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Tetrabutylammonium Iodide-Catalyzed Oxidative Coupling of Enamides with Sulfonylhydrazides: Synthesis of β-keto-Sulfones

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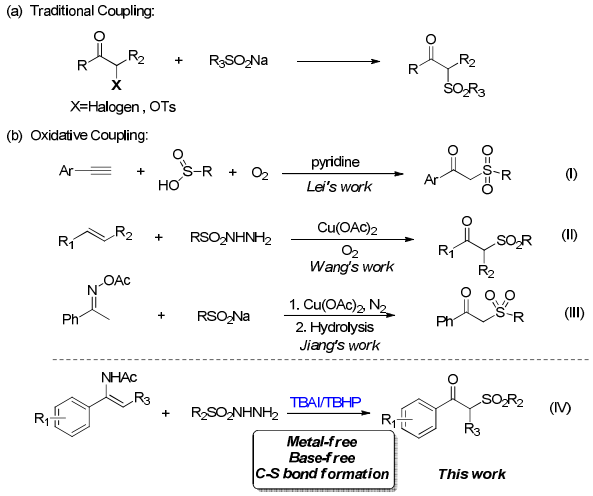
A facile synthetic route towards pharmaceutically interesting *β*-keto-sulfone derivatives by tetrabutylammonium iodide(TBAI)/*tert*-butyl hydroperoxide(TBHP) mediated oxidative coupling of readily prepared enamides with economical sulfonylhydrazides is described. The corresponding *β*-keto-sulfone compounds were obtained in moderate to good yields. The present method features metal-free, base-free and a varity of founctional groups tolerance.

Introduction

C-S bond formation is of great importance in organic synthesis because organosulfur compounds are an attractive component of many biologically active compounds,[1] and also widely present in natural products, medical chemistry and functional materials science.[2] Given the tremendous importance of organosulfur compounds, the development of C-S bond formation has emerged as a significant field of research in organic chemistry. Transition metal-catalyzed C–S bond formation, such as Pd,[3] Cu,[4] Ni,[5] Fe,[6] Ag[7] and other metals,[8] have been successfully developed. Among the very recent report, the groups of Tian[9] and Singh[10] independently developed a copper and nickel catalysed cross-coupling of arylsulfonyl hydrazides with aryl boronic acids for the synthesis of arylsulfides. Nonetheless, these methods suffer from the use of expensive or toxic metal salts, harsh reaction conditions, and narrow substrate scopes. With the development of green chemistry and increased concern over environmental issues, metal-free promoted oxidative coupling for C-S bond formation are of great demanded. Although some progress has been made in this field, [11] there still remains a great challenge in developing a green, efficient and alternative strategy to access organosulfur compounds.

β-keto-sulfones are versatile compounds owing to their unique biological properties, which present in a large array of natural products and important organic compounds.[12] Generally, *β*-keto-sulfones are prepared by the alkylation of sodium sulfinates with *α*-halo-ketones or *α*-tosyloxy ketones [Scheme 1a].[13] However, most of them suffer from some limitations, such as the pre-functionalized materials were required, relatively complicated or harsh reaction conditions, and undesired byproducts. The addition of sulfonyl radicals to carbon−carbon multiple bonds represents a particularly useful contribution to sulfone synthesis. [14] For example, Lei *et al.*[14b] reported an aerobic oxidative difunctionalization of alkynes towards *β*-ketosulfones *via* the generation of sulfonyl radicals from sulfinic acids in the presence of pyridine[Scheme 1b(I)]. Wang and coworkers[14c] developed a copper-catalyzed direct oxysulfonylation of alkenes with dioxygen and sulfonylhydrazides to access *β*-keto-sulfone compounds, in which the side-products are water and nitrogen[Scheme 1b(II)]. Very recently, Jiang *et al.*[15] described a novel copper-catalyzed coupling of oxime acetates with sodium sulfinates to achieve sulfone derivatives[Scheme 1b(III)]. However, expensive and toxic metal salts are still needed in most of these transformations. Therefore, there is still a great demand for developing more mild, convenient and especially green and sustainable approaches to produce *β*-ketosulfones.[16] It is known that the sulfonyl radical could also be generated from the commercially available tetrabutylammonium iodide(TBAI)/*tert*-butyl hydroperoxide(TBHP) catalyst system.[17] We wondered whether we could construct *β*-ketosulfones through oxidative coupling using TBAI as a catalyst and sulfonylhydrazides as sulfonyl radical precursor. Herein, we wish to report a novel TBAI-TBHP mediated oxidative coupling of enamides with sulfonylhydrazides to access useful *β*-keto-sulfone compounds[Scheme 1b(IV)]. The present method features metal-free, base-free and a varity of founctional groups tolerance.



