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Iron-Catalyzed Electrophilic Amination of Sodium Sulfinates with Anthranils

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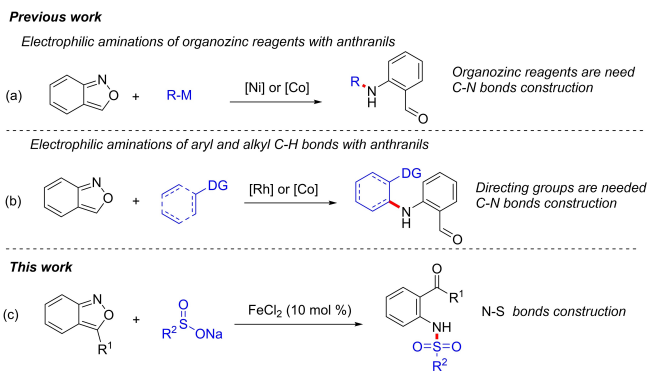
A practical method for the synthesis of *N*-(2-carbonylaryl) benzenesulfonamides via an iron-catalyzed electrophilic amination of sodium sulfinates with anthranils is described. This redox-neutral transformation has high atom efficiency and is achieved under simple and mild reaction conditions. A wide range of anthranils and sodium sulfinates were compatible in this transformation. Moreover, the synthetic potential of this methodology was further demonstrated by the synthesis of various useful N-heterocycles and derivatives.

Introduction

Nitrogen-containing compounds are ubiquitous in a range of biologically active natural products, pharmaceutical targets, agrochemicals, and functional materials.[1] The efficient construction of X–N (such as X=C, O, S) bonds represents an important area in organic synthesis. Among the methods used to construct X–N bonds, electrophilic amination, an umpolung strategy involving an electrophilic nitrogen source (such as R_2N–Y, Y=OR, X) as an aminating reagent, has attracted much attention from chemists because of its high efficiency and broad applications.[2] Over recent decades, various elegant electrophilic aminations have been reported, and have made important contributions to the diversity of C–N bonds.[3] However, there are still challenges involved with this type of reaction. For instance, *O*-benzoylhydroxylamines are the most widely used electrophilic aminating reagents, but they only suitable for alkyl amination reactions, and the reaction atom economy is low due to the leaving groups.[4] Additionally, only Cu[5] and Pd-catalyzed[6] systems have been disclosed, which largely limits the development of the electrophilic aminations. In particular, abundant Fe-catalysts have rarely been used in electrophilic aminations.[7]

Anthranils are fascinating synthetic building blocks that have been widely used in transition metal-catalyzed C–N bond formation and N-heterocycle synthesis.[8] These compounds were first used as electrophilic aminating reagents in the cross-coupling with organometallic reagents such as RZnX.[9] This strategy was reported by Baum and co-workers in 1987[9a] and further improved by Knochel's group in 2019.[9b] Recently, our group also achieved the electrophilic amination of arylboronic acids with a copper catalyst.[9c] Meanwhile, several excellent transition-metal catalyzed C–H aminations with anthranils for the construction of C–N bonds have also been achieved by other research groups (Scheme 1b).[10] Despite advances in the application of anthranils as electrophilic aminating reagents, the iron-catalyzed electrophilic amination reactions or the construction of N-hetero bonds such as N–S bonds have rarely been reported.

N-(2-carbonylaryl) benzenesulfonamides are key structural units found in biologically active molecules, as well as in organic synthesis.[11] Their derivatives have also been reported to display potent insecticidal properties,[11a] and function as protease inhibitors.[11b–f] They are also used in the synthesis of high-value heterocycles such as dihydroquinoline and indole derivatives.[12] Typically, benzenesulfonamides are prepared from the reaction of *o*-carbonylanilines and sulfonyl chlorides



Scheme 1. Electrophilic aminations with anthranils.

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with pyridine as a base.[11] Additionally, the oxidative coupling of anilines and sulfinates has been developed for the synthesis of these compounds.[13] Nevertheless, these processes required the use of a large number of environmentally unfriendly pyridines or stoichiometric oxidants, with low atom economy. Inspired by the scarcity of Fe-catalyzed amination reactions and our continuing interest in N–O bond cleavage chemistry,[9c,14] we herein present our recent progress on an iron-catalyzed electrophilic amination of sodium sulfinates with anthranils for the construction of valuable *N*-(2-carbonylaryl) benzenesulfonamides via N–S bond formation (Scheme 1c).

Results and Discussion

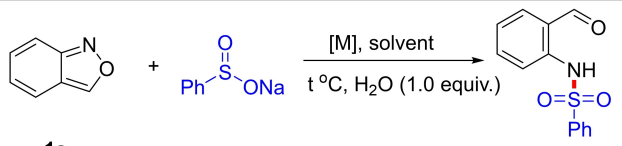
In our initial studies, anthranil (1a) and sodium benzenesulfinate (2a) were chosen as model substrates to investigate different reaction conditions. The results are summarized in Table 1. Pleasingly, the desired product 3aa was detected in 26% GC yield when $Fe(OAc)_2$ was used as the catalyst in CH_3CN at 80 °C in a sealed tube for 8 h (entry 1). Further screening of different catalysts such as $FeCl_2$, $Fe(acac)_2$, $FeBr_2$, $FeCl_3$, CuCl, and $CoCl_2$ suggested that $FeCl_2$ was the best catalyst for this transformation, giving 3aa in 61% GC yield. (entries 2–7). Subsequently, different solvents such as toluene, DMF, DMA, DEF (*N,N*-diethylformamide), 1,4-dioxane, and DCE were investigated. DEF was shown to be the best solvent for this reaction, giving 3aa in 87% GC yield and 83% isolated yield (entries 8–13). Further screening of the reaction temperature showed that 80 °C was optimal (entries 14 and 15). Moreover, no significant effect was observed when the reaction was conducted under an N_2 atmosphere or an O_2 atmosphere (entries 16 and 17), and a control experiment indicated that the $FeCl_2$ catalyst is essential for this reaction (entry 18).

With the optimal reaction conditions established, the scope and limitations of this electrophilic amination reaction were examined. A wide range of anthranils bearing various substitution patterns was tolerated in this transformation (Table 2). For example, a series of 5-substituted, 6-substituted, or 7-substituted anthranils, including some with electron-withdrawing groups, including fluoro, chloro, bromo, hydroxyl, cyano, trifluoromethyl moieties, and some with electron-donating groups afforded the *N*-(2-aldehyde) benzenesulfonamides products **3 ab**–**3 al** in moderate to good yields (61–83%). Moreover, 3-substituted anthranils were also compatible in this transformation, affording *N*-(2-carbonylaryl) benzenesulfonamides in good yield (**3 am**–**3 ao**).

Subsequently, the scope of sodium sulfinates was examined (Table 3). Both aryl and alkyl sodium sulfinates could participate in this transformation. Aryl sodium sulfinates with electron-donating substituents, including methyl, *t*-butyl, and methoxy moieties, and electron-withdrawing substituents such as fluoro, chloro, bromo, and *t*-butyloxycarbonyl on the *para*-position of the aromatic ring smoothly reacted with anthranils under the optimal reaction conditions. The desired products were afforded in moderate to good yields (**3 ba**–**3 im**, 63%–82%). Furthermore, polysubstituted sodium aryl sulfinates and sodium naphthyl sulfinate were also effective substrates, giving the corresponding products in good yields (**3 jm**–**3 lm**). Additionally, sodium thiophene sulfinate is also compatible in the reaction and afforded **3 mm** in 76% yield. Fortunately, sodium alkyl sulfinates such as methyl, ethyl, trifluoromethyl sodium sulfinates are also tolerated in the reaction, producing the desired product in good yield (**3 nm**–**3 pm**).

A gram-scale reaction of **1 a** with **2 b** was carried out on a 10 mmol scale under the standard reaction conditions, providing the desired product **3 ba** in 76% (2.09 g) isolated yield (Scheme 2).

