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Direct sulfonamidation of (hetero)aromatic C–H bonds with sulfonyl azides: a novel and efficient route to *N*-(hetero)aryl sulfonamides

Zhi Liu,^a Abdolghaffar Ebadi,^b Mohsen Toughani,^c Nihat Mert^d and Esmail Vessally^e*

N-Aryl sulfonamides belong to a highly important class of organosulfur compounds which are found in a number of FDA-approved drugs such as dofetilide, dronedarone, ibutilide, sotalol, sulfadiazine, sulfamethizole, vemurafenib, and many more. There is therefore continuing interest in the development of novel and convenient protocols for the preparation of these pharmaceutically important compounds. Recently, direct sulfonamidation of (hetero)aromatic C–H bonds with easily available sulfonyl azides has emerged as an attractive and powerful strategy to access *N*-(hetero)aryl sulfonamides where non-toxic nitrogen gas forms as the sole by-product. This review highlights recent advances and developments (2012–2020) in this fast growing research area with emphasis on the mechanistic features of the reactions.

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^aSchool of Electrical and Automation Engineering, East China Jiaotong University, Nanchang 330013, China. E-mail: liu126lin@gmail.com

^bDepartment of Agriculture, Jouybar Branch, Islamic Azad University, Jouybar, Iran. E-mail: dr_ebadi2000@mail.ru

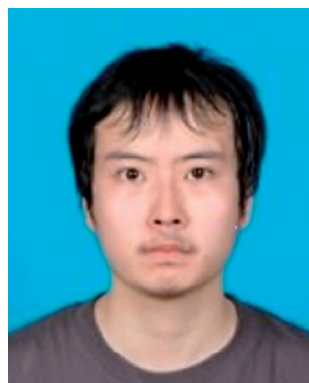
^cDepartment of Fishery, Babol Branch, Islamic Azad University, Babol, Iran. E-mail: m.toughani2008@yahoo.com

^dDepartment of Biochemistry, Faculty of Veterinary Medicine, University of Yuzuncu Yil, 65080, Van, Turkey. E-mail: mertnihat@hotmail.com

^eDepartment of Chemistry, Payame Noor University, Tehran, Iran. E-mail: vessally@yahoo.com; vesali@pnu.ac.ir

1. Introduction

Sulfonamides constitute a very important class of drugs which are called sulfa drugs, and display a broad range of pharmacological activities such as antimicrobial, antiretroviral, anti-convulsant, anti-diabetic, antitumor, and anti-depressant.¹ Seventy-two currently marketed drugs contain this privileged structural motif in their structure and one-fourth of them are *N*-(hetero)aryl sulfonamide derivatives.² For example (Fig. 1), tipranavir **1** with the brand name of Aptivus is a nonpeptidic protease inhibitor marketed worldwide for the treatment of HIV/AIDS infection.³ Sulfamethoxazole **2** is an antibiotic that is

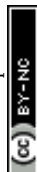


Dr Zhi Liu was born in Nanchang, Jiangxi, P. R. China, in 1987. He received the PhD degree in traffic equipment and information engineering from Central South University (CSU), Changsha, China, in 2018. Now, he is currently a Lecturer with East China Jiaotong University. His research interests include intelligent transportation and vehicle material technology.



Dr Abdol Ghaffar Ebadi finished his doctoral degree in Environmental Biotechnology (Algology) from Tajik Academy of Sciences. Now he is a researcher in TAS in Tajikistan and faculty member at the Islamic Azad University of Jouybar in Mazandaran. Dr Ebadi published more than 400 scientific papers in qualified international journals and attended more than 50 international conferences. He has

cooperation with many research project teams around world such as China, Malaysia, and Thailand. His interests are Environmental Biotechnology, Biochemistry, Gene pathways in the phytoremediation processes.



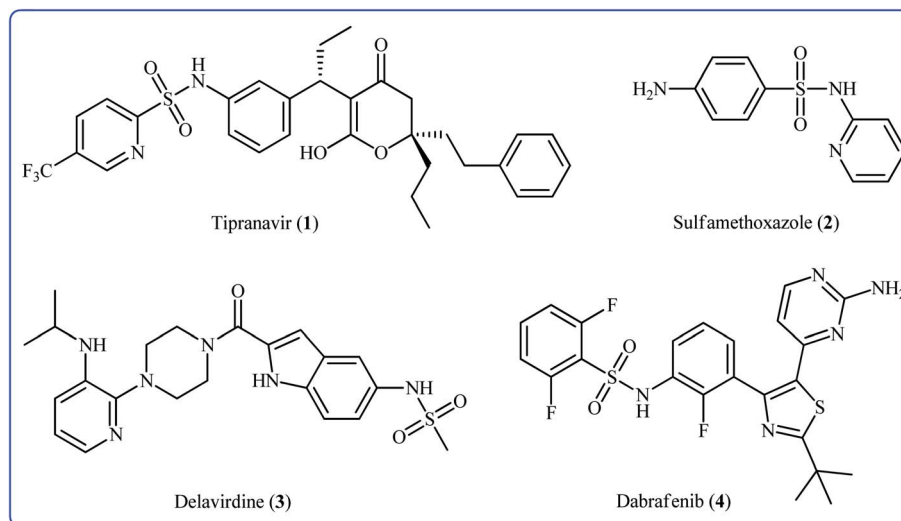


Fig. 1 Selected drugs with *N*-aryl sulfonamide structure motif.

