.9, 119.4, 115.9, 112.5, 110.8, 55.2; HRMS m/z calcd. for $C_{13}H_{13}NOS$ $[M + H]^+$: 232.0796, found: 232.0790.

*2-(3-Methoxyphenylthio)aniline (**3c′**).*[29] Compound **3c′** was obtained in 7% yield (8 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (50:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.43 (d, 1H, J = 8.0 Hz), 7.21 (t, 1H, J = 8.0 Hz), 7.16 (d, 2H, J = 8.0 Hz), 6.83 (d, 2H, J = 8.0 Hz), 6.79–6.74 (m, 2H), 4.29 (s, br, 2H), 3.79 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 158.4, 148.1, 136.3, 130.4, 129.7, 126.9, 118.7, 116.8, 115.4, 114.8, 55.4; HRMS m/z calcd. for $C_{13}H_{13}NOS$ $[M + H]^+$: 232.0796, found: 232.0790.

*4-(Naphthalen-2-ylthio)aniline (**3d**).*[30] Compound **3d** was obtained in 68% yield (86 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (50:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 8.45 (d, 1H, J = 8.0 Hz), 7.90 (d, 1H, J = 8.0 Hz), 7.43 (d, 1H, J = 8.0 Hz), 7.62–7.54 (m, 2H), 7.39–7.34 (m, 3H), 7.27 (d, 1H, J = 8.0 Hz), 6.69 (d, 2H, J = 8.0 Hz), 3.76 (s, br, 2H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 146.8, 136.3, 135.3, 133.9, 131.7, 128.5, 126.7, 126.6, 126.4, 126.3, 125.8, 124.7, 120.8, 116.1; HRMS m/z calcd. for $C_{16}H_{13}NS$ $[M + H]^+$: 252.0847, found: 252.0846.

*2-(Naphthalen-2-ylthio)aniline (**3d′**).*[26] Compound **3d′** was obtained in 6% yield (7 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (50:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 8.38 (d, 1H, J = 8.0 Hz), 7.89 (d, 1H, J = 8.0 Hz), 7.68 (d, 1H, J = 8.0 Hz), 7.63–7.49 (m, 2H), 7.50 (d, 1H, J = 8.0 Hz), 7.33–7.28 (m, 2H), 6.99 (d, 2H, J = 8.0 Hz), 6.86–6.80 (m, 2H), 4.30 (s, br, 2H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 148.7, 137.3, 133.9, 133.6, 131.1, 131.0, 128.6, 126.3, 126.2, 126.1, 125.9, 124.0, 123.7, 119.0, 115.5, 114.1; HRMS m/z calcd. for $C_{16}H_{13}NS$ $[M + H]^+$: 252.0847, found: 252.0846.

*4-(4-Methoxyphenylthio)-N-methylaniline (**3e**).* Compound **3e** was obtained in 73% yield (90 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.32 (d, 2H, J = 8.0 Hz), 7.24 (d, 2H, J = 8.0 Hz), 6.84 (d, 2H, J = 8.0 Hz), 6.59 (d, 2H, J = 8.0 Hz), 3.87 (s, br, 1H), 3.80 (s, 3H), 2.85 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 148.7, 137.3, 133.9, 133.6, 131.1, 131.0, 128.6, 126.3, 126.2, 126.0, 125.9, 124.0, 123.7, 119.0, 115.5, 114.1; HRMS m/z calcd. for $C_{14}H_{15}NOS$ $[M + H]^+$: 246.0953, found: 246.0961.

*N-Methyl-4-(p-tolylthio)aniline (**3f**).* Compound **3f** was obtained in 69% yield (79 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.36 (d, 2H, J = 8.0 Hz), 7.08 (d, 2H, J = 8.0 Hz), 7.06 (d, 2H, J = 8.0 Hz), 6.60 (d, 2H, J = 8.0 Hz), 3.91 (s, br, 1H), 2.88 (s, 3H), 2.31 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 149.5, 136.2, 135.7, 135.1, 129.6, 127.8, 119.5, 113.1, 30.6, 20.9; HRMS m/z calcd. for $C_{14}H_{15}NS$ $[M + H]^+$: 230.1003, found: 230.1011.

*4-(4-Chlorophenylthio)-N-methylaniline (**3g**).* Compound **3g** was obtained in 61% yield (76 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.37 (d, 2H, J = 8.0 Hz), 7.19 (d, 2H, J = 8.0 Hz), 7.05 (d, 2H, J = 8.0 Hz), 6.63 (d, 2H, J = 8.0 Hz), 3.96 (s, br, 1H), 2.89 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 150.0, 139.1, 136.5, 130.8, 128.8, 128.0, 117.3, 113.2, 30.5; HRMS m/z calcd. for $C_{13}H_{12}ClNS$ $[M + H]^+$: 250.0457, found: 250.0449.

*4-(4-Bromophenylthio)-N-methylaniline (**3h**).* Compound **3h** was obtained in 64% yield (94 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.37 (d, 2H, J = 8.0 Hz), 7.34 (d, 2H, J = 8.0 Hz), 6.99 (d, 2H, J = 8.0 Hz), 6.63 (d, 2H, J = 8.0 Hz), 3.98 (s, br, 1H), 2.88 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 150.0, 139.9, 136.6, 131.7, 128.2, 118.5, 117.4, 113.2, 30.5; HRMS m/z calcd. for $C_{13}H_{12}BrNS$ $[M + H]^+$: 293.9952, 295.9932, found: 293.9943, 295.9921.

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J. Org. Chem. 2015, 80, 6083–6092

*N-Methyl-4-(naphthalen-1-ylthio)aniline (**3i**).* Compound **3i** was obtained in 78% yield (104 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 8.43 (d, 1H, J = 8.0 Hz), 7.88 (d, 1H, J = 8.0 Hz), 7.69 (d, 1H, J = 8.0 Hz), 7.61−7.55 (d, 2H, J = 8.0 Hz), 7.40 (d, 2H, J = 8.0 Hz), 7.34 (t, 1H, J = 8.0 Hz), 7.18 (d, 1H, J = 8.0 Hz), 6.64 (d, 1H, J = 8.0 Hz), 3.90 (s, br, 1H), 2.87 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 149.6, 137.0, 135.8, 133.8, 131.4, 128.5, 126.3, 126.2, 126.1, 125.8, 125.7, 124.5, 118.5, 113.3, 30.6; HRMS m/z calcd. for $C_{17}H_{15}NS$ $[M + H]^+$: 266.1003, found: 266.1012.