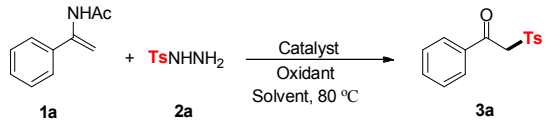
Scheme 1. Traditional coupling and oxidative coupling reactions

Results and discussion

Our investigation commenced with the reaction of *N*-vinylacetamide (**1a**) and *p*-toluenesulfonylhydrazide (**2a**) in CH_3CN at 80 °C under air atmosphere. Gratifyingly, the desired product **3a** was obtained in 44% yield under 20 mol% of TBAI as a catalyst and 2.0 equivalents of TBHP(70 wt% in water) as an external oxidant(Table 1, entry 1). After screening a series of catalysts such as $FeCl_2•4H_2O$, KI, $Cu(OAc)_2$ and I_2, TBAI was found to be most efficient (Table 1, entries 1-5). Further

elaboration of the loading of **2a** proved that 1.5 equivalents was best and 80% yield was obtained (Table 1, entries 6-7). Among the solvents screened, CH_3CN was proved beneficial for this reaction(Table 1, entries 6, 8-10). Some representative oxidants were also examined in the presence of TBAI as catalyst and results proved to be less effective(Table 1, entries 11-12). Gratifyingly, a large scale reaction also proceeded smoothly, furnishing product **3a** in good yield (entry 13).

Table 1 Optimization of Reaction Conditions [a]

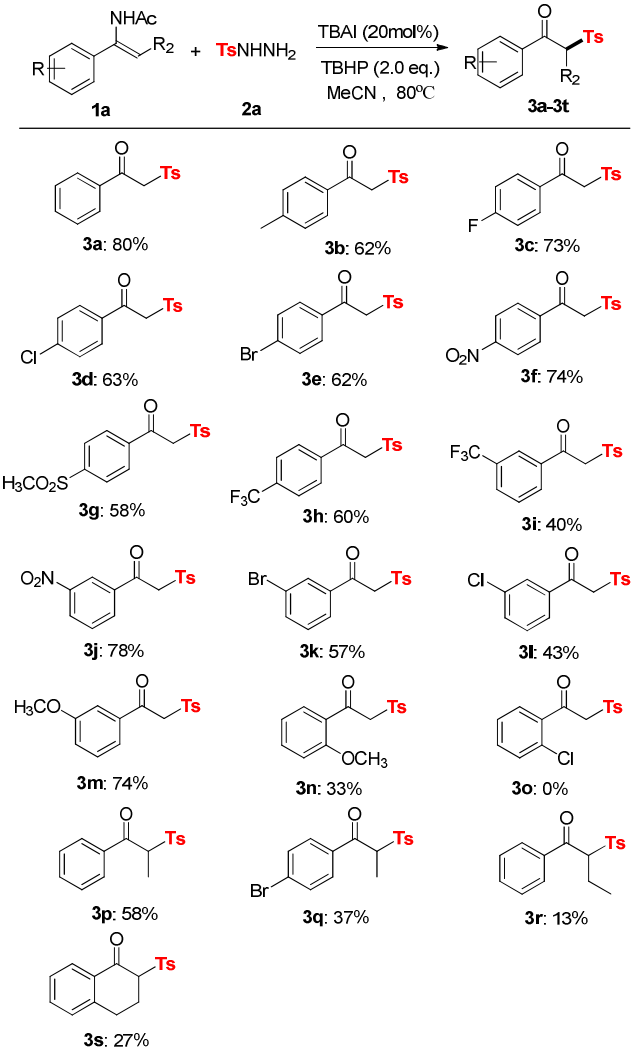


Entry	Catalyst	Oxidant	solvent	Yield % [b]
1	TBAI	TBHP	CH_3CN	44
2	$FeCl_2$•$4H_2O$	TBHP	CH_3CN	0
3	KI	TBHP	CH_3CN	41
4	$Cu(OAc)_2$	TBHP	CH_3CN	36
5	I_2	TBHP	CH_3CN	18
6[c]	TBAI	TBHP	CH_3CN	80
7[d]	TBAI	TBHP	CH_3CN	72
8[c]	TBAI	TBHP	EtOAc	76
9[c]	TBAI	TBHP	H_2O	63
10[c]	TBAI	TBHP	DMF	52
11[c]	TBAI	DTBP	CH_3CN	0
12[c]	TBAI	TBPB	CH_3CN	31
13[e]	TBAI	TBHP	CH_3CN	62

[a] Reaction conditions: **1a** (0.25 mmol), **2a** (1.2 eq), oxidant (2.0eq), catalyst (0.05 mmol), solvent (2.0 mL) at 80 °C. [b] isolated yield. [c] 1.5 equiv of **2a** was used. [d] 2.0 equiv of **2a** was used. [e]**1a** (8 mmol).