Table 1. Optimization of reaction conditions.[a]

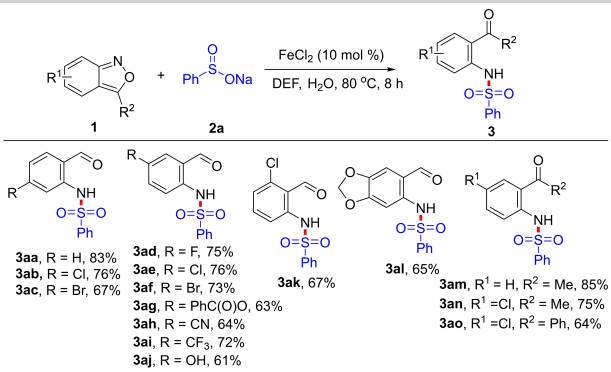


1a 2a 3aa

Entry 1[a]	Catalyst	Temp. [°C]	Solvent	Yield [%][b]
1	$Fe(OAc)_2$	80	CH_3CN	26
2	$FeCl_2$	80	CH_3CN	61
3	$Fe(acac)_2$	80	CH_3CN	20
4	$FeBr_2$	80	CH_3CN	60
5	$FeCl_3$	80	CH_3CN	24
6	CuCl	80	CH_3CN	35
7	$CoCl_2$	80	CH_3CN	trace
8	$FeCl_2$	80	toluene	trace
9	$FeCl_2$	80	DMF	83
10	$FeCl_2$	80	DMA	78
11	$FeCl_2$	80	DEF	87 (83)[c]
12	$FeCl_2$	80	1,4-dioxane	41
13	$FeCl_2$	80	DCE	35
14	$FeCl_2$	70	DEF	73
15	$FeCl_2$	90	DEF	70
16[d]	$FeCl_2$	80	DEF	82
17[e]	FeCl2	80	DEF	83
18	–	80	DEF	n.d.[f]

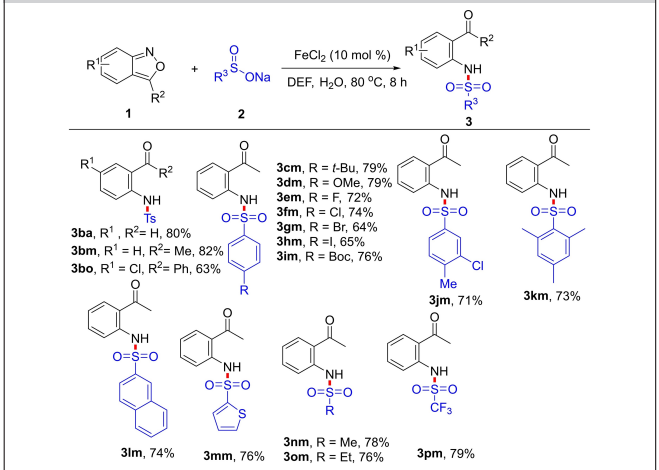
[a] Reaction conditions: Unless otherwise stated, all reactions were performed with **1 a** (0.3 mmol), **2 a** (0.45 mmol), water (0.3 mmol) and catalyst (10 mol%) in solvent (2.0 mL) for 8 h. [b] Yields and conversions analyzed by GC/MS with dodecane as internal standard are based on **1 a**. [c] Isolated yield. [d] Under an O_2 atmosphere. [e] under N_2 protection. [f] n.d. = not detected.

Table 2. Substrate scope of anthranils.[a]

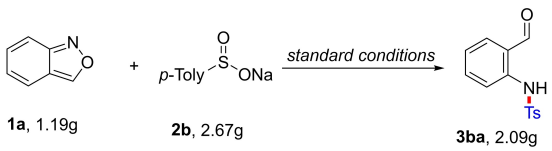


[a] Standard conditions: **1** (0.3 mmol), **2 a** (0.45 mmol), water (0.3 mmol), $FeCl_2$ (10 mol%) in DEF (2.0 mL) at 80 °C for 8 h.

Table 3. Substrate scope of sodium sulfinates.[a]



[a] Standard conditions: **1** (0.3 mmol), **2a** (0.45 mmol), water (0.3 mmol), $FeCl_2$ (10 mol%) in DEF (2.0 mL) at 80 °C for 8 h.

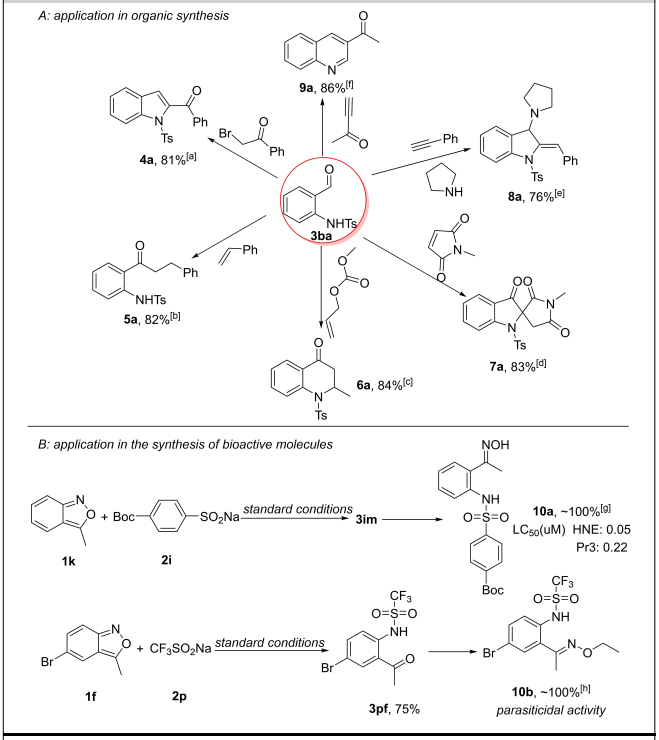


Scheme 2. Gram scale synthesis of **3ba**.

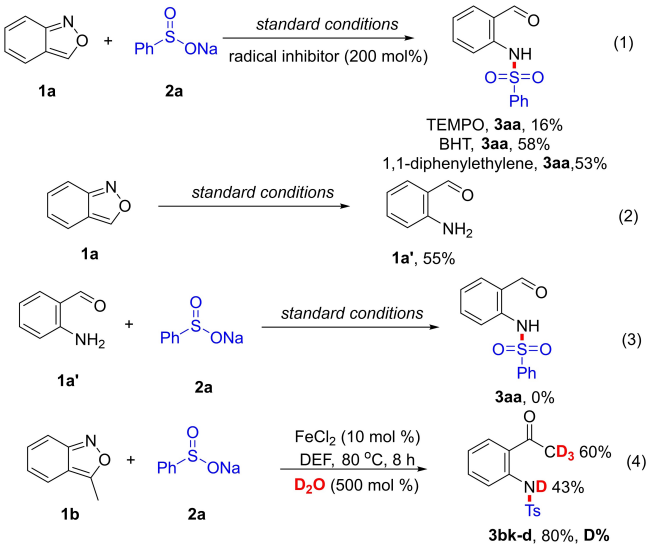
N-(2-Carbonylaryl) benzenesulfonamides are important nitrogen-containing skeletons in organic synthesis. As shown in Table 4, **3ba** could be easily transformed to a variety of high-value nitrogen-containing compounds such as indolines,[15a,b] quinolines,[15c] ketones, hydroquinolones,[15d] and spiroketones,[15e] in good yields. Additionally, this novel method was successfully applied to the synthesis of bioactive compounds. As shown in Table 4B, **3ik** was converted to the corresponding aldoxime compound **10a**, which is a dual inhibitor of neutrophil elastase and proteinase 3.[11e] In addition, the derivative product **10b**, which displays excellent vitro activity against C. felis and R. sanguineus, was obtained in an equivalent yield from **3pf**.[11c]

To gain more insight into the reaction mechanism, control experiments were performed (Scheme 3). First, to investigate the existence of radical intermediates in this reaction, 2 equiv. of radical scavengers TEMPO, BHT, or 1,1-diphenylethylene, were added to the standard reaction. It was found that the reaction still occurred with BHT and 1,1-diphenylethylene as additives, albeit with reduced yields (eq 1). Although the ring-opened by-product **1a'** was detected in the reaction (eq 2), no desired product was observed when **1a'** was treated with **2a** under the standard conditions (eq 3). Thus, **1a'** is not likely to be an intermediate in this transformation. When 5 equiv. D_2O was used to replace H_2O and added to the reaction system, the deuterated product **3bk–d** was obtained in 80% yield, with the incorporation of deuterium on the acetyl unit, which may be due to the formation of NaOH in the reaction system.[16]

Table 4. Verification experiments.

