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Copper-Catalyzed Deoxygenative C2-Sulfonylation of Quinoline *N*-Oxides with DABSO and Phenyldiazonium Tetrafluoroborates for the Synthesis of 2-Sulfonylquinolines via a Radical Reaction

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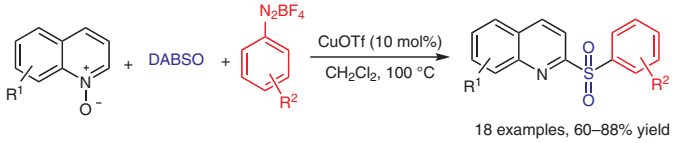

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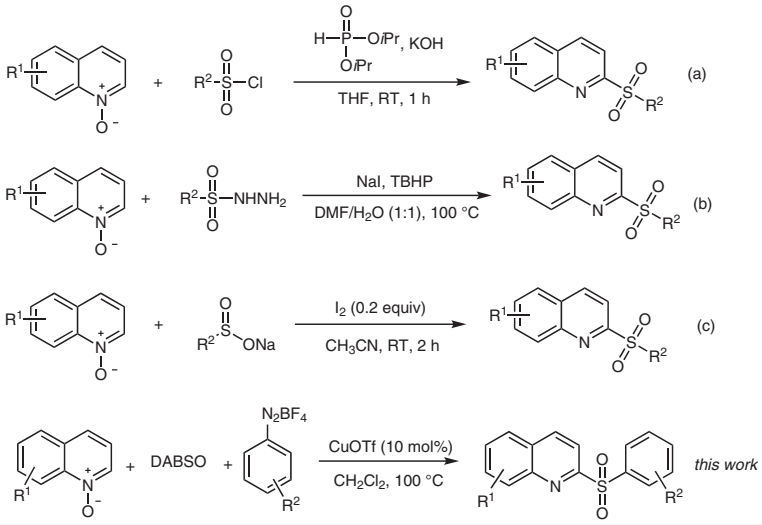
Abstract An efficient and practical method for the synthesis of 2-sulfonylquinolines through copper-catalyzed deoxygenative C2-sulfonylation of quinoline *N*-oxides with 1,4-diazabicyclo[2.2.2]octane bis(sulfur dioxide) (DABSO) and phenyldiazonium tetrafluoroborates is demonstrated. Products with various substituents were obtained in moderate to high yields.

Key words quinoline *N*-oxides, DABSO, radicals, sulfonylation, copper

2-Sulfonylquinolines play an important role in the chemical and pharmaceutical community.[1] Therefore, the synthesis of 2-sulfonylquinolines has become a hot topic in chemistry and has received more and more attention in recent years. Traditionally, the methods for the preparation of 2-sulfonylquinolines are oxidation of the corresponding sulfides[2] or the coupling of sulfinate salts with 2-haloquinolines.[3] However, some limitations of these protocols, such as restricted substrate scope and non-commercial availability of starting materials, limit the utility of these methods. From the perspective of the abundance and accessibility of quinoline *N*-oxides, the direct preparation of 2-sulfonylquinolines from quinoline *N*-oxides would be more desirable. In 2015, an H-phosphonate-mediated synthetic strategy for the deoxygenative sulfonylation of heteroaromatic *N*-oxides using sulfonyl chlorides was reported by Zhao's group. Sulfonyl anions (nucleophile), generated from sulfonyl chlorides (electrophile), were proposed in the mechanism (Scheme 1a).[4] W.-M. He's group[5] found that deoxygenative sulfonylation of quinoline *N*-oxides using sulfonyl chlorides could also be realized under metal-free conditions. Without employing any base and organic solvent, various functionalized 2-sulfonylquinolines were obtained under ultrasound conditions.[5a] Besides sulfonyl chlorides, sulfonyl hydrazides have proved to be good partners for the preparation of 2-sulfonylquinolines. In 2016, C.-L. He's group (Scheme 1b)[6] and Zeng's group[7] independently disclosed the reaction of quinoline *N*-oxides with sulfonyl hydrazides, and a series of the corresponding products was efficiently obtained. In the presence of iodine as catalyst, deoxygenative and regioselective 2-sulfonylation of quinoline *N*-oxides with sodium sulfinate salts was developed by Zhao's group (Scheme 1c)[8] and Yotphan's group,[9] providing the desired products in moderate to high yield at room temperature. Although various methods for the deoxygenative sulfonylation of quinoline *N*-oxides have been established, there are few examples providing a method for the direct construction of 2-sulfonylquinolines via a radical pathway. One example for the direct synthesis of 2-sulfonylquinolines via a Minisci-like radical sulfonylation of quinoline *N*-oxides catalyzed by copper salts was reported by Han and co-workers.[10] In 2018, another example was presented by W.-M. He's group. In the absence of metal catalyst, the deoxygenative sulfonylation of quinoline *N*-oxides with sodium sulfinates was realized via a dual radical coupling process.[11]

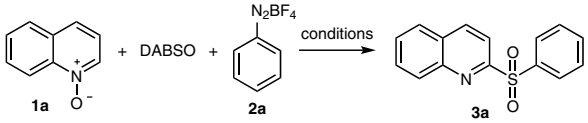


Scheme 1 Synthesis of 2-sulfonylquinolines

Since the palladium-catalyzed aminosulfonylation of aryl iodides using 1,4-diazabicyclo[2.2.2]octane bis(sulfur dioxide) (DABSO) and hydrazines was reported by Willis and co-workers in 2010,[12] rapid progress has been made in sulfonylation reactions using DABSO as the sulfonylation reagent.[13] At present, alkynes,[14] anilines,[15] imidazopyridines,[16] *N*-arylacrylamides,[17] and so on[18] have been used as good substrates to react with DABSO. Consistent with our research interest in C–H bond activation and functionalization of heterocyclic compounds,[3f,19] herein we describe a new protocol to access 2-sulfonylquinolines by the deoxygenative C2-sulfonylation of quinoline *N*-oxides with DABSO via a radical mechanism.