*N,N-Dimethyl-4-(o-tolylthio)aniline (**3j**).* Compound **3j** was obtained in 47% yield (57 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.38 (d, 2H, J = 8.0 Hz), 7.17 (d, 1H, J = 8.0 Hz), 7.06−7.04 (m, 2H), 6.88−6.85 (m, 1H), 6.75 (d, 2H, J = 8.0 Hz), 3.08 (s, 6H), 2.42 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 150.5, 139.2, 136.0, 135.4, 129.9, 126.9, 126.3, 125.0, 117.4, 113.1, 40.4, 20.1; HRMS m/z calcd. for $C_{15}H_{17}NS$ $[M + H]^+$: 244.1160, found: 244.1151.

*(4-(4-Chlorophenylthio)phenyl)hydrazine (**3k**).* Compound **3k** was obtained in 52% yield (65 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.32 (d, 2H, J = 8.0 Hz), 7.20 (d, 2H, J = 8.0 Hz), 7.06 (d, 2H, J = 8.0 Hz), 6.70 (d, 2H, J = 8.0 Hz), 3.08 (s, br, 2H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 147.4, 138.5, 136.3, 131.0, 128.9, 128.4, 119.8, 115.9. HRMS m/z calcd. for $C_{12}H_{11}ClN_2S$ $[M + H]^+$: 251.0410, found: 251.0411.

*(4-(m-Tolylthio)phenyl)hydrazine (**3l**).* Compound **3l** was obtained in 47% yield (54 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.36 (d, 2H, J = 8.0 Hz), 7.18 (t, 1H, J = 8.0 Hz), 7.02 (s, 1H), 6.97 (d, 2H, J = 8.0 Hz), 6.70 (d, 2H, J = 8.0 Hz), 3.85 (s, br, 2H), 2.31 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 147.0, 139.4, 138.7, 136.1, 128.8, 128.0, 126.3, 124.5, 120.6, 115.9; HRMS m/z calcd. for $C_{13}H_{14}N_2S$ $[M + H]^+$: 231.0956, found: 231.0967.

*(4-(4-Methoxyphenylthio)phenyl)hydrazine (**3m**).* Compound **3m** was obtained in 62% yield (77 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.25−7.23 (m, 4H), 6.84 (d, 2H, J = 8.0 Hz), 6.65 (d, 2H, J = 8.0 Hz), 3.80 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 158.5, 146.2, 134.0, 131.5, 128.8, 123.5, 115.8, 114.6, 55.4; HRMS m/z calcd. for $C_{13}H_{14}N_2OS$ $[M + H]^+$: 247.0905, found: 247.0911.

*4-(Butylthio)aniline (**3n**).*[25] Compound **3n** was obtained in 13% yield (12 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.26 (d, 2H, J = 8.0 Hz), 6.64 (d, 2H, J = 8.0 Hz), 3.74 (s, br, 2H), 2.79 (t, 2H, J = 8.0 Hz), 1.57 (dt, 2H, J = 8.0 Hz), 1.42 (dt, 2H, J = 8.0 Hz), 0.91 (t, 3H, J = 8.0 Hz). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 145.7, 133.7, 123.9, 115.6, 36.1, 31.5, 21.8, 13.7; HRMS m/z calcd. for $C_{10}H_{15}NS$ $[M + H]^+$: 182.1003, found: 182.1012.

*4-(Butylthio)-N-methylaniline (**3o**).* Compound **3o** was obtained in 22% yield (22 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.30 (d, 2H, J = 8.0 Hz), 6.58 (d, 2H, J = 8.0 Hz), 3.78 (s, br, 1H), 2.85(s, 3H), 2.79 (t, 2H, J = 8.0 Hz), 1.57 (dt, 2H, J = 8.0 Hz), 1.42 (dt, 2H, J = 8.0 Hz), 0.93 (t, 3H, J = 8.0 Hz). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 148.7, 134.1, 122.0, 112.4, 36.5, 31.6, 30.7, 21.9, 13.7; HRMS m/z calcd. for $C_{11}H_{17}NS$ $[M + H]^+$: 196.1160, found: 196.1147.

*4-(Thiophen-2-ylthio)aniline (**3p**).* Compound **3p** was obtained in 79% yield (13 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.34 (d, 2H, J = 4.0 Hz), 7.24 (d, 2H, J = 8.0 Hz), 7.19 (d, 1H, J = 4.0 Hz), 7.00 (dd, 1H, J = 4.0 Hz), 6.63 (d, 2H, J = 8.0 Hz), 3.74 (s, br, 2H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 148.7, 134.1, 122.0, 112.4, 36.5, 31.6, 30.7, 21.9, 13.7; HRMS m/z calcd. for $C_{10}H_9NS_2$ $[M + H]^+$: 208.0255, found: 208.0261.

*2-Methyl-4-(p-tolylthio)aniline (**5a**).* Compound **5a** was obtained in 99% yield (114 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.25 (s, 1H), 7.22 (d, 1H, J = 8.0 Hz), 7.12 (d, 2H, J = 8.0 Hz), 7.08 (d, 2H, J = 8.0 Hz), 6.68 (d, 1H, J = 8.0 Hz), 3.75 (s, br, 2H), 2.35 (s, 3H), 2.17 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 145.1, 136.4, 135.9, 135.3, 133.2, 129.7, 128.1, 123.3, 121.2, 115.6, 21.0, 17.3; HRMS m/z calcd. for $C_{14}H_{15}NS$ $[M + H]^+$: 230.1003, found: 230.1017.