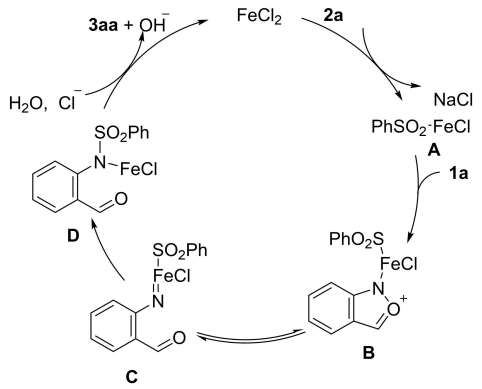


[a] Standard conditions: K_2CO_3, CH_3CN, 80 °C, 8 h. [b] $[Cp^*RhCl_2]_2$ (2.5 mol%), CsOAc, DCE, Ar, 100 °C, 18 h. [c] $[Cp^*RhCl_2]_2$ (2.5 mol%), PivOCs, DCE, Ar, 100 °C, 16 h. [d] $[Cp^*RhCl_2]_2$ (2.5 mol%), Ag_2CO_3, DCE, Ar, 120 °C, 18 h. [e] CuCl (5 mol%), $Cu(OTf)_2$ (5 mol%), DMAP, MeCN, Ar, 80 °C, 12 h. [f] 1) PPh_3 (10 mol%), MeCN, Ar, 80 °C, 12 h; 2) 1 N HCl, rt, 5 min. [g] NH_2OH. HCl, EtOH, reflux, 14 h. [h] NH_2OEt, NaOAc, EtOH/H_2O, reflux, 14 h.



Scheme 3. Control experiments.

Based on previous reports[17] and our preliminary results, a tentative mechanism for the iron-catalyzed electrophilic amination process is proposed in Scheme 4. First, **2a** reacts with $FeCl_2$ to give intermediate **A**, which coordinates with anthranils **1a** to produce intermediate **B**.[17a] This intermediate undergoes oxida-



Scheme 4. Plausible reaction pathways.

tive insertion to the N–O bond of anthranil to afford iron nitrene species **C**.[17b–g] Finally, 1,1-migratory insertion of **C** occurs to give **D**,[17h] which undergoes hydrolysis to deliver the desired product **3 aa**.

Conclusions

In summary, an efficient iron-catalyzed electrophilic amination of sodium sulfinate with anthranils has been developed, providing rapid access to a series of N-(2-carbonylaryl) benzenesulfonamides. This strategy demonstrates a unique iron-catalyzed electrophilic amination reaction. The advantages such as facile operation, mild and redox-neutral conditions, and no required additives or ligands make this method practical and attractive.

Experimental Section

General Information

Melting points were measured with a melting point instrument and were uncorrected. 1H and 13 C NMR spectra were recorded using a 400/500 MHz NMR spectrometer. The chemical shifts are referenced to signals at 7.26 and 77.0 ppm, respectively, and chloroform was used as the solvent with TMS as the internal standard. GC-MS was obtained using electron ionization. TLC was performed by using commercially prepared 200–400 mesh silica gel plates, and visualization was effected at 254 nm. High-resolution mass spectra (ESI) were obtained with an LCMS-IT-TOF mass spectrometer.

Typical procedure for preparation of anthranils 1[18]

Anthranils were synthesized according to the general procedure.[1] *O*-carbonyl nitrobenzene (3.0 mmol, 1.0 equiv), $SnCl_2.H_2O$ (9.0 mmol, 3.0 equiv) was added in EtOAc-MeOH (1:1; 15 mL) and the reaction mixture was stirred at room temperature overnight. The reaction mixture was partitioned between DCM (60 mL) and $NaHCO_3$ (40 mL). The aqueous phase was extracted with DCM (3× 30 mL) and the organic portions were combined, washed with H_2O (30 mL), saturated aqueous NaCl (30 mL), dried over MgSO4, filtered, and reduced in vacuo. Then the residue was purified by silica gel column chromatography to afford the corresponding anthranils.

Typical procedure for preparation of sodium sulfinates[19]

Benzenesulfinic acid sodium salt (**2 k**–**2 m**) was prepared by heating 20 mmol sodium sulfite, 10 mmol sulphonyl chlorides, and 20 mmol of sodium bicarbonate in 10 mL of water at 80 °C for 6 h. After cooling to room temperature, water was removed under vacuum and the residue was extracted by ethanol, recrystallization as white solid.

General Procedure for Products 3

Anthranils **1** (0.3 mmol), sodium sulfinates **2** (0.45 mmol), $FeCl_2$ (3.8 mg, 0.03 mmol), water (0.3 mmol), and 2 mL of DEF were added to a 10 mL screw-capped tube. The reaction vessel was closed with the cap and the reaction mixture was stirred at 80 °C (oil bath) for 8 h. The crude product was cooled to room temperature and concentrated in vacuum to give a residue, which was purified by flash column chromatography to afford the *N*-(2-carbonylaryl) benzenesulfonamides **3**.

***N*-(2-Formylphenyl)benzenesulfonamide** (**3 aa**): light yellow solid (64.5 mg, 83% yield); mp 120–121.3 °C; R_f = 0.4 (PE: EA = 5:1); ^{1}H NMR (500 MHz, $CDCl_3$) δ 10.82 (s, 1H), 9.81 (s, 1H), 7.91–7.85 (m, 2H), 7.68 (d, J = 8.4 Hz, 1H), 7.59 (dd, J = 7.6, 1.5 Hz, 1H), 7.55–7.48 (m, 2H), 7.44 (dd, J = 10.6, 4.8 Hz, 2H), 7.16 (td, J = 7.6, 0.9 Hz, 1H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 195.1, 139.8, 139.3, 136.2, 135.9, 133.3, 129.1, 127.2, 123.2, 122.0, 117.8; HRMS (ESI) m/z: calcd for $C_{13}H_{12}NO_3S$ $[M+H]^+$ 262.0532; found 262.0538.

***N*-(5-Chloro-2-formylphenyl)benzenesulfonamide** (**3 ab**): white solid (67.5 mg, 76% yield); mp 116.5–117.5 °C; R_f = 0.5 (PE: EA = 5:1); ^{1}H NMR (500 MHz, $CDCl_3$) δ 10.92 (s, 1H), 9.78 (s, 1H), 7.94–7.85 (m, 2H), 7.72 (d, J = 1.6 Hz, 1H), 7.56 (d, J = 7.4 Hz, 1H), 7.50 (dd, J = 13.7, 5.8 Hz, 3H), 7.13 (dd, J = 8.2, 1.8 Hz, 1H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 194.0, 142.7, 140.8, 139.0, 137.1, 133.6, 129.4, 127.2, 123.4, 120.1, 117.8; HRMS (ESI) m/z: calcd for $C_{13}H_{11}ClNO_3S$ $[M+H]^+$ 296.0143; found 296.0142.

***N*-(5-bromo-2-formylphenyl)benzenesulfonamide** (**3 ac**): yellow solid (67.9 mg, 67% yield); mp 119–120 °C; R_f = 0.5 (PE: EA = 5:1); ^{1}H NMR (500 MHz, $CDCl_3$) δ 10.88 (s, 1H), 9.78 (s, 1H), 7.91 (d, J = 7.5 Hz, 3H), 7.58 (t, J = 7.4 Hz, 1H), 7.50 (t, J = 7.7 Hz, 2H), 7.44 (d, J = 8.2 Hz, 1H), 7.30 (dd, J = 8.2, 1.6 Hz, 1H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 194.1, 140.7, 139.0, 137.0, 133.6, 131.5, 129.4, 128.7, 127.2, 126.4, 120.8; HRMS (ESI) m/z: calcd for $C_{13}H_{11}BrNO_3S$ $[M+H]^+$ 339.9638; found 339.9633.