At the beginning of our studies, a model reaction of quinoline 1-oxide (**1a**), DABSO, and phenyldiazonium tetrafluoroborate (**2a**) was chosen to optimize the reaction conditions (Table 1). Firstly, the effect of copper catalyst on the reaction was examined. It was pleasing to find that the reaction does indeed proceed, and afforded the desired 2-sulfonylquinoline **3a** in 28% yield (entry 1) in the presence of CuI as catalyst. An improved 50% yield of the desired product was obtained when $Cu(OAc)_2$ was used (entry 2). Other copper catalysts, such as $Cu(acac)_2$, $Cu(OTf)_2$, Cu, and $Cu(NO_3)_2$, could also catalyze the reaction, but the yields of these reactions were not higher (entries 3–6). When CuOTf was employed in this reaction, the highest yield (88%) of product **3a** was obtained (entry 7). Subsequently, a number of solvents were examined with the aim of improving the yield. When the reaction was conducted in DCE or acetone, a low to moderate yield of **3a** was isolated (entries 8 and 9). DMF and DMSO were not effective for this transformation (entries 10 and 11). A lower yield (57%) was obtained when the reaction temperature was decreased from 100 °C to 80 °C (entry 12). However, there was no improvement in the yield when the reaction was conducted at a higher temperature (120 °C, entry 13). The copper catalyst plays an important role in this reaction, as no reaction occurred in the absence of the catalyst (entry 14). The yield of **3a** de-

Table 1 Optimization of the Reaction Conditions[a]



Entry	Catalyst	Solvent	Temp (°C)	Yield (%)[b]
1	CuI	CH_2Cl_2	100	28
2	$Cu(OAc)_2$	CH_2Cl_2	100	50
3	$Cu(acac)_2$	CH_2Cl_2	100	49
4	$Cu(OTf)_2$	CH_2Cl_2	100	22
5	Cu	CH_2Cl_2	100	17
6	$Cu(NO_3)_2$	CH_2Cl_2	100	20
7	CuOTf	CH_2Cl_2	100	88
8	CuOTf	DCE	100	60
9	CuOTf	acetone	100	28
10	CuOTf	DMSO	100	trace
11	CuOTf	DMF	100	trace
12	CuOTf	CH_2Cl_2	80	57
13	CuOTf	CH_2Cl_2	120	87
14	–	CH_2Cl_2	100	NR[c]
15[d]	CuOTf	CH_2Cl_2	100	62

[a] Reaction conditions: **1a** (0.2 mmol), **2a** (0.4 mmol), DABSO (0.4 mmol), catalyst (10 mol%), solvent (1.5 mL), under N_2.
[b] Isolated yields.
[c] NR = no reaction.
[d] Under air.

creased obviously when the reaction was conducted under air (entry 15), indicating that nitrogen gas protection is important for this reaction.

Next, the generality of this sulfonylation reaction was investigated, under the optimal reaction conditions, with respect to both quinoline *N*-oxides and aryldiazonium tetrafluoroborates (Figure 1). To our delight, quinoline *N*-oxides with an electron-donating (**3a**, **3b**, **3g**) or electron-withdrawing group (**3c**, **3d**, **3f**) were compatible with these reaction conditions, and the desired products were obtained in moderate to good yields. No obvious substitution effect was observed. Substituted aryldiazonium tetrafluoroborates bearing various synthetically useful functional groups, such as CH_3, F, Cl, Br, and OCH_3 at the 2-, 3-, or 4-position of the benzene ring, were well tolerated; the corresponding products **3i–r** were obtained in moderate to high yields. Groups such as Br and Cl render the product ready for further modifications. We were pleased to find that the base-labile ester group (**3h**, **3o**) was well tolerated under the reaction system. It is worth noting that the CF_3-substituted aryldiazonium tetrafluoroborate also displayed good reactivity, to afford the corresponding product **3n** in 73% yield.

To clarify the mechanism of this process, radical-trapping reagents, 2,2,6,6-tetramethyl-1-piperidinyloxy (TEMPO) and 2,6-di-*tert*-butyl-4-methylphenol (BHT), were added to the system, whereupon the reaction was completely inhibited (Scheme 2a), which suggests that free-radical intermediates are involved in the reaction. When quinoline was subjected to this reaction, no product was isolated (Scheme 2b). This result indicated that quinoline *N*-oxide is important for this reaction.

Based on the initial mechanistic studies and previous reports,[4–6,13,14,20] a possible pathway is described for this sulfonylation reaction, as shown in Scheme 3. First, sulfonyl radical intermediate **B** is generated from the reaction of DABSO and aryldiazonium tetrafluoroborate. At the same time, tertiary amine radical cation **D**, which can oxidize [Cu^{I}] to [Cu^{II}], is formed. Then, reaction between **B** and intermediate **A**, which is generated from the reaction between quinoline *N*-oxide (**1a**) and [Cu^{II}], occurs to afford intermediate **C**. Finally, the desired product **3a** is obtained from intermediate **C** by deoxygenative elimination. Meanwhile, Cu(I) is regenerated for the next cycle. A Minisci-like reaction mechanism, which would include a hydroxylamine intermediate, has not been excluded.[10]