*4-(4-Chlorophenylthio)-2-methylaniline (**5b**).* Compound **5b** was obtained in 88% yield (110 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.25−7.19 (s, 1H), 7.07 (d, 2H, J = 8.0 Hz), 6.69 (d, 1H, J = 8.0 Hz), 3.80 (s, br, 2H), 2.18 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 145.7, 138.8, 137.1, 134.0, 130.9, 128.9, 128.3, 123.4, 119.4, 115.7, 17.3. HRMS m/z calcd. for $C_{13}H_{12}ClNS$ $[M + H]^+$: 250.0457, found: 250.0462.

*4-(4-Bromophenylthio)-2-methylaniline (**5c**).* Compound **5c** was obtained in 91% yield (134 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.34 (d, 2H, J = 8.0 Hz), 7.25 (s, 1H), 7.23 (d, 1H, J = 8.0 Hz), 7.00 (d, 2H, J = 8.0 Hz), 6.69 (d, 2H, J = 8.0 Hz), 3.81 (s, br, 2H), 2.18 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 145.8, 139.6, 137.2, 134.1, 131.8, 128.5, 123.5, 119.2, 118.7, 115.7, 17.3; HRMS m/z calcd. for $C_{13}H_{12}BrNS$ $[M + H]^+$: 293.9952, 295.9932, found: 293.9941, 295.9926.

*2-Methyl-4-(o-tolylthio)aniline (**5d**).* Compound **5d** was obtained in 86% yield (99 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.26 (s, 1H), 7.24−7.20 (m, 2H), 7.12−7.09 (m, 2H), 6.72 (d, 1H, J = 8.0 Hz), 3.76 (s, br, 2H), 2.47 (s, 3H), 2.20 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 145.3, 138.8, 136.8, 135.7, 133.7, 130.1, 127.3, 126.4, 125.3, 123.5, 119.8, 115.8, 20.3, 17.4. HRMS m/z calcd. for $C_{14}H_{15}NS$ $[M + H]^+$: 230.1003, found: 230.1015.

*2-Chloro-4-(p-tolylthio)aniline (**5e**).* Compound **5e** was obtained in 95% yield (119 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.42 (d, 1H, J = 4.0 Hz), 7.21 (dd, 1H, J = 8.0 Hz), 7.17 (d, 2H, J = 8.0 Hz), 7.11 (d, 2H, J = 8.0 Hz), 6.74 (d, 1H, J = 8.0 Hz), 4.16 (s, br, 2H), 2.35 (s, 3H), 2.20 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 143.0, 136.2, 134.4, 134.3, 133.2, 129.9, 129.1, 123.0, 119.5, 116.3, 21.1; HRMS m/z calcd. for $C_{13}H_{12}ClNS$ $[M + H]^+$: 250.0457, found: 250.0462.

*2-Chloro-4-(4-methoxyphenylthio)aniline (**5f**).* Compound **5f** was obtained in 86% yield (114 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.33 (s, 1H), 7.32 (d, 2H, J = 8.0 Hz), 7.13 (d, 1H, J = 8.0 Hz), 6.86 (d, 2H, J = 8.0 Hz), 6.70 (d, 1H, J = 8.0 Hz), 4.13 (s, br, 2H), 3.81 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 158.9, 142.5, 132.8, 132.4, 131.7, 127.6, 124.9, 119.5, 116.3, 114.8, 55.4; HRMS m/z calcd. for $C_{13}H_{12}ClNOS$ $[M + H]^+$: 266.0406, found: 266.0411.

*2-Chloro-4-(4-chlorophenylthio)aniline (**5g**).* Compound **5g** was obtained in 75% yield (101 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.44 (s, 1H), 7.23−7.20 (m, 3H), 7.10 (d, 2H, J = 8.0 Hz), 6.76 (d, 1H, J = 8.0 Hz), 4.26 (s, br, 2H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 143.7, 137.4, 135.2, 134.1, 131.6, 129.1, 129.0, 121.0, 119.5, 116.4; HRMS m/z calcd. for $C_{12}H_9Cl_2NS$ $[M + H]^+$: 269.9911, found: 269.9923.

*4-(4-Bromophenylthio)-2-chloroaniline (**5h**).* Compound **5h** was obtained in 78% yield (122 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.44 (s, 1H), 7.36 (d, 2H, J = 8.0 Hz), 7.22 (d, 2H, J = 8.0 Hz), 7.02 (d, 2H, J = 8.0 Hz), 6.77 (d, 2H, J = 8.0 Hz), 4.26 (s, br, 2H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 143.8, 138.2, 135.4, 134.3, 132.0, 129.2, 120.7, 119.5, 119.4, 116.4; HRMS m/z calcd. for $C_{12}H_9BrClNS$ $[M + H]^+$: 313.9406, 315.9385, found: 313.9417, 315.9392.

*2-Chloro-4-(o-tolylthio)aniline (**5i**).* Compound **5i** was obtained in 79% yield (99 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.43 (s, 1H), 7.25−4.13 (m, 4H), 7.05 (d, 2H, J = 8.0 Hz),

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6.76 (d, 2H, J = 8.0 Hz), 4.22 (s, br, 2H), 2.48 (s, br, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 143.2, 137.3, 136.7, 134.6, 133.5, 130.4, 128.6, 126.7, 126.2, 121.7, 119.7, 116.5, 20.4; HRMS m/z calcd. for $C_{13}H_{12}ClNS$ $[M + H]^+$: 250.0457, found: 250.0462.

*2-Ethyl-4-(p-tolylthio)aniline (**5j**).* Compound **5j** was obtained in 99% yield (121 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.31 (s, 1H), 7.24 (d, 1H, J = 8.0 Hz), 7.15 (d, 2H, J = 8.0 Hz), 7.10 (d, 2H, J = 8.0 Hz), 6.70 (d, 1H, J = 8.0 Hz), 3.76 (s, br, 2H), 2.52 (dd, 2H, J = 8.0 Hz), 2.35 (s, 3H), 1.30 (t, 3H, J = 8.0 Hz). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 144.6, 136.8, 136.1, 135.3, 134.4, 133.1, 129.7, 129.0, 128.0, 116.1, 23.9, 21.0, 12.9; HRMS m/z calcd. for $C_{15}H_{17}NS$ $[M + H]^+$: 244.1160, found: 244.1154.