***N*-(4-Fluoro-2-formylphenyl)benzenesulfonamide** (**3 ad**): yellow solid (62.7 mg, 75% yield); mp 80–81 °C; R_f = 0.6 (PE: EA = 5:1); ^{1}H NMR (500 MHz, $CDCl_3$) δ 10.50 (s, 1H), 9.77 (s, 1H), 7.91–7.82 (m, 2H), 7.75 (dd, J = 5, 5, 1H),7.59–7.54 (m, 1H), 7.50–7.44(m, 2H), 7.33–7.25 (m, 2H); ^{13}C NMR (126 MHz, $CDCl_3$) δ ^{13}C NMR (126 MHz, $CDCl_3$) δ 193.7, 158.3 (d, J = 246.7), 139.0, 135.9 (d, J = 2.7), 133.4, 129.2, 127.2, 123.2 (d, J = 5.5), 123.1 (d, J = 22.8), 121.3 (d, J = 22.8), 120.8 (d, J = 7.2); HRMS (ESI) m/z: calcd for $C_{13}H_{11}FNO_3S$ $[M+H]^+$ 280.0438; found 280.0432.

***N*-(4-Chloro-2-formylphenyl)benzenesulfonamide** (**3 ae**): yellow solid (67.3 mg, 76% yield); mp 97–98 °C; R_f = 0.60 (PE: EA = 5:1); ^{1}H NMR (500 MHz, $CDCl_3$) δ = 10.66 (s, 1H), 9.75 (s, 1H), 7.85 (d, J = 5.0, 2H), 7.66 (d, J = 10.0, 1H), 7.57–7.52 (m, 2H), 7.45 (t, J = 7.6, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 193.9, 139.0, 138.2, 135.7, 135.2, 133.5, 129.3, 128.6, 127.2, 123.0, 119.6; HRMS (ESI) m/z: calcd for $C_{13}H_{11}ClNO_3S$ $[M+H]^+$ 296.0143; found 296.0138.

***N*-(4-Bromo-2-formylphenyl)benzenesulfonamide** (**3af**): yellow solid (74.1 mg, 73% yield); mp 125–126 °C; R_f = 0.65 (PE: EA = 5:1); ^{1}H NMR (500 MHz, $CDCl_3$) δ 10.69 (s, 1H), 9.75 (s, 1H), 7.86 (d, J = 5, 2H), 7.70 (s, 1H), 7.67–7.59 (m, 2H), 7.58–7.53 (m, 1H), 7.52–7.41 (m, 2H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 193.8, 139.0, 138.8, 138.6, 138.2, 133.5, 129.3, 127.2, 123.2, 119.8, 115.6; HRMS (ESI) m/z: calcd for $C_{13}H_{11}BrNO_3S$ $[M+H]^+$ 339.9638; found 339.9630.

3-Formyl-4-(phenylsulfonamido)phenyl benzoate (**3ag**): white solid (72.0 mg, 63% yield); mp 109.4–110.7 °C; R_f = 0.4 (PE: EA = 5:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.71 (s, 1H), 9.80 (s, 1H), 8.16 (d, J = 7.8 Hz, 2H), 7.90 (d, J = 7.8 Hz, 2H), 7.80 (d, J = 9.0 Hz, 1H), 7.66 (t, J = 7.4 Hz, 1H), 7.57–7.46 (m, 6H), 7.39 (dd, J = 9.0, 2.5 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 194.1, 164.9, 146.2, 139.2, 137.4, 134.1, 133.5, 130.2, 129.4, 129.3, 128.8, 128.7, 128.4, 127.2, 122.5, 119.4; HRMS (ESI) m/z: calcd for $C_{20}H_{16}NO_5S$ $[M+H]^+$ 382.0744; found 382.0740.

***N*-(4-Cyano-2-formylphenyl)benzenesulfonamide** (**3ah**): yellow solid (55.5 mg, 6% yield); mp 128–130 °C; R_f = 0.2 (PE: EA = 5:1); ^{1}H NMR (500 MHz, DMSO) δ 11.09 (s, 1H), 9.98 (s, 1H), 8.30 (s, 1H), 8.00 (d, J = 8.5 Hz, 1H), 7.86 (d, J = 7.5 Hz, 2H), 7.69 (s, 1H), 7.59 (dd, J = 10.2, 4.5 Hz, 2H), 7.42 (d, J = 8.5 Hz, 1H); ^{13}C NMR (126 MHz, DMSO) δ 192.7, 142.7, 138.8, 138.7, 137.7, 134.5, 130.2, 127.4, 126.1, 121.4, 118.1, 107.5; HRMS (ESI) m/z: calcd for calcd for $C_{14}H_{11}N_2O_3S$ $[M+H]^+$ 287.0485; found 287.0491.

***N*-(2-Formyl-4-(trifluoromethyl)phenyl)benzenesulfonamide** (**3ai**): yellow solid (70.8 mg, 72% yield); mp 71–73 °C; R_f = 0.5 (PE: EA = 5:1); ^{1}H NMR (500 MHz, $CDCl_3$) δ 11.08 (s, 1H), 9.92 (s, 1H), 7.95 (d, J = 8.2 Hz, 2H), 7.91 (s, 1H), 7.81 (s, 1H), 7.76 (s, 1H), 7.61 (s, 1H), 7.53 (t, J = 7.7 Hz, 2H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 194.1, 142.6, 138.9, 133.8, 133.1 (J = 3.8 Hz), 132.4 (J = 3.8 Hz), 129.5, 127.3, 125.1, (J = 37.8 Hz), 123.3 (J = 270 Hz), 121.0, 117.5; HRMS (ESI) m/z: calcd for calcd for $C_{14}H_{11}F_3NO_3S$ $[M+H]^+$ 330.0406; found 330.0403.

***N*-(2-Formyl-4-hydroxyphenyl)benzenesulfonamide** (**3aj**): yellow solid (50.5 mg, 61% yield); mp 80–81 °C; R*f* = 0.65 (PE: EA = 5:1); ^{1}H NMR (500 MHz, $CDCl_3$) δ 10.70 (s, 1H), 9.78 (s, 1H), 7.89 (d, J = 5.0, 2H), 7.72 (d, J = 5.0, 1H), 7.67–7.61 (m, 2H), 7.58 (t, J = 7.4, 1H), 7.49 (t, J = 7.7, 2H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 193.8, 139.1, 138.8, 138.6, 138.2, 133.5, 129.3, 127.2, 123.2, 119.8, 115.6; HRMS (ESI) m/z: calcd for calcd for $C_{13}H_{12}NO_4S$ $[M+H]^+$ 278.0482; found 278.0478.

***N*-(3-Chloro-2-formylphenyl)benzenesulfonamide** (**3ak**): yellow solid (59.3 mg, 67% yield); mp 80–81 °C; R_f = 0.65 (PE: EA = 5:1); ^{1}H NMR (500 MHz, $CDCl_3$) δ 11.43–11.29 (m, 1H), 10.49–10.40 (m, 1H), 7.91–7.85 (m, 2H), 7.62–7.59 (m, 1H), 7.55 (td, J = 4.3, 0.9 Hz, 1H), 7.49–7.44 (m, 2H), 7.41–7.36 (m, 1H), 7.10–7.06 (m, 1H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 193.8, 142.1, 140.4, 139.1, 136.4, 133.5, 129.3, 127.3, 124.7, 117.7, 116.7; HRMS (ESI) m/z: calcd for $C_{13}H_{11}ClNO_3S$ $[M+H]^+$ 296.0143; found 296.0136.