In conclusion, we have described an efficient copper-catalyzed deoxygenative C2-sulfonylation reaction of quinoline *N*-oxides for the preparation of 2-sulfonylquinolines. The resulting products with various functional groups were readily obtained in moderate to high yields. Mechanism

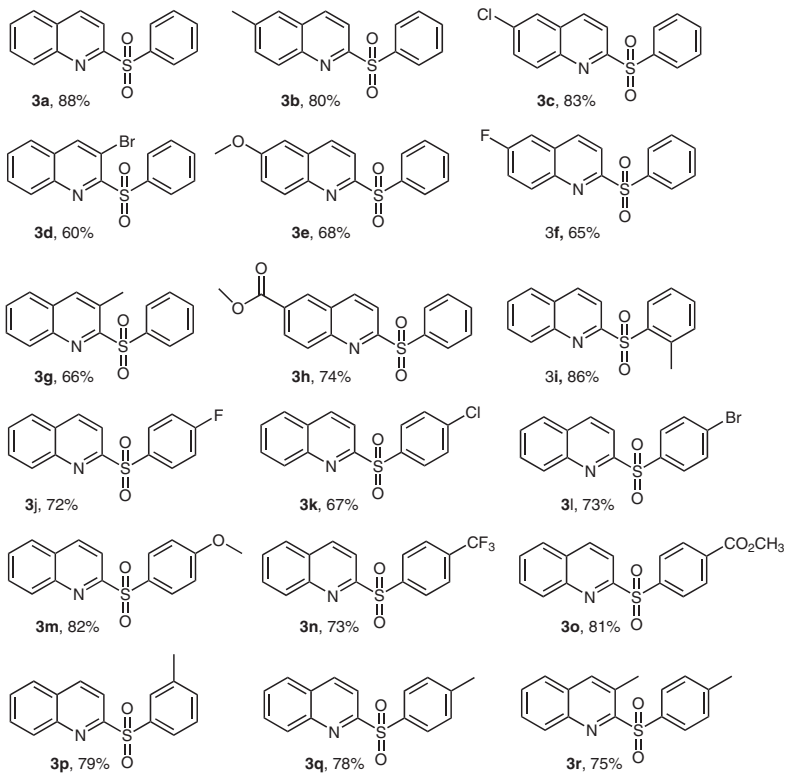
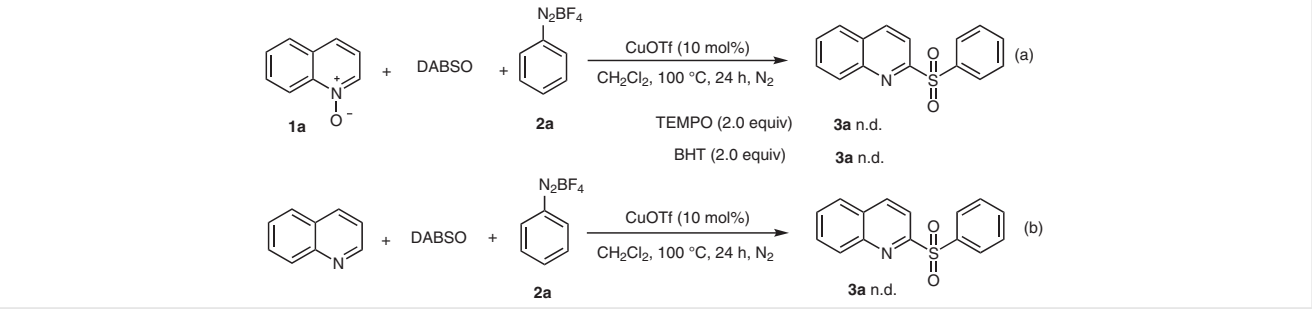
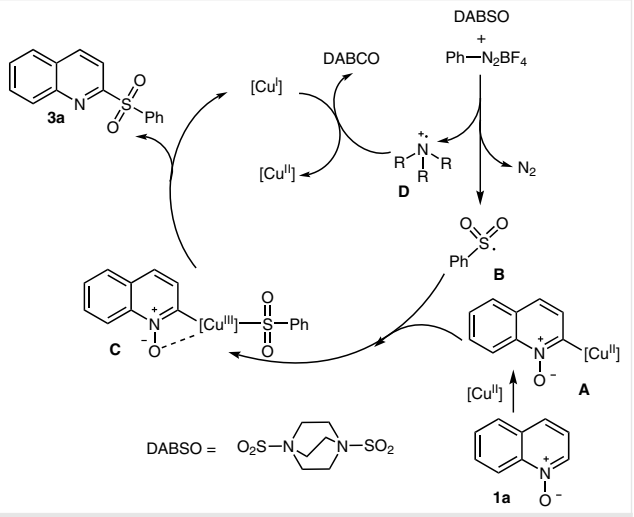


Figure 1 Reaction scope. *Reagents and conditions*: quinoline *N*-oxide (0.2 mmol), aryldiazonium tetrafluoroborate (0.4 mmol), DABSO (0.4 mmol), CuOTf (10 mol%), CH_2Cl_2 (1.5 mL), under N_2, 100 °C.



Scheme 2 Mechanism research (n.d.= not detected)



Scheme 3 Possible reaction pathway

studies indicated that free-radical intermediates are involved in the reaction. Further work toward expanding this protocol and further applications are underway in our laboratory.