*2-Ethyl-4-(4-methoxyphenylthio)aniline (**5k**).* Compound **5k** was obtained in 99% yield (128 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.26 (d, 2H, J = 8.0 Hz), 7.22 (s, 1H), 7.15 (d, 2H, J = 8.0 Hz), 6.85 (d, 2H, J = 8.0 Hz), 6.65 (d, 1H, J = 8.0 Hz), 3.81 (s, 3H), 3.74 (s, br, 2H), 2.50 (dd, 2H, J = 8.0 Hz), 1.26 (t, 3H, J = 8.0 Hz). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 158.4, 144.1, 133.1, 131.7, 131.1, 129.2, 128.9, 123.1, 116.1, 114.7, 55.4, 23.9, 12.9; HRMS m/z calcd. for $C_{15}H_{17}NOS$ $[M + H]^+$: 259.1031, found: 259.1022.

*4-(4-Chlorophenylthio)-2-ethylaniline (**5l**).* Compound **5l** was obtained in 97% yield (128 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.30 (s, 1H), 7.26−7.21 (m, 3H), 7.09 (d, 2H, J = 8.0 Hz), 6.71 (d, 2H, J = 8.0 Hz), 3.84 (s, br, 2H), 2.53 (dd, 2H, J = 8.0 Hz), 1.29 (t, 3H, J = 8.0 Hz). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 145.2, 138.9, 136.8, 135.5, 135.2 133.9, 128.9, 128.2, 117.4, 116.2, 23.9, 12.8; HRMS m/z calcd. for $C_{14}H_{14}ClNS$ $[M + H]^+$: 264.0614, found: 264.0603.

*4-(4-Bromophenylthio)-2-ethylaniline (**5m**).* Compound **5m** was obtained in 97% yield (150 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.35 (d, 2H, J = 8.0 Hz), 7.29 (s, 1H), 7.24 (d, 1H, J = 8.0 Hz), 7.02 (d, 2H, J = 8.0 Hz), 6.71 (d, 1H, J = 8.0 Hz), 3.85 (s, br, 2H), 2.53 (dd, 2H, J = 8.0 Hz), 1.29 (t, 3H, J = 8.0 Hz). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 145.3, 139.7, 136.8, 135.2, 134.0, 131.8, 129.1, 128.4, 23.8, 12.8; HRMS m/z calcd. for $C_{14}H_{14}BrNS$ $[M + H]^+$: 308.0109, 310.0088, found: 309.0121, 310.0095.

*4-(4-Chlorophenylthio)-2,6-dimethylaniline (**5n**).* Compound **5n** was obtained in 99% yield (130 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.22−7.19 (m, 4H), 7.09 (d, 2H, J = 8.0 Hz), 3.72 (s, br, 2H), 2.21 (s, 6H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 144.0, 139.1, 136.5, 135.1, 128.9, 128.2, 122.8, 118.5, 17.6; HRMS m/z calcd. for $C_{14}H_{14}ClNS$ $[M + H]^+$: 263.0535, found: 263.0528.

*2,6-Dimethyl-4-(p-tolylthio)aniline (**5o**).* Compound **5o** was obtained in 99% yield (121 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.19 (s, 2H), 7.16−7.09 (m, 4H), 3.76 (s, br, 2H), 2.36 (s, 3H), 2.22 (s, 6H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 143.4, 136.2, 135.2, 134.4, 129.7, 127.9, 122.6, 120.2, 21.0, 17.6. HRMS m/z calcd. for $C_{15}H_{17}NS$ $[M + H]^+$: 244.1160, found: 244.1154.

*4-Methyl-2-(m-tolylthio)aniline (**7a**).* Compound **7a** was obtained in 84% yield (97 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.35 (s, 1H), 7.16 (t, 1H, J = 8.0 Hz), 7.10 (d, 1H, J = 8.0 Hz), 7.01−6.79 (m, 2H), 6.93 (d, 1H, J = 8.0 Hz), 6.76 (d, 1H, J = 8.0 Hz), 4.17 (s, br, 2H), 2.33 (s, 3H), 2.31 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 146.5, 138.9, 137.5, 136.8, 131.9, 128.9, 128.1, 127.1, 126.4, 123.6, 115.5, 114.5, 21.5, 20.3; HRMS m/z calcd. for $C_{14}H_{15}NS$ $[M + H]^+$: 230.1003, found: 230.1017.

*4-Methyl-2-(o-tolylthio)aniline (**7b**).* Compound **7b** was obtained in 81% yield (93 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.34 (s, 1H), 7.25 (d, 1H, J = 8.0 Hz), 7.16−7.12 (m, 3H), 6.81 (t, 2H, J = 8.0 Hz), 4.18 (s, br, 2H), 2.53 (s, br, 3H), 2.34 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 146.6, 137.5, 136.0, 135.2, 131.9, 130.3, 128.3, 126.7, 125.5, 125.2, 115.6, 114.0, 20.4, 20.2; HRMS m/z calcd. for $C_{14}H_{15}NS$ $[M + H]^+$: 230.1003, found: 230.1017.

*4-Chloro-2-(p-tolylthio)aniline (**7c**).* Compound **7c** was obtained in 86% yield (108 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.42 (d, 1H, J = 4.0 Hz), 7.17(d, 1H, J = 8.0 Hz), 7.11−7.06 (m, 4H), 6.72 (d, 1H, J = 8.0 Hz), 4.28 (s, br, 2H), 2.32 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 146.9, 136.2, 135.6, 131.8, 130.5, 130.0, 127.7, 122.5, 117.2, 116.3, 21.0; HRMS m/z calcd. for $C_{13}H_{12}ClNS$ $[M + H]^+$: 250.0457, found: 250.0462.