***N*-(6-Formylbenzo[*d*][1,3]dioxol-5-yl)benzenesulfonamide** (**3al**): yellow solid (59.5 mg, 65% yield); mp 102.6–102.6 °C; R_f = 0.4 (PE: EA = 5:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 11.10 (s, 1H), 9.54 (s, 1H), 7.87–7.76 (m, 2H), 7.52 (d, J = 7.5 Hz, 1H), 7.44 (t, J = 7.6 Hz, 2H), 7.26 (s, 1H), 6.90 (s, 1H), 6.02 (s, 2H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 192.6, 154.0, 143.8, 139.2, 137.9, 133.3, 129.2, 127.2, 116.1, 112.9, 102.6, 99.8; HRMS (ESI) m/z: calcd for $C_{14}H_{12}NO_5S$ $[M+H]^+$ 306.0431; found 306.0436.

***N*-(2-Acetylphenyl)benzenesulfonamide** (**3am**) yellow solid (73.5 mg, 85% yield); mp 172–173 °C; R_f = 0.6 (PE: EA = 5:1); ^{1}H NMR (500 MHz, $CDCl_3$) δ 11.49 (s, 1H), 7.86-7.82 (m, 2H), 7.80–7.78 (m, 1H), 7.70–7.78 (dd, J = 8.4, 0.8 Hz, 1H), 7.54–7.49 (m, 1H), 7.48–7.40 (m, 3H), 7.10–7.04 (m, 1H), 2.55 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 202.5, 139.9, 139.5, 135.0, 133.0, 131.9, 129.1, 127.2, 122.8, 122.4, 119.3, 28.2; HRMS (ESI) m/z: calcd for $C_{14}H_{14}NO_3S$ $[M+H]^+$ 276.0689;. found 276.0682.

***N*-(2-Acetyl-4-chlorophenyl)benzenesulfonamide** (**3an**): yellow solid (72.2 mg, 75% yield); mp 140–141 °C; R_f = 0.6 (PE: EA = 5:1); ^{1}H NMR (500 MHz, $CDCl_3$) δ 11.27 (s, 1H), 7.82 (d, J = 5, 2H), 7.72 (d, J = 5, 1H), 7.68 (d, J = 10, 1H), 7.56–7.51 (m, 1H), 7.49–7.40 (m, 3H), 2.53 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 196.0, 133.9, 133.1, 129.4, 127.9, 126.1, 123.9, 122.9, 121.9, 118.3, 115.7, 22.8; HRMS (ESI) m/z: calcd for $C_{14}H_{13}ClNO_3S$ $[M+H]^+$ 310.0299; found 310.0292.

***N*-(2-Benzoyl-4-chlorophenyl)benzenesulfonamide** (**3ao**): light yellow solid (71.4 mg, 64% yield); mp 100.1–101.9 °C; R_f = 0.4 (PE: EA = 5:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.87 (s, 1H), 7.80 (d, J = 8.8 Hz, 1H), 7.73–7.68 (m, 2H), 7.61 (s, 1H), 7.50 (dd, J = 8.8, 2.5 Hz, 1H), 7.47–7.34 (m, 6H), 7.29 (dd, J = 10.3, 5.0 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.2, 138.6, 137.3, 136.9, 133.6, 133.2, 133.0, 132.3, 129.8, 129.2, 129.1, 128.4, 127.5, 127.1, 124.6; HRMS (ESI) m/z: calcd for $C_{19}H_{15}ClNO_3S$ $[M+H]^+$ 372.0456; found 372.0445.

***N*-(2-Acetylphenyl)-4-methylbenzenesulfonamide** (**3ba**): brown solid (62.1 mg, 76% yield); mp 102.4–103.6 °C; R_f = 0.6 (PE: EA = 5:1); ^{1}H NMR (500 MHz, $CDCl_3$) δ 10.82 (s, 1H), 9.85 (s, 1H), 7.81–7.77 (m, 2H), 7.70 (d, J = 8.4 Hz, 1H), 7.61 (dd, J = 7.6, 1.5 Hz, 1H), 7.55–7.50 (m, 1H), 7.27–7.24 (m, 2H), 7.18 (t, J = 7.5 Hz, 1H), 2.38 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 195.1, 144.2, 139.9, 136.3, 136.2, 135.9, 129.8, 127.3, 123.0, 121.8, 117.7, 21.6; HRMS (ESI) m/z: calcd for $C_{14}H_{14}NO_3S$ $[M+H]^+$ 276.0689; found 276.0682.

***N*-(2-Acetylphenyl)-4-methylbenzenesulfonamide** (**3bm**): yellow solid (71.0 mg, 82% yield); mp 156.2–156.7 °C; R_f = 0.6(PE: EA = 5:1); ^{1}H NMR (500 MHz, $CDCl_3$) δ 11.47 (s, 1H), 7.80-7.78 (dd, 1H), 7.72 (d, J = 8.3, 2H), 7.67 (dd, J = 8.4, 0.9, 1H), 7.48–7.41 (m, 1H), 7.21 (d, J = 8.1, 2H), 7.08–7.02 (m, 1H), 2.56 (d, J = 5.1, 3H), 2.35 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 202.5, 143.9, 140.1, 136.5, 135.0, 132.0, 129.7, 127.3, 122.6, 122.2, 119.0, 28.2, 21.6; HRMS (ESI) m/z: calcd for $C_{15}H_{16}NO_3S$ $[M+H]^+$ 290.0845; found 290.0836.

***N*-(2-Benzoyl-4-chlorophenyl)-4-methylbenzenesulfonamide** (**3bo**): brown solid (72.0 mg, 63% yield); mp 102.4–103.6 °C; R_f = 0.35 (PE: EA = 5:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.71 (s, 1H), 7.78 (d, J = 8.8 Hz, 1H), 7.61 (d, J = 7.3 Hz, 1H), 7.57–7.53 (m, 2H), 7.50 (dd, J = 8.8, 2.5 Hz, 1H), 7.44 (t, J = 7.8 Hz, 2H), 7.38 (dd, J = 8.3, 1.3 Hz, 2H), 7.35 (d, J = 2.5 Hz, 1H), 7.05 (d, J = 8.0 Hz, 2H), 2.25 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.0, 144.0, 137.3, 136.8, 135.5, 133.5, 133.2, 132.2, 129.9, 129.7, 129.3, 128.3, 127.9, 127.2, 125.1, 21.4; HRMS (ESI) m/z: calcd for $C_{20}H_{17}ClNO_3S$ $[M+H]^+$ 386.0612; found 386.0603.

***N*-(2-Acetylphenyl)-4-(tert-butyl)benzenesulfonamide** (**3cm**): yellow soild (78.0 mg, 79% yield); mp 156.2–156.7 °C; R_f = 0.6 (PE: EA = 5:1); ^{1}H NMR (500 MHz, $CDCl_3$) δ 11.45 (s, 1H), 7.78 (ddt, J = 10.7, 8.9, 1.8, 3H), 7.69 (d, J = 9.0, 1H), 7.49–7.42 (m, 3H), 7.09–7.05 (m, 1H), 2.55 (s, 3H), 1.28 (s, 9H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 202.4, 156.8, 140.1, 136.5, 135.0, 131.9, 127.1, 126.1, 122.5,122.4, 119.1, 35.2, 31.0, 28.2; HRMS (ESI) m/z: calcd for $C_{18}H_{22}NO_3S$ $[M+H]^+$ 332.1315; found 332.1305.

***N*-(2-Acetylphenyl)-4-methoxybenzenesulfonamide** (**3dm**): yellow soild (72.6 mg, 79% yield); mp 148.0–149.1 °C;R_f = 0.65 (PE: EA = 5:1); ^{1}H NMR (500 MHz, $CDCl_3$) δ = 7.51 (d, J = 8.9, 2H), 7.27 (d, J = 9.0, 2H), 6.87 (dd, J = 14.6, 8.9, 4H), 3.88 (d, J = 5.3, 3H), 3.83 (d, J = 9.2, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 163.6, 162.2, 138.4, 134.8, 129.9, 118.9, 114.9, 113.9, 55.8, 55.5; HRMS (ESI) m/z: calcd for $C_{15}H_{16}NO_4S$ $[M+H]^+$ 306.0795; found 306.0750.