NMR spectra were recorded on BRUKER AVANCE III HD 500MHz spectrometers, operating at 500 MHz for ^{1}H NMR and at 126 MHz for ^{13}C NMR acquisitions. ^{1}H NMR chemical shifts (δ) are given in ppm relative to TMS (δ = 0.0); chemical shifts for ^{13}C NMR spectra are reported in ppm from TMS with the solvent as the internal standard. Data are reported as follows: chemical shift, multiplicity (standard abbreviations), coupling constant(s), integration. HRMS spectra were performed on Orbitrap Fusion Lumos. All major chemicals and solvents were obtained from commercial sources and used without further purification.

Substituted Quinoline *N*-Oxides; General Procedure[21]

To a solution of the corresponding quinoline substrate (5 mmol) in CH_2Cl_2 (30 mL), *m*-CPBA (7.5 mmol, 1.5 equiv) was added at 0 °C. The reaction mixture was allowed to stir at room temperature for 24 h. Next, saturated aq $NaHCO_3$ solution (100 mL) was added to the reaction mixture. Then, the mixture was extracted with CH_2Cl_2 (3 × 50 mL) and the organic extracts were dried over anhydrous Na_2SO_4, filtered, and concentrated under reduced pressure. The crude product was purified by column chromatography on silica gel to obtain the pure quinoline *N*-oxide (70–90% yield).

2-(Arylsulfonyl)quinolines 3; General Procedure

A sealable reaction tube equipped with a magnetic stirrer bar was charged with a quinoline *N*-oxide (0.2 mmol), DABSO (0.4 mmol), an aryldiazonium tetrafluoroborate (0.4 mmol), CuOTf (10 mol%), and CH_2Cl_2 (1.5 mL). The reaction was carried out at 100 °C, under N_2. After completion, the mixture was diluted with EtOAc and washed with water. After the solvent was removed under reduced pressure, the residue was purified by column chromatography on silica gel to afford the corresponding 2-(arylsulfonyl)quinoline **3**.

2-(Phenylsulfonyl)quinoline (3a)[8]

White solid; yield: 47 mg (88%); mp 159–161 °C.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.30 (d, *J* = 8.5 Hz, 1 H), 8.14 (d, *J* = 8.5 Hz, 1 H), 8.11–8.05 (m, 3 H), 7.80 (d, *J* = 8.2 Hz, 1 H), 7.71 (ddd, *J* = 8.4, 6.9, 1.3 Hz, 1 H), 7.61–7.55 (m, 1 H), 7.55–7.50 (m, 1 H), 7.49–7.43 (m, 2 H).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 158.11, 147.48, 139.16, 138.78, 133.76, 131.03, 130.43, 129.25, 129.11, 129.06, 128.87, 127.74, 117.75.

6-Methyl-2-(phenylsulfonyl)quinoline (3b)[8]

White solid; yield: 45 mg (80%); mp 152–154 °C.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.19 (d, *J* = 8.5 Hz, 1 H), 8.08 (dd, *J* = 14.7, 8.1 Hz, 3 H), 7.99 (d, *J* = 8.6 Hz, 1 H), 7.53 (dd, *J* = 13.9, 8.3 Hz, 3 H), 7.46 (t, *J* = 7.6 Hz, 2 H), 2.48 (s, 3 H).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 157.17, 146.15, 139.74, 139.38, 137.84, 133.63, 133.42, 130.07, 129.07, 128.99, 126.44, 117.84, 21.83.

6-Chloro-2-(phenylsulfonyl)quinoline (3c)[8]

White solid; yield: 50 mg (83%); mp 169–171 °C.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.23 (d, *J* = 8.6 Hz, 1 H), 8.16 (d, *J* = 8.6 Hz, 1 H), 8.10–8.01 (m, 3 H), 7.80 (d, *J* = 2.2 Hz, 1 H), 7.65 (dd, *J* = 9.1, 2.2 Hz, 1 H), 7.55 (t, *J* = 7.4 Hz, 1 H), 7.48 (t, *J* = 7.7 Hz, 2 H).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 158.45, 145.82, 138.86, 137.82, 135.38, 133.91, 132.14, 131.95, 129.40, 129.17, 129.13, 126.37, 118.68.

3-Bromo-2-(phenylsulfonyl)quinoline (3d)[8]

White solid; yield: 42 mg (60%); mp 150–152 °C.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.47 (s, 1 H), 8.03 (d, *J* = 7.6 Hz, 2 H), 7.88 (d, *J* = 8.5 Hz, 1 H), 7.75–7.67 (m, 2 H), 7.61 (q, *J* = 7.9 Hz, 2 H), 7.51 (t, *J* = 7.7 Hz, 2 H).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 154.44, 144.46, 142.96, 138.00, 133.89, 131.12, 130.29, 130.12, 129.84, 128.72, 126.54, 111.39.

6-Methoxy-2-(phenylsulfonyl)quinoline (3e)[8]

White solid; yield: 41 mg (68%); mp 143–145 °C.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.15 (d, *J* = 8.6 Hz, 1 H), 8.07 (dd, *J* = 13.2, 8.0 Hz, 3 H), 7.98 (d, *J* = 9.3 Hz, 1 H), 7.51 (t, *J* = 7.4 Hz, 1 H), 7.45 (t, *J* = 7.6 Hz, 2 H), 7.34 (dd, *J* = 9.3, 2.7 Hz, 1 H), 7.01 (d, *J* = 2.7 Hz, 1 H), 3.86 (s, 3 H).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 159.89, 155.45, 143.69, 139.56, 136.86, 133.56, 131.86, 130.47, 129.06, 128.89, 124.36, 118.32, 104.62, 55.76.