To explore the substrate scope of this protocol, the optimized reaction conditions were applied to a series of substituted *N*-vinylacetamides and results are summarized in Table 2. The substituents on the phenyl ring of the *N*-vinylacetamide with $TsNHNH_2$(**2a**) were first tested. It was found that various functional groups at the *para* –position were tolerated well under the present oxidative conditions affording the products in good yields(products **3b**-**3h**). Notably, halogen and nitro groups were tolerable, which were suitable for potential further functionalization. The reaction also proceeded smoothly with both electron-withdrawing (CF_3, NO_2 and halide) and electron-donating(MeO) substituents at the *meta* position of the aromatic ring under the reaction conditions (products **3i-3m**). *N*-vinylacetamide bearing *ortho* substituent on the aromatic ring revealed different reactivity probably result from the electronic effect(products **3n, 3o**). In addition, the propiophenone and *n*-butyrophenone substituted *N*-vinylacetamides were also applied as substrates in this reaction, the corresponding products could be isolated in reasonable yields(products **3p**-**3r**). Furthermore, the dihydronaphthalen-derived enamide could also be used well and afforded the desired product **3s** in 27% yield.

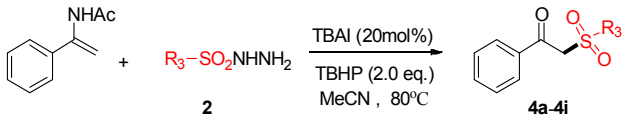
Table 2. Scope of the reaction with enamides [a,b]

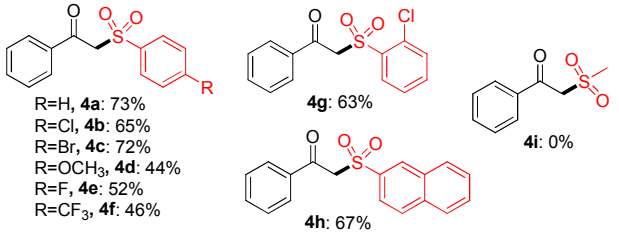


[a] Reaction conditions:**1a** (0.25 mmol), **2a** (1.5 eq), TBAI (20 mol%), TBHP(2.0eq, 70% aqueous solution) in 2.0 mL of MeCN at 80 °C. [b] isolated yield.

Next, the reaction was examined with substituted sulfonylhydrazides, which were treated with *N*-vinylacetamide(**1a**) under the standard reaction conditions and the results are summarized in Table 3. Various *para*-substituted sulfonylhydrazides such as those bearing H, F, Cl, Br, CF_3, or OMe groups afforded the products **4a**-**4f** in moderate to good yields. 2-chlorobenzenesulfonohydrazide and naphthalene-2-sulfonohydrazide could also transform into the corresponding products in 63% and 67% yields, respectively (products **4g**, **4h**). However, alkyl sulfonylhydrazide was not suitable for this reaction and corresponding ketone was detected(product **4i**).

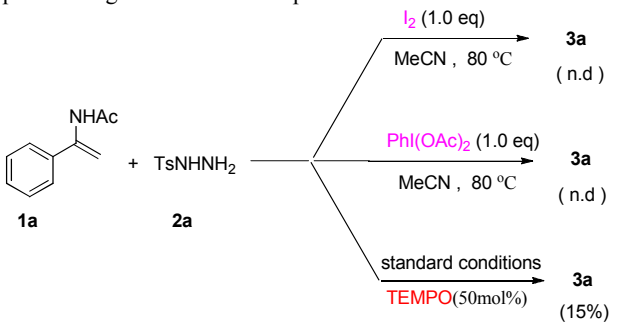
Table 3. Scope of the reaction with sulfonylhydrazides [a,b]