***N*-(2-Acetylphenyl)-4-fluorobenzenesulfonamide** (**3em**): yellow soild (63.3 mg, 72% yield); mp 148.0–149.1 °C; R_f = 0.55 (PE: EA = 5:1); ^{1}H NMR (500 MHz, $CDCl_3$) δ 11.50 (s, 1H), 7.89–7.83(m,3H), 7.81 (d, J = 8.0, 0H), 7.67 (dd, J = 8.4, 1.7, 1H), 7.50–7.43 (m, 1H), 7.15–

7.05(m, 3H), 2.56 (d, J=1.7, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 202.7, 165.2 (d, J=255.78), 139.7, 135.5, 135.1, 132.1, 130.0 (d, J=10.0), 123.1, 122.4, 119.2, 116.4 (d, J=22.7), 28.2; HRMS (ESI) m/z: calcd for $C_{14}H_{13}FNO_3S$ [M+H]+ 294.0595; found 294.0588.

***N*-(2-Acetylphenyl)-4-chlorobenzenesulfonamide** (**3 fm**): yellow soild (68.8 mg, 74% yield); mp 138.2–139.1 °C; R_f=0.55 (PE: EA= 5:1); ^{1}H NMR (500 MHz, $CDCl_3$) δ 11.53 (s, 1H), 7.85–7.75 (m, 3H), 7.69 (d, J=8.4 Hz, 1H), 7.50–7.46 (m, 1H), 7.40 (d, J=8.6 Hz, 2H), 7.10 (t, J=7.7 Hz, 1H), 2.58 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 202.6, 139.7, 139.6, 138.0, 135.1, 132.1, 129.4, 128.7, 123.1, 122.4, 119.2, 28.2; HRMS (ESI) m/z: calcd for $C_{14}H_{13}ClNO_3S$ [M+H]+ 310.0299; found 310.0290.

***N*-(2-Acetylphenyl)-4-bromobenzenesulfonamide** (**3 gm**): yellow solid (67.5 mg, 64% yield); mp 153.9–154.5 °C; R_f=0.55(PE: EA= 5:1); ^{1}H NMR (500 MHz, $CDCl_3$) δ 11.54 (s, 1H), 7.81 (dd, J=8.0, 1.4 Hz, 1H), 7.76–7.65 (m, 3H), 7.59–7.52 (m, 2H), 7.51–7.41 (m, 1H), 7.13–7.02 (m, 1H), 2.57 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 202.7, 139.6, 138.5, 135.1, 132.4, 132.1, 128.8, 128.1, 123.1, 122.4, 119.1, 28.2; HRMS (ESI) m/z: calcd for $C_{14}H_{13}BrNO_3S$ $[M+H]^+$ 353.9794; found 353.9789.

***N*-(2-acetylphenyl)-4-iodobenzenesulfonamide** (**3 hm**): brown solid (78.1 mg, 65% yield); mp 168.1–168.6 °C; R_f=0.55 (PE: EA=5:1); ^{1}H NMR (500 MHz, $CDCl_3$) δ 11.53 (s, 1H), 7.81 (dd, J=8.0, 1.4 Hz, 1H), 7.80–7.73 (m, 2H), 7.67 (dd, J=8.4, 0.9 Hz, 1H), 7.58–7.52 (m, 2H), 7.50–7.42 (m, 1H), 7.13–7.07 (m, 1H), 2.57 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 202.6, 139.6, 139.2, 138.3, 1351, 132.1, 128.6, 123.1, 122.4, 119.1, 100.6, 28.2; HRMS (ESI) m/z: calcd for $C_{14}H_{13}INO_3S$ $[M+H]^+$ 401.9655; found 401.9647.

***tert*-Butyl-4-(*N*-(2-acetylphenyl)sulfamoyl)benzoate** (**3 im**): yellow solid (85.1 mg, 76% yield); mp 156–157 °C; R_f=0.55(PE: EA=5:1); ^{1}H NMR (500 MHz, $CDCl_3$) δ 11.46 (s, 1H), 7.87–7.81 (m, 2H), 7.79 (dd, J=8.0, 1.3 Hz, 1H), 7.69 (d, J=8.3 Hz, 1H), 7.49–7.40 (m, 1H), 7.16–7.10 (m, 2H), 7.10–7.05 (m, 1H), 2.55 (s, 3H), 1.32 (s, 9H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 202.7, 176.3, 154.6, 139.7, 136.5, 135.0, 132.0, 128.9, 123.1, 122.6, 122.3, 119.4, 39.2, 28.2, 27.0; HRMS (ESI) m/z: calcd for $C_{19}H_{22}NO_5S$ $[M+H]^+$ 376.1213; found 376.1216.

***N*-(2-Acetylphenyl)-3-chloro-4-methylbenzenesulfonamide** (**3 jm**): white solid (68.5 mg, 71% yield); mp 148.5–149.0 °C; R_f=0.55(PE: EA=5:1); ^{1}H NMR (500 MHz, $CDCl_3$) δ 11.55 (s, 1H), 7.84–7.81 (m, 2H), 7.68–7.62 (m, 2H), 7.48 (t, J=7.9 Hz, 1H), 7.29 (d, J=8.0 Hz, 1H), 7.09 (t, J=7.6 Hz, 1H), 2.58 (d, J=1.6 Hz, 3H), 2.37 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 202.5, 142.0, 139.7, 138.5, 135.2, 135.1, 132.1, 131.5, 127.8, 125.3, 122.9, 122.3, 119.0, 28.2, 20.3; HRMS (ESI) m/z: calcd for $C_{15}H_{15}ClNO_3S$ $[M+H]^+$ 324.0456; found 324.0448.

***N*-(2-Acetylphenyl)-2,4,6-trimethylbenzenesulfonamide** (**3 km**): yellow solid (69.5 mg, 73% yield); mp 160.8–161.2 °C; R_f=0.56 (PE: EA=5:1);^{1}H NMR (500 MHz, $CDCl_3$) δ 11.64 (s, 1H), 7.82 (dd, J=8.0, 1.4 Hz, 1H), 7.38 (s, 1H), 7.30 (dd, J=8.4, 1.0 Hz, 1H), 7.00 (s, 1H), 6.92 (s, 2H), 2.67 (s, 6H), 2.61 (s, 3H), 2.25 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 202.4, 142.8, 140.4, 139.4, 134.9, 133.8, 132.2, 132.1, 121.7, 121.3, 117.4, 28.2, 22.8, 21.0; HRMS (ESI) m/z: calcd for $C_{17}H_{20}NO_3S$ $[M+Na]^+$ 340.0978; found 340.0974.

***N*-(2-Acetylphenyl)naphthalene-2-sulfonamide** (**3 lm**): brown solid (72.0 mg, 74% yield); mp 141.2–142.0 °C; R_f=0.55(PE: EA=5:1); ^{1}H NMR (500 MHz, $CDCl_3$) δ 11.63 (s, 1H), 8.45 (d, J=1.4 Hz, 1H), 7.92 (d, J=8.0 Hz, 1H), 7.86 (dd, J=14.6, 8.4 Hz, 2H), 7.80 (dd, J=8.7, 1.9 Hz, 1H), 7.76 (dd, J=8.3, 1.2 Hz, 2H), 7.60 (dtd, J=13.4, 6.9, 3.5 Hz, 2H), 7.50–7.37 (m, 1H), 7.08–6.95 (m, 1H), 2.52 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 202.5, 140.0, 136.4, 135.0, 134.9, 132.0, 129.5, 129.3, 129.0, 128.9, 127.9, 127.6, 122.7, 122.3, 119.0, 28.2; HRMS (ESI) m/z: calcd for $C_{18}H_{16}NO_3S$ $[M+H]^+$ 326.0845; found 326.0840.

***N*-(2-Acetylphenyl)thiophene-2-sulfonamide** (**3 mm**): light yellow solid (64.0 mg, 76% yield); mp 246.5–247.3 °C; R_f=0.50, (PE: EA= 5:1); ^{1}H NMR (500 MHz, $CDCl_3$) δ 11.53 (s, 1H), 7.77 (d, J=7.9, 1H), 7.71 (d, J=8.4, 1H), 7.53 (s, 1H), 7.44 (d, J=6.9, 2H), 7.06 (t, J=7.6, 1H), 6.93 (s, 1H), 2.52 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 202.5, 140.2, 139.6, 135.1, 132.9, 132.5, 132.0, 127.3, 123.1, 122.5, 119.3, 28.2; HRMS (ESI) m/z: calcd for $C_{12}H_{12}NO_3S_2$ $[M+H]^+$ 282.0253; found 282.0247.