6-Fluoro-2-(phenylsulfonyl)quinoline (3f)[22]

White solid; yield: 37 mg (65%); mp 119–121 °C.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.26 (d, *J* = 8.6 Hz, 1 H), 8.16 (d, *J* = 8.6 Hz, 1 H), 8.11 (dd, *J* = 9.3, 5.3 Hz, 1 H), 8.09–8.03 (m, 2 H), 7.55 (t, *J* = 7.4 Hz, 1 H), 7.52–7.45 (m, 3 H), 7.42 (dd, *J* = 8.5, 2.7 Hz, 1 H).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 162.98, 160.97, 157.70, 144.56, 139.01, 138.06 (d, *J* = 5.8 Hz), 133.84, 133.18 (d, *J* = 9.6 Hz), 129.83 (d, *J* = 10.6 Hz), 129.15, 129.08, 121.69 (d, *J* = 26.2 Hz), 118.55, 110.8 (d, *J* = 22.2 Hz).

3-Methyl-2-(phenylsulfonyl)quinoline (3g)[6]

White solid; yield: 37 mg (66%); mp 150–152 °C.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.05–7.94 (m, 3 H), 7.81 (d, *J* = 8.4 Hz, 1 H), 7.69 (d, *J* = 8.0 Hz, 1 H), 7.63–7.54 (m, 2 H), 7.54–7.46 (m, 3 H), 2.81 (s, 3 H).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 156.94, 144.67, 139.89, 138.79, 133.56, 129.97, 129.80, 129.50, 129.16, 129.04, 128.67, 128.59, 126.72, 18.81.

Methyl 2-(Phenylsulfonyl)quinoline-6-carboxylate (3h)

White solid; yield: 48 mg (74%); mp 146–148 °C.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.63 (s, 1 H), 8.50 (d, *J* = 8.5 Hz, 1 H), 8.36 (d, *J* = 8.9 Hz, 1 H), 8.28 (d, *J* = 8.5 Hz, 1 H), 8.20 (d, *J* = 8.9 Hz, 1 H), 8.16 (d, *J* = 7.9 Hz, 2 H), 7.64 (t, *J* = 7.3 Hz, 1 H), 7.56 (t, *J* = 7.6 Hz, 2 H), 4.00 (s, 3 H).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 165.98, 160.22, 149.14, 140.21, 138.63, 134.01, 130.73, 130.64, 130.49, 130.39, 129.27, 129.19, 128.04, 118.38, 52.73.

HRMS (ESI): *m*/*z* $[M + H]^+$ calcd for $C_{17}H_{13}NO_4S$: 328.06467; found: 328.06381.

2-(*o*-Tolylsulfonyl)quinoline (3i)[11a,22]

White solid; yield: 49 mg (86%); mp 115–117 °C.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.31 (d, *J* = 8.5 Hz, 1 H), 8.23 (d, *J* = 7.9 Hz, 1 H), 8.10 (d, *J* = 8.5 Hz, 1 H), 8.04 (d, *J* = 8.6 Hz, 1 H), 7.81 (d, *J* = 8.2 Hz, 1 H), 7.73–7.66 (m, 1 H), 7.59 (t, *J* = 7.5 Hz, 1 H), 7.43 (t, *J* = 7.5 Hz, 1 H), 7.35 (t, *J* = 7.6 Hz, 1 H), 7.18 (d, *J* = 8.1 Hz, 1 H), 2.49 (s, 3 H).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 158.25, 147.21, 139.16, 138.64, 137.17, 133.94, 132.49, 130.99, 130.67, 130.44, 129.21, 128.93, 127.75, 126.43, 117.78, 20.75.

2-((4-Fluorophenyl)sulfonyl)quinoline (3j)[11a,22]

White solid; yield: 41 mg (72%); mp 124–126 °C.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.33 (d, *J* = 8.5 Hz, 1 H), 8.18–8.06 (m, 4 H), 7.82 (d, *J* = 8.2 Hz, 1 H), 7.77–7.69 (m, 1 H), 7.60 (t, *J* = 7.5 Hz, 1 H), 7.15 (t, *J* = 8.6 Hz, 2 H).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 167.00, 164.96, 158.02, 147.46, 138.86, 135.02, 132.03 (d, *J* = 9.7 Hz), 131.13, 130.37, 129.33, 128.89, 127.76, 117.49, 116.53, 116.35.

2-((4-Chlorophenyl)sulfonyl)quinoline (3k)[8]

White solid; yield: 41 mg (67%); mp 189–191 °C.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.32 (d, *J* = 8.5 Hz, 1 H), 8.14 (d, *J* = 8.5 Hz, 1 H), 8.08 (d, *J* = 8.6 Hz, 1 H), 8.01 (d, *J* = 8.6 Hz, 2 H), 7.82 (d, *J* = 8.2 Hz, 1 H), 7.73 (t, *J* = 7.5 Hz, 1 H), 7.60 (t, *J* = 7.5 Hz, 1 H), 7.44 (d, *J* = 8.6 Hz, 2 H).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 157.82, 147.48, 140.60, 138.89, 137.53, 131.17, 130.61, 130.38, 129.44, 129.39, 128.92, 127.77, 117.52.

2-((4-Bromophenyl)sulfonyl)quinoline (3l)[11a,22]

White solid; yield: 51 mg (73%); mp 145–147 °C.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.32 (d, *J* = 8.5 Hz, 1 H), 8.13 (d, *J* = 8.5 Hz, 1 H), 8.08 (d, *J* = 8.6 Hz, 1 H), 7.93 (d, *J* = 8.5 Hz, 2 H), 7.82 (d, *J* = 8.2 Hz, 1 H), 7.73 (dd, *J* = 11.4, 4.0 Hz, 1 H), 7.65–7.57 (m, 3 H).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 157.77, 147.49, 138.90, 138.08, 132.42, 131.18, 130.66, 130.38, 129.40, 129.25, 128.92, 127.77, 117.52.