*4-Chloro-2-(4-methoxyphenylthio)aniline (**7d**).* Compound **7d** was obtained in 72% yield (96 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.38 (d, 1H, J = 4.0 Hz), 7.21(d, 2H, J = 8.0 Hz), 7.14 (d, 1H, J = 8.0 Hz), 6.86 (d, 2H, J = 8.0 Hz), 6.68 (d, 1H, J = 8.0 Hz), 4.29 (s, br, 2H), 3.80 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 155.8, 146.3, 134.6, 130.7, 130.0, 125.5, 122.6, 118.9, 116.3, 115.0, 55.4; HRMS m/z calcd. for $C_{13}H_{12}ClNOS$ $[M + H]^+$: 266.0406, found: 266.0411.

*4-Chloro-2-(4-chlorophenylthio)aniline (**7e**).*[23] Compound **7e** was obtained in 88% yield (118 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.45 (s, 1H), 7.24−7.20 (m, 3H), 7.05 (d, 2H, J = 8.0 Hz), 6.74 (d, 1H, J = 8.0 Hz), 4.31 (s, br, 2H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 147.3, 136.2, 134.4, 131.8, 131.3, 129.3, 128.2, 122.6, 116.4, 115.5; HRMS m/z calcd. for $C_{12}H_9Cl_2NS$ $[M + H]^+$: 269.9911, found: 269.9923.

*2-(4-Bromophenylthio)-4-chloroaniline (**7f**).* Compound **7f** was obtained in 84% yield (132 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.46 (s, 1H), 7.37 (d, 2H, J = 8.0 Hz), 7.22 (d, 1H, J = 8.0 Hz), 6.98 (d, 2H, J = 8.0 Hz), 6.73 (d, 1H, J = 8.0 Hz), 4.31 (s, br, 2H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 147.3, 136.2, 135.1, 132.2, 131.3, 129.3, 128.4, 122.6, 119.7, 116.5. HRMS m/z calcd. for $C_{12}H_9BrClNS$ $[M + H]^+$: 313.9406, 315.9385, found: 313.9417, 315.9392.

*4-Chloro-2-(m-tolylthio)aniline (**7g**).* Compound **7g** was obtained in 69% yield (86 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.48 (s, 1H), 7.22−7.16 (m, 2H), 7.01 (d, 2H, J = 8.0 Hz), 6.94 (d, 1H, J = 8.0 Hz), 6.74 (d, 1H, J = 8.0 Hz), 4.31 (s, br, 2H), 2.33 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 147.3, 139.1, 136.1, 135.4, 130.8, 129.1, 127.7, 127.0, 124.2, 122.5, 116.4, 116.3, 21.5; HRMS m/z calcd. for $C_{13}H_{12}ClNS$ $[M + H]^+$: 250.0457, found: 250.0462.

*4-Chloro-2-(o-tolylthio)aniline (**7h**).* Compound **7h** was obtained in 62% yield (78 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.39 (s, 1H), 7.21 (d, 2H, J = 8.0 Hz), 7.14−7.07 (m, 2H), 6.82 (d, 1H, J = 8.0 Hz), 6.75 (d, 1H, J = 8.0 Hz), 4.27 (s, br, 2H), 2.45 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 147.1, 135.9, 135.7, 134.5, 130.6, 130.4, 126.7, 126.3, 125.9, 122.7, 116.3, 116.0, 20.1; HRMS m/z calcd. for $C_{13}H_{12}ClNS$ $[M + H]^+$: 250.0457, found: 250.0462.

*4-Methoxy-2-(p-tolylthio)aniline (**7i**).* Compound **7i** was obtained in 64% yield (79 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.10−7.04 (m, 4H), 7.04 (s, 1H), 6.88 (d, 1H, J = 8.0 Hz), 6.77 (d, 1H, J = 8.0 Hz), 4.01 (s, br, 2H), 3.77 (s, 3H), 2.32 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 152.4, 142.4, 135.7, 132.7, 129.9, 127.4, 120.6, 117.7, 116.7, 116.4, 55.9, 21.0; HRMS m/z calcd. for $C_{14}H_{15}NOS$ $[M + H]^+$: 246.0953, found: 246.0961.

*4-Methoxy-2-(m-tolylthio)aniline (**7j**).* Compound **7j** was obtained in 64% yield (79 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^{1}H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.16 (t, 1H, J = 8.0 Hz), 7.06 (s, 1H), 6.98 (d, 2H, J = 8.0 Hz), 6.94−6.88 (m, 2H), 6.79 (d, 1H, J = 8.0 Hz), 3.99 (s, br, 2H), 3.78 (s, 3H), 2.31 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 152.3, 142.7, 138.9, 136.3, 129.0, 127.4, 126.6, 123.8, 120.9, 118.0, 116.7, 115.6,

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J. Org. Chem. 2015, 80, 6083−6092

55.9, 21.5. HRMS m/z calcd. for $C_{14}H_{15}NOS$ $[M + H]^+$: 246.0953, found: 246.0961.

*4-Methoxy-2-(o-tolylthio)aniline (**7k**).* Compound **7k** was obtained in 61% yield (75 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^1H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.23 (d, 1H, J = 8.0 Hz), 7.13−7.09 (m, 2H), 7.03 (s, 1H), 6.93 (d, 2H, J = 8.0 Hz), 6.85−6.80 (m, 2H), 3.97 (s, br, 2H), 3.70 (s, 3H), 2.49 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 152.6, 142.8, 135.6, 135.4, 130.3, 126.7, 125.9, 125.6, 120.6, 117.9, 116.8, 115.2, 55.9, 20.2. HRMS m/z calcd. for $C_{14}H_{15}NOS$ $[M + H]^+$: 246.0953, found: 246.0961.

*4-Methoxy-2-(4-methoxyphenylthio)aniline (**7l**).* Compound **7l** was obtained in 57% yield (75 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^1H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.19 (d, 2H, J = 8.0 Hz), 6.98 (d, 1H, J = 4.0 Hz), 6.84 (d, 2H, J = 8.0 Hz), 6.82 (d, 1H,, J = 4.0 Hz), 6.74 (d, 1H, J = 8.0 Hz), 6.85−6.80 (m, 2H), 3.95 (s, br, 2H), 3.79 (s, 3H), 3.75 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 158.5, 152.4, 141.8, 130.2, 126.4, 119.9, 118.2, 116.9, 116.7, 114.9, 55.8, 55.4; HRMS m/z calcd. for $C_{14}H_{15}NO_2S$ $[M + H]^+$: 262.0902, found: 262.0911.