***N*-(2-Acetylphenyl)methanesulfonamide** (**3 nm**): light yellow solid (50.0 mg, 78% yield); mp 257.6–258.6 °C; R_f=0.50 (PE: EA=5:1); ^{1}H NMR (500 MHz, $CDCl_3$) δ 11.36 (s, 0H), 7.96 (d, J=8.0, 0H), 7.74 (d, J=8.4, 0H), 7.58 (t, J=7.8, 0H), 7.17 (t, J=7.6, 0H), 3.08 (d, J=2.6, 3H), 2.68 (d, J=2.7, 3H).; ^{13}C NMR (126 MHz, $CDCl_3$) δ 202.7, 140.4, 135.4, 132.5, 122.6, 121.6, 117.8, 40.2, 28.3; HRMS (ESI) m/z: calcd for $C_9H_{12}NO_3S$ $[M+H]^+$ 214.0532; found 214.0527.

***N*-(2-Acetylphenyl)ethanesulfonamide** (**3 om**): yellow solid (51.8 mg, 76% yield); mp 247.9–248.6 °C; R_f=0.35 (PE: EA=5:1); ^{1}H NMR (500 MHz, $CDCl_3$) ^{1}H NMR (500 MHz, $CDCl_3$) δ 11.28 (s, 1H), 7.95 (dd, J=35.9, 7.9 Hz, 1H), 7.73 (d, J=8.3 Hz, 1H), 7.61–7.48 (m, 1H), 7.15 (dt, J=14.9, 7.4 Hz, 1H), 3.15 (dd, J=14.6, 7.3 Hz, 2H), 2.64 (s, 3H), 1.37–1.21 (m, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 202.7, 140.6, 135.4, 132.5, 122.4, 121.4, 117.8, 46.5, 28.3, 8.2; HRMS (ESI) m/z: calcd for $C_{10}H_{14}NO_3S$ $[M+H]^+$ 228.0689; found 228.0681.

***N*-(2-Acetylphenyl)-1,1,1-trifluoromethanesulfonamide** (**3 pm**): grey solid (47.8 mg, 79% yield); mp 249.3–250.1 °C; R_f=0.4 (PE: EA=5:1); ^{1}H NMR (500 MHz, $CDCl_3$) δ 12.25 (s, 1H), 7.97 (dd, J=8.0, 1.4 Hz, 1H), 7.79 (d, J=8.3 Hz, 1H), 7.63–7.55 (m, 1H), 7.31–7.26 (m, 1H), 2.71 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 203.2, 138.2, 135.5, 132.1, 124.5, 122.6, 119.7 (q, J=323.8 Hz), 119.4, 28.1; HRMS (ESI) m/z: calcd for $C_9H_9F_3NO_3S$ $[M+H]^+$ 268.0250; found 268.0241.

***N*-(2-Acetyl-4-bromophenyl)-1,1,1-trifluoromethanesulfonamide** (**3 pf**)[4b] graw solid (77.2 mg, 75% yield); mp 240.9–241.6 °C; R_f=0.4 (PE: EA=5:1); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.72 (s, 1H), 7.40 (d, J= 12.5 Hz, 2H), 2.52 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 203.1, 140.1, 136.5, 133.1, 129.8, 124.4, 120.2, (q, J=325.2 Hz), 116.9, 115.4, 29.2.

General Procedure for phenyl(1-tosyl-1*H*-indol-2-yl)methanone (4 a):[20a] *N*-(2-acetylphenyl)-4- methylbenzene sulfonamide (**3 ba**) (0.3 mmol), K_2CO_3 (0.6 mmol), 2-bromoacetophenone (0.6 mmol), and 2 mL of dry CH_3CN were added to a 10 mL screw-capped tube. The reaction vessel was closed with the cap and the reaction mixture was stirred at 80 °C (oil bath) for 8 h. The crude product was cooled to room temperature and concentrated in vacuum to give a residue, which was purified by flash column chromatography to afford the **4 a**. It is yellow solid; R_f=0.55 (PE: EA=10:1); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.14 (d, J=8.5 Hz, 1H), 8.01–7.96 (m, 2H), 7.95 (d, J=8.4 Hz, 2H), 7.62 (t, J=7.4 Hz, 1H), 7.56 (s, 1H), 7.49 (dd, J= 17.3, 9.7 Hz, 3H), 7.28 (t, J=7.8 Hz, 3H), 6.93 (s, 1H), 2.37 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 187.7, 145.1, 137.9, 137.7, 137.5, 135.2, 133.6, 130.1, 129.7, 128.7, 128.5, 127.6, 127.0, 124.2, 122.6, 116.7, 115.2, 21.7; HRMS (ESI) m/z: calcd for $C_{22}H_{18}NO_3S$ $[M+H]^+$ 376.1002; found 376.1000

General Procedure for 4-methyl-*N*-(2-(3-phenylpropanoyl)phenyl) benzenesulfonamide (**5 a**):[20e] **3 ba** (0.3 mmol), styrene (3 equiv), CsOAc (0.36 mmol), $[RhCp^*Cl_2]_2$ (0.0075 mmol), DCE (3 mL) were added to a 10 mL screw-capped tube and the reaction mixture was stirred at at 100 °C for 18 h under argon atmosphere. The crude product was cooled to room temperature and concentrated in vacuum to give a residue, which was purified by flash column chromatography to afford the **5 a**. This is white solid. R_f=0.4 (PE: EA=10:1); ^{1}H NMR (500 MHz, $CDCl_3$) δ 11.42 (s, 1H), 7.78 (dd, J= 8.0, 1.1 Hz, 1H), 7.70 (dd, J=11.0, 8.5 Hz, 3H), 7.44 (s, 1H), 7.30 (d, J=7.4 Hz, 2H), 7.25–7.17 (m, 5H), 7.04 (s, 1H), 3.21 (t, J=7.6 Hz, 2H), 2.96 (t, J=7.6 Hz, 2H), 2.35 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ

203.3, 143.9, 140.7, 140.0, 136.5, 134.8, 130.9, 129.7, 128.6, 128.4, 127.3, 126.3, 122.8, 122.4, 119.6, 41.4, 30.0, 21.6; HRMS (ESI) m/z: calcd for $C_{22}H_{22}NO_3S$ $[M+H]^+$ 380.1315; found 380.1306.

General Procedure for 2-methyl-1-tosyl-2,3-dihydroquinolin-4(1*H*)-one (6 a):[20d] **3 ba** (0.3 mmol), allyl carbonates (0.9 mmol), $[Cp^*RhCl_2]_2$ (2.5 mol%), and PivOCs (0.45 mol) were charged into the sealed tube, to which was added DCE (3 mL) under argon. The reaction mixture was stirred at 100 °C for 18 h. After cooled to room temperature, the solvent was removed under reduced pressure and the residue was purified by silica gel chromatography using EA/PE (R_f = 0.4, PE: EA = 10:1) to afford **6 a**. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.99–7.78 (m, 2H), 7.62–7.52 (m, 1H), 7.49 (d, J = 8.3 Hz, 2H), 7.24 (dd, J = 10.2, 3.5 Hz, 1H), 7.19 (d, J = 8.4 Hz, 2H), 4.88 (dd, J = 9.9, 4.1 Hz, 1H), 2.37 (d, J = 5.9 Hz, 1H), 2.34 (s, 3H), 2.21 (dd, J = 17.7, 1.4 Hz, 1H), 1.25 (d, J = 7.0 Hz, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 192.5, 144.5, 139.7, 136.6, 135.0, 130.1, 127.1, 126.9, 126.3, 125.7, 125.4, 51.9, 41.9, 21.6, 19.6; HRMS (ESI) m/z: calcd for $C_{17}H_{18}NO_3S$ $[M+H]^+$ 316.1002; found 316.0992.