2-((4-Methoxyphenyl)sulfonyl)quinoline (3m)[11a,22]

White solid; yield: 49 mg (82%); mp 130–132 °C.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.29 (d, *J* = 8.3 Hz, 1 H), 8.11 (dd, *J* = 11.6, 4.7 Hz, 2 H), 8.00 (dd, *J* = 8.7, 1.5 Hz, 2 H), 7.79 (d, *J* = 8.1 Hz, 1 H), 7.71 (t, *J* = 7.7 Hz, 1 H), 7.57 (t, *J* = 7.5 Hz, 1 H), 6.92 (dd, *J* = 8.7, 1.4 Hz, 2 H), 3.77 (d, *J* = 1.5 Hz, 3 H).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 163.91, 158.68, 147.46, 138.68, 131.32, 130.92, 130.52, 130.41, 129.07, 128.78, 127.70, 117.57, 114.41, 55.67.

2-((4-(Trifluoromethyl)phenyl)sulfonyl)quinoline (3n)[11a,22]

White solid; yield: 49 mg (73%); mp 126–128 °C.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.35 (d, *J* = 8.5 Hz, 1 H), 8.22 (d, *J* = 8.2 Hz, 2 H), 8.17 (d, *J* = 8.5 Hz, 1 H), 8.08 (d, *J* = 8.6 Hz, 1 H), 7.83 (d, *J* = 8.2 Hz, 1 H), 7.74 (t, *J* = 6.7 Hz, 3 H), 7.62 (t, *J* = 7.5 Hz, 1 H).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 157.38, 147.52, 142.66, 139.00, 135.47, 135.20, 131.28, 130.39, 129.75, 129.56, 129.00, 127.80, 126.21, 126.19, 126.16, 126.13, 124.26, 122.09, 117.59.

Methyl 4-(Quinolin-2-ylsulfonyl)benzoate (3o)

White solid; yield: 53 mg (81%); mp 130–132 °C.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.34 (d, *J* = 8.5 Hz, 1 H), 8.20–8.10 (m, 5 H), 8.07 (d, *J* = 8.6 Hz, 1 H), 7.82 (d, *J* = 8.2 Hz, 1 H), 7.73 (t, *J* = 7.7 Hz, 1 H), 7.61 (t, *J* = 7.5 Hz, 1 H), 3.87 (s, 3 H).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 165.60, 157.58, 147.50, 142.98, 138.92, 134.75, 131.20, 130.41, 130.18, 129.46, 129.21, 128.96, 127.77, 117.66, 52.70.

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{17}H_{13}NO_4S$: 328.06451; found: 328.06381.

2-(*m*-Tolylsulfonyl)quinoline (3p)

White solid; yield: 45 mg (79%); mp 125–127 °C.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.31 (d, *J* = 8.5 Hz, 1 H), 8.13 (t, *J* = 9.0 Hz, 2 H), 7.87 (d, *J* = 7.7 Hz, 2 H), 7.81 (d, *J* = 8.2 Hz, 1 H), 7.72 (t, *J* = 7.7 Hz, 1 H), 7.59 (t, *J* = 7.5 Hz, 1 H), 7.38–7.31 (m, 2 H), 2.35 (s, 3 H).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 158.23, 147.51, 139.38, 139.02, 138.72, 134.58, 130.98, 130.49, 129.28, 129.20, 128.99, 128.87, 127.71, 126.22, 117.84, 21.34.

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{16}H_{13}NO_2S$: 284.07465; found: 284.07398.

2-Tosylquinoline (3q)[8]

White solid; yield: 44 mg (78%); mp 142–144 °C.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.29 (d, *J* = 8.5 Hz, 1 H), 8.11 (dd, *J* = 11.1, 8.7 Hz, 2 H), 7.95 (d, *J* = 8.3 Hz, 2 H), 7.80 (d, *J* = 8.1 Hz, 1 H), 7.74–7.66 (m, 1 H), 7.58 (t, *J* = 7.5 Hz, 1 H), 7.25 (d, *J* = 8.1 Hz, 2 H), 2.33 (s, 3 H).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 158.41, 147.48, 144.82, 138.69, 136.17, 130.95, 130.45, 129.79, 129.14, 129.10, 128.82, 127.70, 117.70, 21.67.

3-Methyl-2-tosylquinoline (3r)[7,11a]

White solid; yield: 45 mg (75%); mp 114–116 °C.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.99 (s, 1 H), 7.86 (t, *J* = 9.6 Hz, 3 H), 7.70 (d, *J* = 8.0 Hz, 1 H), 7.58 (dd, *J* = 11.2, 4.0 Hz, 1 H), 7.52 (t, *J* = 7.4 Hz, 1 H), 7.30 (d, *J* = 8.1 Hz, 2 H), 2.80 (s, 3 H), 2.40 (s, 3 H).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 157.14, 144.73, 144.51, 139.83, 135.84, 130.03, 129.72, 129.51, 129.37, 129.16, 128.96, 128.62, 126.68, 21.74, 18.90.