*2-(4-Chlorophenylthio)-4-methoxyaniline (**7m**).* Compound **7m** was obtained in 87% yield (116 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^1H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.21 (d, 2H, J = 8.0 Hz), 7.05−7.03 (m, 3H), 6.88 (d, 1H, J = 4.0 Hz), 6.78 (d, 1H, J = 8.0 Hz), 4.01 (s, br, 2H), 3.77 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 152.4, 142.7, 135.2, 131.4, 129.2, 127.9, 120.9, 118.5, 116.8, 114.8, 55.9. HRMS m/z calcd. for $C_{13}H_{12}ClNOS$ $[M + H]^+$: 266.0406, found: 266.0411.

*2-(4-Bromophenylthio)-4-methoxyaniline (**7n**).* Compound **7n** was obtained in 85% yield (132 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^1H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.36 (d, 2H, J = 8.0 Hz), 7.05 (s, 1H), 6.98 (d, 2H, J = 8.0 Hz), 6.91 (d, 1H, J = 8.0 Hz), 6.78 (d, 1H, J = 8.0 Hz), 4.01 (s, br, 2H), 3.77 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 152.4, 142.8, 136.0, 132.1, 128.1, 120.9, 119.2, 118.6, 116.9, 114.5, 55.9. HRMS m/z calcd. for $C_{13}H_{12}BrNOS$ $[M + H]^+$: 309.9901, 31.9881, found: 309.9912, 311.9891.

*1-(4-Chlorophenylthio)naphthalen-2-amine (**7o**).*[22] Compound **7o** was obtained in 97% yield (139 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^1H NMR ($CDCl_3$, 400 MHz, ppm) δ 8.27 (d, 1H, J = 8.0 Hz), 7.82−7.76 (m, 2H), 7.49 (t, 1H, J = 8.0 Hz), 7.32 (t, 1H, J = 8.0 Hz), 7.16 (d, 2H, J = 8.0 Hz), 7.08 (d, 1H, J = 8.0 Hz), 6.98 (d, 2H, J = 8.0 Hz), 4.76 (s, br, 2H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 148.5, 136.5, 135.5, 132.1, 130.9, 129.1, 128.5, 128.4, 128.0, 127.1, 124.0, 122.8, 117.7, 104.0; HRMS m/z calcd. for $C_{16}H_{12}ClNS$ $[M + H]^+$: 286.0457, found: 286.0451.

*1-(4-Bromophenylthio)naphthalen-2-amine (**7p**).*[22] Compound **7p** was obtained in 94% yield (155 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^1H NMR ($CDCl_3$, 400 MHz, ppm) δ 8.27 (d, 1H, J = 8.0 Hz), 7.82−7.76 (m, 2H), 7.49 (t, 1H, J = 8.0 Hz), 7.32 (t, 1H, J = 8.0 Hz), 7.16 (d, 2H, J = 8.0 Hz), 7.08 (d, 1H, J = 8.0 Hz), 6.98 (d, 2H, J = 8.0 Hz), 4.76 (s, br, 2H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 148.5, 136.5, 135.5, 132.1, 130.9, 129.1, 128.5, 128.4, 128.0, 127.1, 124.0, 122.8, 117.7, 104.0; HRMS m/z calcd. for $C_{16}H_{12}BrNS$ $[M + H]^+$: 329.9952, 331.9932, found: 329.9937, 331.9923.

*1-(p-Tolylthio)naphthalen-2-amine (**7q**).*[22] Compound **7q** was obtained in 90% yield (119 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^1H NMR ($CDCl_3$, 400 MHz, ppm) δ 8.40 (d, 1H, J = 8.0 Hz), 7.82−7.79 (m, 2H), 7.50 (t, 1H, J = 8.0 Hz), 7.34 (t, 1H, J = 8.0 Hz), 7.09−7.01 (m, 5H), 4.75 (s, br, 2H), 2.31 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 148.5, 136.7, 135.0, 133.3, 131.8, 129.9, 128.5, 127.9, 126.1, 124.4, 123.1, 122.6, 117.8, 105.2; HRMS m/z calcd. for $C_{17}H_{15}NS$ $[M + H]^+$: 266.1003, found: 266.1012.

*1-(4-Methoxyphenylthio)naphthalen-2-amine (**7r**).*[22] Compound **7r** was obtained in 89% yield (125 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^1H NMR ($CDCl_3$, 400 MHz, ppm) δ 8.39 (d, 1H, J = 8.0 Hz), 7.78−7.75 (m, 2H), 7.50 (t, 1H, J = 8.0 Hz), 7.31 (t, 1H, J = 8.0 Hz), 7.06 (d, 3H, J = 8.0 Hz), 6.77 (d, 1H, J = 8.0 Hz), 4.73 (s, br, 2H), 3.74 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 157.8, 148.3, 136.7, 131.6, 128.5, 128.4, 127.9, 127.8, 127.5, 124.4, 122.6, 117.7, 114.8, 106.2, 55.3. HRMS m/z calcd. for $C_{17}H_{15}NOS$ $[M + H]^+$: 282.0953, found: 282.0947.

*3-Chloro-4-(2,4-dichlorophenylthio)aniline (**9a**).*[23] Compound **9a** was obtained in 92% yield (140 mg) according to the general procedure. Eluent petroleum ether/ethyl acetate (20:1). ^1H NMR ($CDCl_3$, 400 MHz, ppm) δ 7.39−7.37 (m, 2H), 7.05 (d, 1H, J = 8.0 Hz), 6.88 (s, 1H), 6.59 (t, 2H, J = 8.0 Hz), 4.03 (s, br, 2H). ^{13}C NMR ($CDCl_3$, 100 MHz, ppm) δ 149.4, 140.7, 138.8, 136.4, 131.3, 131.0, 129.2, 127.7, 127.4, 116.3, 116.1, 114.4. HRMS m/z calcd. for $C_{12}H_8Cl_3NS$ $[M + H]^+$: 303.9521, found: 303.9532.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

^1H and ^{13}C NMR spectra for all compounds. The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.joc.5b00540.