General Procedure for 1′-Methyl-1-tosylspiro[indoline-2,3′-pyrrolidine]-2′,3,5′-trione (7 a):[20e] **3 ba** (0.3 mmol), *N*-Methyl maleimide (0.6 mmol, 2.0 equiv), $[Cp^*RhCl_2]_2$ (0.0075 mmol, 2.5 mol%), Ag_2CO_3 (1.0 equiv) and DCE (2 mL) were added to a 12 mL glass under argon and stirred at 120 °C for 18 h. After been cooled to room temperature, the solvent was removed under reduced pressure and the residue was purified by flash column chromatography on silica gel to afford the compound **7 a** as pale yellow liquid (R_f = 0.3, Hexanes/EtOAc = 5/1) in 83 % yield. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.94 (d, J = 8.4 Hz, 2H), 7.72 (d, J = 7.7 Hz, 1H), 7.64–7.57 (m, 1H), 7.46 (d, J = 8.4 Hz, 1H), 7.35 (d, J = 8.3 Hz, 2H), 7.18 (t, J = 7.5 Hz, 1H), 3.51 (d, J = 17.8 Hz, 1H), 3.17 (s, 3H), 3.13 (d, J = 17.8 Hz, 1H), 2.43 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 192.7, 172.9, 170.8, 153.2, 145.8, 138.3, 130.2, 128.1, 125.8, 124.1, 121.2, 113.9, 73.6, 39.1, 26.0, 21.7; HRMS (ESI) m/z: calcd for $C_{19}H_{17}N_2O_5S$ $[M+H]^+$ 385.0853; found 385.0837.

General Procedure for (*Z*)-2-benzylidene-3-(pyrrolidin-1-yl)-1-tosylindoline (8 a):[20b] **3 ba** (0.3 mmol, 1 equiv.), CuCl (0.015 mmol, 5 mol%), $Cu(OTf)_2$ (5.4 mg, 0.015 mmol, 5 mol%), DMAP (0.3 mmol, 1 equiv.) were suspended in dry acetonitrile (0.3 mL). Secondary tetrahydropyrrole (0.3 mmol, 1 equiv.) and alkyne 3 (0.45 mmol, 1.5 equiv.) were added and the reaction mixture was stirred at 80 °C until TLC analysis showed full conversion of the **3 ba**. The reaction mixture was then filtered through Celite and washed with dichloromethane. The crude product was concentrated in vacuo and purified by column chromatography on silica gel to afford **8 a** as yellow oil (R_f = 0.5, Hexanes/EtOAc = 10/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.80 (dd, J = 14.7, 7.8 Hz, 3H), 7.42–7.28 (m, 5H), 7.25 (s, 1H), 7.17 (d, J = 7.3 Hz, 1H), 7.10 (d, J = 7.4 Hz, 1H), 7.03 (d, J = 8.1 Hz, 2H), 6.40 (s, 1H), 4.01 (s, 1H), 2.61–2.49 (m, 4H), 2.31 (s, 3H), 1.65–1.58 (m, 4H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 143.8, 143.2, 139.2, 135.8, 134.3, 133.6, 129.5, 128.7, 128.5, 128.2, 128.0, 127.4, 125.5, 125.3, 122.6, 119.9, 66.3, 49.6, 23.6, 21.6; HRMS (ESI) m/z: calcd for $C_{26}H_{27}N_2O_2S$ $[M+H]^+$ 431.1788; found 431.1794.

General Procedure for 1-(quinolin-3-yl)ethan-1-one (9 a):[20c] Compound **3 ba** (0.3 mmol), acetylacetylene (0.45 mmol, 1.5 equiv), PPh_3 (0.03 mmol, 10 mol%), and MeCN (1.5 mL) were added to a 12 mL glass vial under argon. The reaction mixture was stirred at 80 °C for 12 h. After been cooled to room temperature, 1 M aqueous solution of HCl (2 mL) was added, and the mixture was stirred for 5 min before quenched with aqueous $NaHCO_3$ (2 mL). The mixture was extracted with EtOAc for three times and the combined organic layer was dried over anhydrous Na_2SO_4, filtered and concentrated. The residue was purified by flash column chromatography on silica gel to afford compound **9 a** as yellow solid (mp 86–87 °C, R_f = 0.4, Hexanes/EtOAc = 5/1) in 86 % yield.^{1}H NMR (500 MHz, $CDCl_3$) δ 9.40 (d, J = 2.1 Hz, 1H), 8.67 (d, J = 1.6 Hz, 1H), 8.12 (d, J = 8.5 Hz, 1H), 7.91 (d, J = 8.1 Hz, 1H), 7.81 (ddd, J = 8.4, 7.0, 1.4 Hz, 1H), 7.64–7.54 (m, 1H), 2.71 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 196.8, 149.8, 149.2, 137.4, 132.1, 129.5, 129.4, 129.2, 127.6, 126.8, 26.8; HRMS (ESI) m/z: calcd for $C_{11}H_{10}NO$ $[M+H]^+$ 172.0757; found 172.0752.

General Procedure for *tert*-butyl(*Z*)-4-(*N*-(2-(1-(hydroxyimino)ethyl)phenyl)sulfamoyl)benzoate (10 a):[15a] to a solution of **3 ik** (0.3 mmol) in the C_2H_5OH was added hydroxylamine hydrochloride (0.36 mmol) in one portion, and the reaction mixture was stirred at 100 °C for 6–8 h. Upon completion of the reaction as indicated by TLC, the reaction mixture was diluted with water, extracted with ethyl acetate, and dried over anhydrous Na_2SO_4. The solvent was removed and concentrated under reduced pressure to give **10 a** as light yellow oil (R_f = 0.4, Hexanes/EtOAc = 5/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 10.92 (s, 1H), 8.59 (s, 1H), 7.79–7.70 (m, 2H), 7.66 (d, J = 8.2 Hz, 1H), 7.35 (dd, J = 7.9, 1.3 Hz, 1H), 7.32–7.28 (m, 1H), 7.17–7.05 (m, 3H), 2.08 (s, 3H), 1.35 (s, 9H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 176.6, 157.0, 154.4, 136.1, 135.3, 129.7, 128.8, 128.6, 124.7, 122.4, 122.1, 115.6, 39.2, 27.0, 12.5.

General Procedure for (*E*)-*N*-(4-bromo-2-(1-(ethoxyimino)ethyl)phenyl)-1,1,1-trifluoromethanesulfonamide (10 b):[15b] To a solution of **3 pf** (0.3 mmol) in the mixture of C_2H_5OH/H_2O (v/v = 1:1) was added *O*-ethyl-hydroxylamine (0.36 mmol), NaOAc (0.3 mmol) in one portion, and the reaction mixture was stirred at 100 °C for 6–8 h. Upon completion of the reaction as indicated by TLC, the reaction mixture was diluted with water, extracted with ethyl acetate, and dried over anhydrous Na_2SO_4. The solvent was removed and concentrated under reduced pressure to give 10b as light yellow oil (R_f = 0.4, Hexanes/EtOAc = 5/1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 12.03 (s, 1H), 7.63 (d, J = 2.2 Hz, 1H), 7.59 (d, J = 8.8 Hz, 1H), 7.46 (dd, J = 8.8, 2.2 Hz, 1H), 4.28 (q, J = 7.1 Hz, 2H), 2.31 (s, 3H), 1.37 (t, J = 7.1 Hz, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 155.1, 133.4, 132.8, 131.4, 125.4, 121.9, 118.3, 71.0, 14.5, 13.1.

General Procedure for the deuterium-labeling experiment: **1 ak** (0.3 mmol), **2 b** (0.45 mmol), $FeCl_2$ (3.8 mg, 0.03 mmol), D_2O (1.5 mmol), and 2 mL of DEF were added to a 10 mL screw-capped tube. The reaction vessel was closed with the cap and the reaction mixture was stirred at 80 °C (oil bath) for 8 h. The crude product was cooled to room temperature and concentrated in vacuum to give a residue, which was purified by flash column chromatography to afford the **3 bk–d**.

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Conflict of Interest

The authors declare no conflict of interest.

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