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Supporting Information

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References

(1) (a) Lee, H.-Y.; Chang, J.-Y.; Nien, C.-Y.; Kuo, C.-C.; Shih, K.-H.; Wu, C.-H.; Chang, C.-Y.; Lai, W.-Y.; Liou, J.-P. *J. Med. Chem.* **2011**, *54*, 8517. (b) Hussain, I.; Yawer, M. A.; Lalk, M.; Lindequist, U.; Villinger, A.; Fischer, C.; Langer, P. *Bioorg. Med. Chem.* **2008**, *16*, 9898. (c) Grassberger, M. A.; Turnowsky, F.; Hildebrandt, J. *J. Med. Chem.* **1984**, *27*, 947. (d) Liang, Q.; Zhang, Y.; Zeng, M.; Guan, L.; Xiao, Y.; Xiao, F. *Toxicol. Res.* **2018**, *7*, 521. (e) Stevens, M.; Pannecouque, C.; De Clercq, E.; Balzarini, J. *Antimicrob. Agents Chemother.* **2003**, *47*, 2951. (f) Sun, P.; Yang, D.; Wei, W.; Jiang, M.; Wang, Z.; Zhang, L.; Zhang, H.; Zhang, Z.; Wang, Y.; Wang, H. *Green Chem.* **2017**, *19*, 4785. (g) Wei, W.; Cui, H.; Yang, D.; Yue, H.; He, C.; Zhang, Y.; Wang, H. *Green Chem.* **2017**, *19*, 5608. (h) Wei, W.; Bao, P.; Yue, H.; Liu, S.; Wang, L.; Li, Y.; Yang, D. *Org. Lett.* **2018**, *20*, 5291. (i) Yu, Q.; Yang, Y.; Wan, J.; Liu, Y. *J. Org. Chem.* **2018**, *83*, 11385. (j) Hu, F.; Gao, W.; Chang, H.; Li, X.; Wei, W. *Chin. J. Org. Chem.* **2015**, *35*, 1848.

(2) (a) Xue, F.; Wang, D.; Li, X.; Wan, B. *J. Org. Chem.* **2012**, *77*, 3071. (b) Furukawa, N.; Ogawa, S.; Matsumur, K.; Fujihara, H. *J. Org. Chem.* **1991**, *56*, 6341.

(3) (a) Cacchi, S.; Fabrizi, G.; Goggiamani, A.; Parisi, L. M.; Bernini, R. *J. Org. Chem.* **2004**, *69*, 5608. (b) Kar, A.; Sayyed, I. A.; Lo, W. F.; Kaiser, H. M.; Beller, M.; Tse, M. K. *Org. Lett.* **2007**, *9*, 3405. (c) Maloney, K. M.; Kuethe, J. T.; Linn, K. *Org. Lett.* **2011**, *13*, 102. (d) Xie, L.-Y.; Duan, Y.; Lu, L.-H.; Li, Y.-J.; Peng, S.; Wu, C.; Liu, K.-J.; Wang, Z.; He, W.-M. *ACS Sustainable Chem. Eng.* **2017**, *5*, 10407. (e) Lu, L.-H.; Zhou, S.-J.; He, W.-B.; Xia, W.; Chen, P.; Yu, X.; Xu, X.; He, W.-M. *Org. Biomol. Chem.* **2018**, *16*, 9064. (f) Li, G.-H.; Dong, D.-Q.; Yang, Y.; Yu, X.-Y.; Wang, Z.-L. *Adv. Synth. Catal.* **2019**, *361*, 832. (g) Li, G.-H.; Dong, D.-Q.; Yu, X.-Y.; Wang, Z.-L. *New J. Chem.* **2019**, *43*, 1667. (h) Xie L.-Y., Peng S., Liu F., Liu Y.-F., Sun M., Tang Z.-L., Jiang S., Cao Z., He W.-M. *ACS Sustainable Chem. Eng.* **2019**, 7, 7193

(4) Sun, K.; Chen, X.-L.; Li, X.; Qu, L.-B.; Bi, W.-Z.; Chen, X.; Ma, H.-L.; Zhang, S.-T.; Han, B.-W.; Zhao, Y.-F.; Li, C.-J. *Chem. Commun.* **2015**, *51*, 12111.

(5) (a) Xie, L.-Y.; Li, Y.-J.; Qu, J.; Duan, Y.; Hu, J.; Liu, K.-J.; Cao, Z.; He, W.-M. *Green Chem.* **2017**, *19*, 5642. (b) Xie, L.-Y.; Peng, S.; Liu, F.; Yi, J.-Y.; Wang, M.; Tang, Z.; Xu, X.; He, W.-M. *Adv. Synth. Catal.* **2018**, *360*, 4259. (c) Xie, L.-Y.; Peng, S.; Lu, L.-H.; Hu, J.; Bao, W.-H.; Zeng, F.; Tang, Z.; Xu, X.; He, W.-M. *ACS Sustainable Chem. Eng.* **2018**, *6*, 7989.

(6) Su, Y.; Zhou, X.-J.; He, C.-L.; Zhang, W.; Ling, X.; Xiao, X. *J. Org. Chem.* **2016**, *81*, 4981.

(7) Wang, R.-J.; Zeng, Z.-B.; Chen, C.; Yi, N.-N.; Jiang, J.; Cao, Z.; Deng, W.; Xiang, J.-N. *Org. Biomol. Chem.* **2016**, *14*, 5317.

(8) Fu, W.-K.; Sun, K.; Qu, C.; Chen, X.-L.; Qu, L.-B.; Bi, W.-Z.; Zhao, Y.-F. *Asian J. Org. Chem.* **2017**, *6*, 492.

(9) Sumunnee, L.; Buathongjan, C.; Pimpasri, C.; Yotphan, S. *Eur. J. Org. Chem.* **2017**, 1025.

(10) Du, B.; Qian, P.; Wang, Y.; Mei, H.; Han, J.; Pan, Y. *Org. Lett.* **2016**, *18*, 4144.