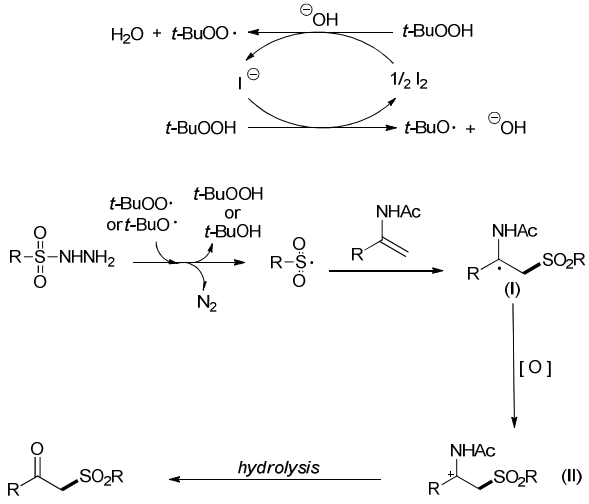
[a] Reaction conditions: **1a** (0.25 mmol), **2a** (1.5 eq), TBAI (20 mol%), TBHP(2.0 eq, 70% aqueous solution) in 2.0 mL of MeCN at 80 °C. [b] isolated yield. [c] not detected.

In order to better understand the mechanism of this transformation, additional experiments were carried out. No compound **3a** were formed when 1.0 equivalents of I_2 and $PhI(OAc)_2$ were added to the reaction in the absence of TBHP. The results exclude the possibility that the *in situ* generated I_2 or I^{3+} are involved in the oxidative N-S bond cleavage of sulfonylhydrazides.[11b,11f] In addition, when the reaction of **1a** with $TsNHNH_2$ was performed in the presence of TEMPO, a common radical scavenger, the desired coupling product **3a** was sharply decreased to 15% yield, which indicated that a radical process might involved in the present transformation.



Scheme 2. control experiment

Based on the experimental results and previously reported results,[17] a probable mechanistic explanation for this transformation is shown in Scheme 3. Initially, TBAI-assisted decomposition of TBHP generated the *tert*-butoxyl radical and *tert*-butylperoxy radicals, which abstracted hydrogen of carbazates to form sulfonyl radicals with the release of molecular nitrogen.[17,18] The addition of resultant sulfonyl radicals to alkenes and subsequent furnish a carbon-centered radical intermediate(**I**). Futher oxidation leads to the corresponding carbocation intermediate(**II**), which following by hydrolysis reaction afford *β*-keto-sulfones.



Scheme 3. Proposed preliminary mechanisms

Conclusion

In summary, we have developed a novel protocol for direct synthesis of *β*-keto-sulfone derivatives starting from readily prepared enamides and commercially available sulfonylhydrazides. The reported reactions employ cheap and convenient TBAI/TBHP as the catalyst-oxidation system, which makes this transformation more environmentally benign. In addition, this reaction tolerates a variety of functional groups and the corresponding *β*-keto-sulfone compounds were obtained in moderate to good yields. Further investigations of this reaction system are under way in our laboratory.

Experimental Section

General Procedures: All reagents and solvents were purchased from commercial suppliers and used without purifications. Melting points are uncorrected. The ^1H NMR and ^{13}C NMR spectra were recorded at 25 °C in $CDCl_3$ at 500 and 125 MHz or 100 MHz, respectively, with TMS as the internal standard. Chemical shifts (δ) are expressed in ppm and coupling constants *J* are given in Hz. The enamides were synthesized according to literature method.[19]

Typical Procedure for the synthesis of β-keto-sulfones: To a stirred solution of enamide (0.25 mmol), $TsNHNH_2$ (0.375 mmol) and TBAI (0.05 mmol) in MeCN (2 mL) was added TBHP (0.5 mmol, 70% aqueous solution) at room temperature. The mixture was heated at 80 °C for 12 h and cooled down to room temperature. The excess solvent was removed under vacuum, and the residue was directly purified by silica gel column chromatography to afford desired *β*-keto-sulfones .

1-phenyl-2-tosylethanone (3a) [20-23]. White solid (54.8 mg, 80%); mp 102-103°C; ^1H NMR (500 MHz, $CDCl_3$) δ 7.97 – 7.92 (m, 2H), 7.76 (d, *J* = 8.2 Hz, 2H), 7.64 – 7.60 (m, 1H), 7.48 (t, *J* = 7.8 Hz, 2H), 7.33 (d, *J* = 8.2 Hz, 2H), 4.72 (s, 2H), 2.44 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 188.1, 145.4, 135.8, 135.8, 134.3, 129.8, 129.3, 128.8, 128.6, 63.6, 21.7.