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Notes

The authors declare no competing financial interest.

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■ REFERENCES

(1) (a) Nakazawa, T.; Xu, J.; Nishikawa, T.; Oda, T.; Fujita, A.; Ukai, K.; Mangindaan, R. E. P.; Rotinsulu, H.; Kobayashi, H.; Namikoshi, M. *J. Nat. Prod.* **2007**, *70*, 439−442. (b) Nielsen, S. F.; Nielsen, E. O.; Olsen, G. M.; Liljefors, T.; Peters, D. *J. Med. Chem.* **2000**, *43*, 2217−2226. (c) Gangjee, A.; Zeng, Y. B.; Talreja, T.; McGuire, J. J.; Kisliuk, R. L.; Queener, S. F. *J. Med. Chem.* **2007**, *50*, 3046−3053. (d) Zhou, Y.; Liu, W.-J.; Ma, Y.; Wang, H.; Qi, L.; Cao, Y.; Wang, J.; Pei, J. *J. Am. Chem. Soc.* **2007**, *129*, 12386−12387. (e) Takimiya, K.; Shinamura, S.; Osaka, I.; Miyazaki, E. *Adv. Mater.* **2011**, *23*, 4347−4370. (f) Mori, T.; Nishimura, T.; Yamamoto, T.; Doi, I.; Miyazaki, E.; Osaka, I.; Takimiya, K. *J. Am. Chem. Soc.* **2013**, *135*, 13900−13913.

(2) (a) Kondo, T.; Mitsudo, T.-a. *Chem. Rev.* **2000**, *100*, 3205−3220. (b) Li, G. Y. *Angew. Chem., Int. Ed.* **2001**, *40*, 1513−1516.

(3) (a) Migita, T.; Shimizu, T.; Asami, Y.; Shiobara, J.; Kato, Y.; Kosugi, M. *Bull. Chem. Soc. Jpn.* **1980**, *53*, 1385−1398. (b) Mann, G.; Baranano, D.; Hartwig, J. F.; Rheingold, A. L.; Guzei, I. A. *J. Am. Chem. Soc.* **1998**, *120*, 9205−9219. (c) Baranano, D.; Hartwig, J. F. *J. Am. Chem. Soc.* **1995**, *117*, 2937−2938. (d) Jiang, Z.; She, J.; Lin, X. *Adv. Synth. Catal.* **2009**, *351*, 2558−2562.

(4) (a) Ma, D.; Cai, Q. *Acc. Chem. Res.* **2008**, *41*, 1450−1460. (b) Kwong, F. Y.; Buchwald, S. L. *Org. Lett.* **2002**, *4*, 3517−3520. (c) Chen, C. K.; Chen, Y. W.; Lin, C. H.; Lin, H. P.; Lee, C. F. *Chem. Commun.* **2010**, *46*, 282−284. (d) Bhadra, S.; Sreedhar, B.; Ranu, B. C. *Adv. Synth. Catal.* **2009**, *351*, 2369−2378.

(5) (a) Wu, W.-Y.; Wang, J.-C.; Tsai, F.-Y. *Green Chem.* **2009**, *11*, 326−329. (b) Correa, A.; Carril, M.; Bolm, C. *Angew. Chem., Int. Ed.* **2008**, *47*, 2880−2883.