(11) (a) Xie, L.-Y.; Peng, S.; Liu, F.; Chen, G.-R.; Xia, W.; Yu, X.-Y.; Li, W.-F.; Cao, Z.; He, W.-M. *Org. Chem. Front.* **2018**, *5*, 2604. (b) Xie, L.-Y.; Peng, S.; Jiang, L.-L.; Peng, X.; Xia, W.; Yu, X.; Wang, X.-X.; Cao, Z.; He, W.-M. *Org. Chem. Front.* **2019**, *6*, 167.

(12) Nguyen, B.; Emmet, E. J.; Willis, M. C. *J. Am. Chem. Soc.* **2010**, *132*, 16372.

(13) For selected examples, see: (a) Qiu, G.-Y.-S.; Lai, L.-F.; Cheng, J.; Wu, J. *Chem. Commun.* **2018**, *54*, 10405. (b) Mao, R.-Y.; Zheng, D.-Q.; Xia, H.-G.; Wu, J. *Org. Chem. Front.* **2016**, *3*, 693. (c) Wang, H.-P.; Sun, S.; Cheng, J. *Org. Lett.* **2017**, *19*, 5844. (d) Vedovato, V.; Talbot, E. P. A.; Willis, M. C. *Org. Lett.* **2018**, *20*, 5493. (e) Bao, W.-H.; Wu, C.; Wang, J.-T.; Xia, W.; Chen, P.; Tang, Z.; Xu, X.; He, W.-M. *Org. Biomol. Chem.* **2018**, *16*, 8403. (f) Wang, Y.; Deng, L.-L.; Deng, Y.; Han, J.-L. *J. Org. Chem.* **2018**, *83*, 4674. (g) Zhu, T.-H.; Zhang, X.-C.; Zhao, K.; Loh, T. P. *Org. Chem. Front.* **2019**, *6*, 94. (h) Tribby, A. L.; Rodríguez, I.; Shariffudin, S.; Ball, N. D. *J. Org. Chem.* **2017**, *82*, 2294. (i) Du, B.; Wang, Y.; Sha, W.; Qian, P.; Mei, H.; Han, J.; Pan, Y. *Asian J. Org. Chem.* **2017**, *6*, 153. (j) Sheng, J.; Li, Y.; Qi, G. *Org. Chem. Front.* **2017**, *4*, 95. (k) Xie L.-Y., Peng S.,

Fan T.-G., Liu Y.-F., Sun M., Jiang L.-L., Wang X.-X., Cao Z., He W.-M. *Sci. China Chem.* **2019**, *62*, 460. (l) Wang, X.; Xue, L.; Wang, Z. *Org. Lett.* **2014**, *16*, 4056. (m) Li G., Gan Z., Kong K., Dou X., Yang D.; *Adv. Synth. Catal.*; **2019**, in press; DOI: 10.1002/adsc.201900157

(14) (a) Sun, K.; Shi, Z.-D.; Liu, Z.-H.; Luan, B.-X.; Zhu, J.-L.; Xue, Y.-R. *Org. Lett.* **2018**, *20*, 6687. (b) Xiang, Y.-C.; Kuang, Y.-Y.; Wu, J. *Chem. Eur. J.* **2017**, *23*, 6996.

(15) Zhou, K.-D.; Zhang, J.; Lai, L.-F.; Cheng, J.; Sun, J.-T.; Wu, J. *Chem. Commun.* **2018**, *54*, 7459.

(16) Yang, D.-S.; Sun, P.-F.; Wei, W.; Liu, F.-J.; Zhang, H.; Wang, H. *Chem. Eur. J.* **2018**, *24*, 4423.

(17) Liu, N.-W.; Chen, Z.-K.; Herbert, A.; Ren, H.-J.; Manolikakes, G. *Eur. J. Org. Chem.* **2018**, 5725.

(18) (a) Zheng, D.-Q.; Yu, J.-Y.; Wu, J. *Angew. Chem. Int. Ed.* **2016**, *55*, 11925. (b) Gong, X.-X.; Ding, Y.-C.; Fan, X.-N.; Wu, J. *Adv. Synth. Catal.* **2017**, *359*, 2999. (c) Sheng, J.; Li, Y.-W.; Qiu, G.-Y.-S. *Org. Chem. Front.* **2017**, *4*, 95. (d) Tsai, A. S.; Curto, J. M.; Rocke, B. N.; Schmitt, A. M. R. D.; Ingle, G. K.; Mascitti, V. *Org. Lett.* **2016**, *18*, 508.

(19) (a) Dong, D.-Q.; Chen, W.-J.; Yang, Y.; Gao, X.; Wang, Z.-L. *ChemistrySelect* **2019**, *4*, 2480. (b) Hao, S.-H.; Li, L.-X.; Dong, D.-Q.; Wang, Z.-L.; Yu, X. *Tetrahedron Lett.* **2018**, *59*, 4073. (c) Dong, D.-Q.; Gao, X.; Li, L.-X.; Hao, S.-H.; Wang, Z.-L. *Res. Chem. Intermed.* **2018**, *44*, 7557. (d) Li, L.-X.; Dong, D.-Q.; Hao, S.-H.; Wang, Z.-L. *Tetrahedron Lett.* **2018**, *59*, 1517.

(20) Chen, X.; Zhu, C.-W.; Cui, C.-L.; Wu, Y.-J. *Chem. Commun.* **2013**, *49*, 6900.

(21) Biswas, A.; Karmakar, U.; Pal, A.; Samanta, R. *Chem. Eur. J.* **2016**, *22*, 13826.

(22) Li, P.; Jiang, Y.-J.; Li, H.; Dong, W.-R.; Peng, Z.-H.; An, D.-L. *Synth. Commun.* **2018**, *48*, 1909.