1-(p-tolyl)-2-tosylethanone(3b) [20c, 20g~20i, 21~23]. White solid(44.6 mg, 62%); mp 104-105°C; ^1H NMR (500 MHz, $CDCl_3$) δ 7.85 (d, *J* = 8.3 Hz, 2H), 7.76 (d, *J* = 8.3 Hz, 2H), 7.33 (d, *J* = 8.1 Hz, 2H), 7.27 (d, *J* = 9.4 Hz, 2H), 4.69 (s, 2H), 2.44 (s, 3H), 2.42 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$)

δ 187.7, 145.5, 145.3, 135.9, 133.4, 129.8, 129.6, 129.5, 128.6, 63.6, 21.8, 21.7.

1-(4-fluorophenyl)-2-tosylethanone(3c) [20c, 21]. White solid(53.3 mg, 73%); mp 128-129°C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.03 – 7.98 (m, 2H), 7.75 (d, *J* = 8.3 Hz, 2H), 7.34 (d, *J* = 8.1 Hz, 2H), 7.18 – 7.13 (m, 2H), 4.69 (s, 2H), 2.45 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 186.6, 167.5(d, *J* = 256.3 Hz), 145.5, 135.7, 132.3(d, *J* = 2.5 Hz), 132.2, 129.9, 128.6, 116.1(d, *J* = 22.5 Hz), 63.8, 21.7.

1-(4-chlorophenyl)-2-tosylethanone(3d) [20c, 20i, 20j, 21, 23]. White solid(48.5 mg, 63%); mp 137-138°C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.90 (d, *J* = 8.6 Hz, 2H), 7.74 (d, *J* = 8.2 Hz, 2H), 7.45 (d, *J* = 8.6 Hz, 2H), 7.34 (d, *J* = 8.1 Hz, 2H), 4.69 (s, 2H), 2.44 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 186.0, 144.5, 140.0, 134.7, 133.1, 129.8, 128.9, 128.2, 127.5, 62.7, 20.7.

1-(4-bromophenyl)-2-tosylethanone(3e) [20~20c, 21, 22]. White solid(54.5 mg, 62%); mp 120-121°C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.84 – 7.81 (m, 2H), 7.76 – 7.72 (m, 2H), 7.65 – 7.62 (m, 2H), 7.35 (d, *J* = 8.0 Hz, 2H), 4.67 (s, 2H), 2.46 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 187.3, 145.6, 135.6, 134.5, 132.2, 130.8, 129.92, 128.9, 128.6, 63.8, 21.7.

1-(4-nitrophenyl)-2-tosylethanone(3f) [20c, 24]. Yellow solid(59.0 mg, 74%); mp 144-145°C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.34 (d, *J* = 8.8 Hz, 2H), 8.16 (d, *J* = 8.8 Hz, 2H), 7.75 (d, *J* = 8.3 Hz, 2H), 7.37 (d, *J* = 8.1 Hz, 2H), 4.75 (s, 2H), 2.47 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 187.0, 150.9, 145.9, 140.0, 135.4, 130.5, 130.1, 128.5, 124.0, 64.2, 21.8.

1-(4-(methylsulfonyl)phenyl)-2-tosylethanone(3g). White solid(51.0mg, 58%); mp 156-157°C; ^{1}H NMR (500 MHz, CDCl3) δ 8.16 (d, J = 8.2 Hz, 2H), 8.06 (d, J = 8.2 Hz, 2H), 7.75 (d, J = 8.1 Hz, 2H), 7.36 (d, J = 8.0 Hz, 2H), 4.77 (s, 2H), 3.10 (s, 3H), 2.46 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 187.4, 145.8, 145.1, 139.6, 135.6, 130.3, 130.0, 128.5, 127.9, 63.9, 44.2, 21.7. HRMS (ESI) calcd for $C_{16}H_{17}S_2O_5$ (M + H^+) 353.0517, found 353.0513.

2-tosyl-1-(4-(trifluoromethyl)phenyl)ethanone(3h)[20c]. White solid(51.3mg, 60%); mp 143-144°C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.07 (d, *J* = 8.2 Hz, 2H), 7.74 (d, *J* = 8.2 Hz, 4H), 7.34 (d, *J* = 8.0 Hz, 2H), 4.75 (s, 2H), 2.45 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 187.5, 145.7, 138.4, 135.6, 135.4(q, *J* = 32.5 Hz), 129.9, 129.8, 128.6, 125.9 (q, *J* = 3.8 Hz), 123.4(q, *J* = 271.3 Hz), 63.9, 21.7.