DOI: 10.1021/acs.joc.5b00540
J. Org. Chem. 2015, 80, 6083−6092

(6) (a) Zhang, Y.; Ngeow, K. C.; Ying, J. Y. *Org. Lett.* **2007**, *9*, 3495−3499. (b) Joyce, L. L.; Evindar, G.; Batey, R. A. *Chem. Commun.* **2004**, 446−447. (c) Prasad, D. J. C.; Naidu, A. B.; Sekar, G. *Tetrahedron Lett.* **2009**, *50*, 1411−1415. (d) Bates, C. G.; Saejueng, P.; Doherty, M. Q.; Venkataraman, D. *Org. Lett.* **2004**, *6*, 5005−5008. (e) Rout, L.; Sen, T. K.; Punniyamurthy, T. *Angew. Chem., Int. Ed.* **2007**, *46*, 5583−5586. (f) Ramana, T.; Saha, P.; Das, M.; Punniyamurthy, T. *Org. Lett.* **2010**, *12*, 84−87.
(7) Wong, Y. C.; Jayanth, T. T.; Cheng, C. H. *Org. Lett.* **2006**, *8*, 5613−5616.
(8) Arisawa, M.; Suzuki, T.; Ishikawa, T.; Yamaguchi, M. *J. Am. Chem. Soc.* **2008**, *130*, 12214−12215.
(9) Yonova, I. M.; Osborne, C. A.; Morrissette, N. S.; Jarvo, E. R. *J. Org. Chem.* **2014**, *79*, 1947−1953.
(10) (a) Stoll, H.; Krasovskiy, A.; Knochel, P. *Angew. Chem., Int. Ed.* **2006**, *45*, 606−609. (b) Cheng, J.-H.; Ramesh, C.; Kao, H.-L.; Wang, Y.-J.; Chan, C.-C.; Lee, C.-F. *J. Org. Chem.* **2012**, *77*, 10369−10374.
(11) For recent reviews, see: (a) Sun, C.-L.; Li, B.-J.; Shi, Z.-J *Chem. Rev.* **2011**, *111*, 1293−1314. (b) Lewis, J. C.; Bergman, R. G.; Ellman, J. A. *Acc. Chem. Res.* **2008**, *41*, 1013−1025. (c) Engle, K. M.; Mei, T.-S.; Wasa, M.; Yu, J.-Q. *Acc. Chem. Res.* **2012**, *45*, 788−802. (d) Mkhalid, I. A. I.; Barnard, J. H.; Marder, T. B.; Murphy, J. M.; Hartwig, J. F. *Chem. Rev.* **2010**, *110*, 890−931. (e) Colby, D. A.; Tsai, A. S.; Bergman, R. G.; Ellman, J. A. *Acc. Chem. Res.* **2012**, *45*, 814−825. (f) Neufeldt, S. R.; Sanford, M. S. *Acc. Chem. Res.* **2012**, *45*, 936−946.
(12) Anbarasan, P.; Neumann, H.; Beller, M. *Chem. Commun.* **2011**, *47*, 3233−3235.
(13) (a) Prasad, C. D.; Balkrishna, S. J.; Kumar, A.; Bhakuni, B. S.; Shrimali, K.; Biswas, S.; Kumar, S. *J. Org. Chem.* **2013**, *78*, 1434−1443. (b) Tudge, M.; Tamiya, M.; Savarin, C.; Humphrey, G. R. *Org. Lett.* **2006**, *8*, 565−568. (c) Silveira, C. S.; Medes, S. R.; Wolf, L.; Marins, G. M. *Tetrehedron Lett.* **2010**, *51*, 2014−2016.
(14) (a) Saravanan, P.; Anbarasan, P. *Org. Lett.* **2014**, *16*, 848−851. (b) Anbarasan, P.; Neumann, H.; Beller, M. *Chem. Commun.* **2011**, *47*, 3233−3235.
(15) (a) Chen, X.; Hao, X.-S.; Goodhue, C. E.; Yu, J.-Q. *J. Am. Chem. Soc.* **2006**, *128*, 6790−6791. (b) Zhang, S.; Qian, P.; Zhang, M.; Hu, M.; Cheng, J. *J. Org. Chem.* **2010**, *75*, 6732−6735. (c) Chu, L.; Yue, X.; Qing, F.-L. *Org. Lett.* **2010**, *12*, 1644−1666. (d) Ranjit, S.; Lee, R.; Heryadi, D.; Shen, C.; Wu, J. E.; Zhang, P.; Huang, K.-W.; Liu, X. *J. Org. Chem.* **2011**, *76*, 8999−9007.
(16) (a) Zhang, M.; Zhang, S.; Pan, C.; Chen, F. *Synth. Commun.* **2012**, *42*, 2844−2853. (b) Fang, X.-L.; Tang, R.-Y.; Zhang, X.-G.; Li, J.-H. *Synthesis* **2011**, 1099−1105.
(17) Tian, H.; Zhu, C.; Yang, H.; Fu, H. *Chem. Commun.* **2014**, *50*, 8875−8877.
(18) (a) Thome, I.; Besson, C.; Kleine, T.; Bolm, C. *Angew. Chem., Int. Ed.* **2013**, *52*, 7509−7513. (b) Kano, T.; Shirozu, F.; Maruoka, K. *J. Am. Chem. Soc.* **2013**, *135*, 18036−18039. (c) Sun, C.-L.; Shi, Z.-J. *Chem. Rev.* **2014**, *114*, 9219−9280.
(19) (a) Zmitek, K.; Zupan, M.; Stavber, S.; Iskra, J. *Org. Lett.* **2006**, *8*, 2491−2494. (b) Nobuta, T.; Tada, N.; Fujiya, A.; Kariya, A.; Miura, T.; Itoh, A. *Org. Lett.* **2013**, *15*, 574−577. (c) Pan, X.; Boussonnière, A.; Curran, D. P. *J. Am. Chem. Soc.* **2013**, *135*, 14433−14437. (d) Humne, V.; Dangat, Y.; Vank, K.; Lokhande, P. *Org. Biomol. Chem.* **2014**, *12*, 4832−4836.
(20) Zou, L.-H.; Reball, J.; Mottweiler, J.; Bolm, C. *Chem. Commun.* **2012**, *48*, 11307−11309.
(21) (a) Liao, Y.; Jiang, P.; Chen, S.; Qia, H.; Deng, G.-J. *Green Chem.* **2013**, *15*, 3302−3306. (b) Du, H.-A.; Tang, R.-Y.; Deng, C.-L.; Liu, Y.; Li, J.-H.; Zhang, X.-G. *Adv. Synth. Catal.* **2011**, *353*, 2739−2748. (c) Hiebel, M.-A.; Berteina-Raboin, S. *Green Chem.* **2015**, *17*, 937−944.
(22) Kang, X.; Yan, R.; Yu, G.; Pang, X.; Liu, X.; Li, X.; Xiang, L.; Huang, G. *J. Org. Chem.* **2014**, *79*, 10605−10610.
(23) Kerry, F.; Mark, O.; Donald E. S.; Janet, A. (Icos Corp., USA). Patent WO0059878, 2000.
(24) Du, H. A.; Tang, R. Y.; Deng, C. L.; Liu, Y.; Li, J. H.; Zhang, X. G. *Adv. Synth. Catal.* **2011**, *353*, 2739−2748.
(25) Duan, Z.; Ranjit, S.; Liu, X. *Org. Lett.* **2010**, *12*, 2430−2433.
(26) Feng, Y.-S.; Qi, H.-X.; Wang, W.-C.; Liang, Y.-F.; Xu, H.-J. *Tetrahedron Lett.* **2012**, *53*, 2914−2917.
(27) Cabrero-Antonino, J. R.; García, T.; Rubio-Marqués, P.; Vidal-Moya, J. A.; Leyva-Pérez, A.; Al-Deyab, S. S.; Al-Resayes, S. I.; Díaz, U.; Corma, A. *ACS Catal.* **2011**, *1*, 147−158.
(28) Kabir, M. S.; Lorenz, M.; Van Linn, M. L.; Namjoshi, O. A.; Ara, S.; Cook, J. M. *J. Org. Chem.* **2010**, *75*, 3626−3643.
(29) Wang, C.; Ma, Z.; Sun, X.-L.; Gao, Y.; Guo, Y.-H.; Tang, Y.; Shi, L.-P. *Organometallics* **2006**, *25*, 3259−3266.
(30) Sivan, V.; Reena, V.; Amarendar, C.; Ravindra, P. P.; Ajayan, V. *Synlett* **2010**, *18*, 2733−2736.

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