2-tosyl-1-(3-(trifluoromethyl)phenyl)ethanone(3i). White solid(34.2mg, 40%); mp 165-166°C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.18 (d, *J* = 7.9 Hz, 1H), 8.14 (s, 1H), 7.87 (d, *J* = 7.8 Hz, 1H), 7.75 (d, *J* = 8.3 Hz, 2H), 7.66 (t, *J* = 7.8 Hz, 1H), 7.35 (d, *J* = 8.0 Hz, 2H), 4.74 (s, 2H), 2.45 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 187.1, 145.8, 136.3, 132.6, 131.53 (q, *J* = 25.4), 130.8(q, *J* = 34 Hz), 130.6(q, *J* = 3.8 Hz), 129.9, 128.5, 125.2 (q, *J* = 275 Hz), 126.0 (q, *J* = 3.8 Hz), 63.8, 21.7. HRMS (ESI) calcd for $C_{16}H_{14}F_3O_3S$ (M + H^+) 343.0616, found 343.0613.

1-(3-nitrophenyl)-2-tosylethanone(3j). Yellow solid(62.2mg, 78%); mp 128-129°C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.73 (t, *J* = 1.9 Hz, 1H), 8.47 (ddd, *J* = 8.2, 2.2, 1.0 Hz, 1H), 8.35 – 8.32 (m, 1H), 7.74 (ddd, *J* = 14.0, 9.3, 4.8 Hz, 3H), 7.36 (d, *J* = 8.0 Hz, 2H), 4.78 (s, 2H), 2.46 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 186.4, 148.5, 145.9, 136.9, 135.5, 134.9, 130.1, 130.0, 128.5, 128.4, 124.1, 63.9, 21.7. HRMS (ESI) calcd for $C_{15}H_{14}NO_5S$ (M + H^+) 320.0593, found 320.0590.

1-(3-bromophenyl)-2-tosylethanone(3k)[20c, 21]. White solid(50.2mg, 57%); mp 129-130°C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.00 (t, *J* = 1.8 Hz, 1H), 7.91 – 7.88 (m, 1H), 7.76 – 7.72 (m, 3H), 7.39 – 7.32 (m, 3H), 4.68 (s, 2H), 2.45 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 186.9, 145.6, 137.5, 137.1, 135.6, 132.1, 130.4, 129.9, 128.6, 128.0, 123.2, 63.7, 21.7.

1-(3-chlorophenyl)-2-tosylethanone(3l) [20c, 21]. White solid(33.1mg, 43%); mp 128-129°C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.87 – 7.83 (m, 2H), 7.77 – 7.73 (m, 2H), 7.60 – 7.56 (m, 1H), 7.46 – 7.41 (m, 1H), 7.34 (d, *J* = 8.0 Hz, 2H), 4.69 (s, 2H), 2.45 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 187.1, 145.6, 137.3, 135.6, 135.3, 134.2, 130.2, 129.9, 129.2, 128.6, 127.6, 63.7, 21.7.

1-(3-methoxyphenyl)-2-tosylethanone(3m). Colorless oil (56.2 mg, 74%); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.78 – 7.75 (m, 2H), 7.52 – 7.49 (m, 1H), 7.44 – 7.42 (m, 1H), 7.37 (t, *J* = 8.0 Hz, 1H), 7.33 (d, *J* = 8.0 Hz, 2H), 7.15 (ddd, *J* = 8.2, 2.6, 0.7 Hz, 1H), 4.71 (s, 2H), 3.83 (s, 3H), 2.43 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 187.9, 145.3, 137.1, 135.9, 129.8, 128.6, 128.2, 128.0, 122.2, 121.1, 113.0, 63.7, 55.5, 21.7. HRMS (ESI) calcd for $C_{16}H_{17}O_4S$ (M + H^+) 305.0848, found 305.0844.

1-(2-methoxyphenyl)-2-tosylethanone(3n). Yellow oil(25.1 mg, 33%); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.76 – 7.73 (m, 2H), 7.66 (dd, *J* = 7.8, 1.8 Hz, 1H), 7.49 (ddd, *J* = 8.5, 7.3, 1.8 Hz, 1H), 7.29 (d, *J* = 8.0 Hz, 2H), 7.01 – 6.96 (m, 1H), 6.90 (d, *J* = 8.3 Hz, 1H), 4.92 (s, 2H), 3.88 (s, 3H), 2.42 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 189.2, 158.9, 144.8, 136.7, 135.2, 131.3, 129.5, 128.6, 126.4, 120.9, 111.70, 67.5, 55.7, 21.6. HRMS (ESI) calcd for $C_{16}H_{17}O_4S$ (M + H^+) 305.0848, found 305.0843.

1-phenyl-2-tosylpropan-1-one(3p)[20b, 20c]. White solid(41.8mg, 58%); mp 81-82°C; 1H NMR (500 MHz, CDCl3) δ 7.99 – 7.96 (m, 2H), 7.65 (d, J = 8.3 Hz, 2H), 7.61 (t, J = 7.4 Hz, 1H), 7.49 (t, J = 7.8 Hz, 2H), 7.31 (d, J = 8.1 Hz, 2H), 5.00 (dd, J = 10.9, 3.6 Hz, 1H), 2.43 (s, 3H), 2.16 (dqd, J = 15.1, 7.5, 3.6 Hz, 1H), 2.03 (ddq, J = 14.6, 11.0, 7.3 Hz, 1H), 0.88 (t, J = 7.4 Hz, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 192.6, 145.4, 136.3, 133.1, 129.8, 129.5, 129.2, 128.7, 125.6, 65.0, 21.7, 13.2.

1-(4-bromophenyl)-2-tosylpropan-1-one(3q). White solid(33.8mg, 37%); mp 130-131°C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.87 – 7.83 (m, 2H), 7.66 – 7.60 (m, 4H), 7.32 (d, *J* = 8.0 Hz, 2H), 5.08 (q, *J* = 6.9 Hz, 1H), 2.45 (s, 3H), 1.54 (d, *J* = 6.9 Hz, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 191.7, 145.6, 135.1, 132.8, 132.1, 130.7, 129.8, 129.6, 129.5 , 65.2, 21.7, 13.1. HRMS (ESI) calcd for $C_{16}H_{16}BrO_3S$ (M + H^+) 367.0004, found 367.0001.

1-phenyl-2-tosylbutan-1-one(3r)[20b, 20c]. Colorless oil (9.8 mg, 13%); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.98 (d, *J* = 7.3 Hz, 2H), 7.65 (d, *J* = 8.3 Hz, 2H), 7.61 (t, *J* = 7.4 Hz, 1H), 7.49 (t, *J* = 7.8 Hz, 2H), 7.31 (d, *J* = 8.1 Hz, 2H), 5.00 (dd, *J* = 10.9, 3.6 Hz, 1H), 2.43 (s, 3H), 2.16 (dqd, *J* = 18.7, 7.5, 3.6 Hz, 1H), 2.08 – 2.00 (m, 1H), 0.88 (t, *J* = 7.4 Hz, 3H).^{13}C NMR (125 MHz, $CDCl_3$) δ 192.8, 145.3, 137.5, 133.9, 133.8, 129.8, 129.5, 129.0, 128.8, 71.5, 22.1, 21.7, 11.5.

2-tosyl-3,4-dihydronaphthalen-1(2H)-one(3s). White solid (20.3mg, 27%); mp 146-147°C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.98 (dd, *J* = 7.9, 1.1 Hz, 1H), 7.80 – 7.77 (m, 2H), 7.51 (td, *J* = 7.5, 1.4 Hz, 1H), 7.36 (d, *J* = 8.0 Hz, 2H), 7.29 (dt, *J* = 7.4, 4.8 Hz, 2H), 4.09 (t, *J* = 5.7 Hz, 1H), 3.51 (ddd, *J* = 16.8, 9.8, 4.7 Hz, 1H), 2.98 (dt, *J* = 17.0, 5.4 Hz, 1H), 2.89 – 2.82 (m, 1H), 2.65 (ddd, *J* = 14.8, 10.1, 5.1 Hz, 1H), 2.45 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 188.7, 145.0, 143.6, 136.2, 134.4, 131.9, 129.6, 129.2, 128.9, 128.0, 127.0, 69.8, 26.6, 23.7, 21.7. HRMS (ESI) calcd for $C_{17}H_{17}O_3S$ (M + H^+) 301.0898, found 301.0894.

1-phenyl-2-(phenylsulfonyl)ethanone(4a)[20-23]. White solid(47.4mg, 73%); mp 83-84°C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.93 (dd, *J* = 8.3, 1.1 Hz, 2H), 7.91 – 7.88 (m, 2H), 7.68 – 7.64 (m, 1H), 7.62 (dd, *J* = 10.6, 4.2 Hz, 1H), 7.54 (t, *J* = 7.8 Hz, 2H), 7.47 (t, *J* = 7.8 Hz, 2H), 4.75 (s, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 187.9, 138.8, 135.7, 134.3, 134.2, 129.3, 129.2, 128.9, 128.6, 63.4.

2-((4-chlorophenyl)sulfonyl)-1-phenylethanone(4b)[20a, 20c~20e, 20g, 20h, 20j]. White solid (47.7mg, 65%); mp 135-136°C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.93 (dt, *J* = 8.5, 1.5 Hz, 2H), 7.86 – 7.81 (m, 2H), 7.66 – 7.62 (m, 1H), 7.54 – 7.47 (m, 4H), 4.75 (s, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 187.9, 141.1, 137.1, 135.6, 134.5, 130.2, 129.5, 129.3, 128.9, 63.3.

2-((4-bromophenyl)sulfonyl)-1-phenylethanone(4c)[20a, 20c~20e, 20g, 20h, 20j]. White solid (60.8mg, 72%); mp 120-121°C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.92 (d, *J* = 7.4 Hz, 2H), 7.75 (d, *J* = 8.6 Hz, 2H), 7.68 (d, *J* = 8.5 Hz, 2H), 7.63 (t, *J* = 7.4 Hz, 1H), 7.48 (t, *J* = 7.8 Hz, 2H), 4.75 (s, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 187.9, 137.7, 135.6, 134.5, 132.5, 130.2, 129.7, 129.2, 128.9, 63.3.

2-((4-methoxyphenyl)sulfonyl)-1-phenylethanone(4d)[20a, 20c~20e, 20g]. White solid (31.9mg, 44%); mp 93-94°C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.95 (dd, *J* = 8.4, 1.1 Hz, 2H), 7.82 – 7.79 (m, 2H), 7.64 – 7.60 (m, 1H), 7.48 (t, *J* = 7.8 Hz, 2H), 7.00 – 6.97 (m, 2H), 4.71 (s, 2H), 3.88 (s, 3H).^{13}C NMR (100 MHz, $CDCl_3$) δ 187.9, 163.8, 134.1, 130.7, 129.9, 129.1, 128.6, 127.9, 114.2, 63.7, 55.7.

2-((4-fluorophenyl)sulfonyl)-1-phenylethanone(4e)[20a, 20c~20e, 20g, 20h, 20j]. White solid (36.1mg, 52%); mp 145-146°C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.97 – 7.87 (m, 4H), 7.63 (t, *J* = 6.8 Hz, 1H), 7.49 (q, *J* = 6.7 Hz, 2H), 7.21 (t, *J* = 8.4 Hz, 2H), 4.75 (s, 2H).^{13}C NMR (100 MHz, $CDCl_3$) δ 187.6, 165.5(d, *J* = 256 Hz), 135.3, 134.6, 134.3, 131.7(d, *J* = 10 Hz), 129.0, 128.7, 116.3(d, *J* = 23Hz), 63.3.

1-phenyl-2-((4-(trifluoromethyl)phenyl)sulfonyl)ethanone(4f)[20c]. White solid (37.7mg, 46%); mp 111-112°C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.05 (d, *J* = 8.2 Hz, 2H), 7.92 (dd, *J* = 8.3, 1.1 Hz, 2H), 7.81 (d, *J* = 8.4 Hz, 2H), 7.63 (t, *J* = 7.4 Hz, 1H), 7.49 (t, *J* = 7.9 Hz, 2H), 4.80 (s, 2H).^{13}C NMR (100 MHz, $CDCl_3$) δ 187.4, 141.8, 135.7, 135.3 (d, *J* = 15.7 Hz), 134.4, 129.2, 129.0, 128.8, 126.9 (q, *J* = 3 Hz), 123.1(q, *J* = 272 Hz), 62.9.

2-((2-chlorophenyl)sulfonyl)-1-phenylethanone(4g)[20c]. Colorless oil (46.3 mg, 63%); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.07 – 8.03 (m, 1H), 7.96 – 7.92 (m, 2H), 7.63 – 7.56 (m, 3H), 7.50 – 7.42 (m, 3H), 5.06 (s, 2H).^{13}C NMR (100 MHz, $CDCl_3$) δ 187.4, 136.1, 135.5, 134.9, 134.2, 132.4, 131.8, 131.6 128.9, 128.7, 127.2, 60.8.

2-(naphthalen-2-ylsulfonyl)-1-phenylethanone(4h)[20a, 20c, 20g ,20h]. White solid (51.9mg, 67%); mp 134-135°C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.46 (s, 1H), 8.00 – 7.91 (m, 5H), 7.87 (dd, *J* = 8.6, 1.9 Hz, 1H), 7.70 – 7.65 (m, 1H), 7.60 (ddd, *J* = 8.4, 5.0, 1.0 Hz, 2H), 7.45 (t, *J* = 7.8 Hz, 2H), 4.81 (s, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 187.6, 135.5, 135.4, 135.3, 134.1, 131.8, 130.4, 129.4, 129.3, 129.1, 128.6,128.0, 127.8, 127.5, 122.7, 63.5.

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Notes and references

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