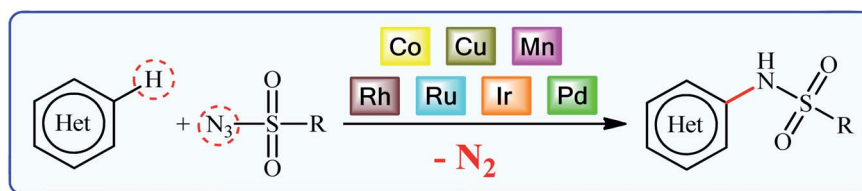
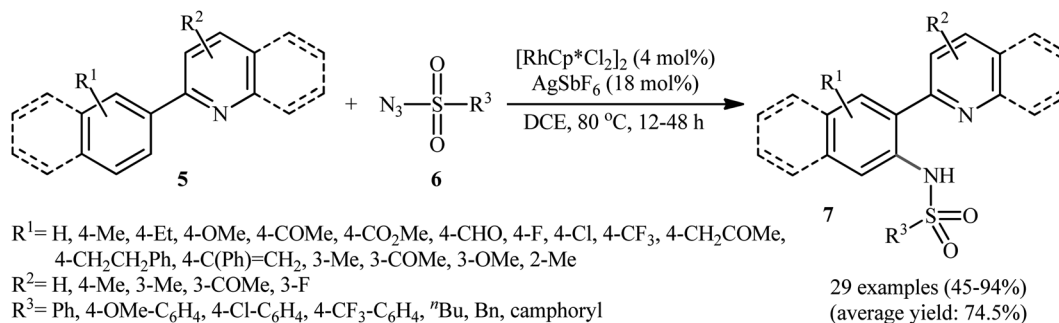


Fig. 2 Transition-metal catalyzed direct sulfonamidation of (hetero)aromatic C–H bonds with sulfonyl azides.



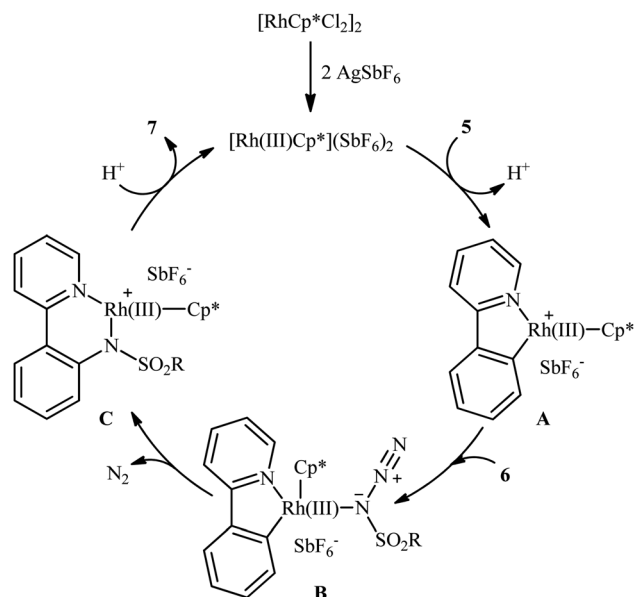
Scheme 1 Cheng's synthesis of *N*-aryl sulfonamides 7.

under atmospheric environment and afforded the target *N*-aryl sulfonamides **7** in moderate to excellent yields (Scheme 1). It should be noticed that other directing groups, such as pyrazole, pyrimidine, and oxime were also found to effectively mediate this transformation. Based on kinetic isotope effect studies and X-ray crystallographic analysis, the following mechanism is proposed by the authors for this transformation (Scheme 2). Firstly, a cationic Rh(III) species $[\text{Rh}(\text{III})\text{Cp}^*][\text{SbF}_6]_2$ generated upon treatment of the $[\text{RhCp}^*\text{Cl}_2]_2$ precursor with AgSbF_6 . Next, coordination of nitrogen atom of the phenylpyridine **5** to this species followed by *ortho*-metalation affords a five-membered rhodacyclic intermediate **A**. Subsequently, coordination of azide **6** to **A** leads to the intermediate **B** that, after insertion of

a sulfonamido moiety into the rhodacycle forms a Rh(III) amido complex **C**. Finally, protonolysis of **C** produces the desired product **7** and regenerates the cationic Rh(III) species. Later, based on density functional theory (DFT) calculations, the same authors suggested that the liberation of N_2 from intermediate **B** forms a key Rh(V)-nitrenoid species and then a collapse of this intermediate affords the insertion intermediate **C**.²⁰

In the same year, Zhou and Li along with their co-workers described an interesting regioselective Rh-catalyzed direct C2-sulfonamidation of indoles **8** bearing a 2-pyrimidyl unit as a directing group through C–H activation by using sulfonyl azides **9** as the sulfonamide source.²¹ The reactions were carried out in the presence of a catalytic amount of $[\text{Cp}^*\text{Rh}(\text{MeCN})_3]$





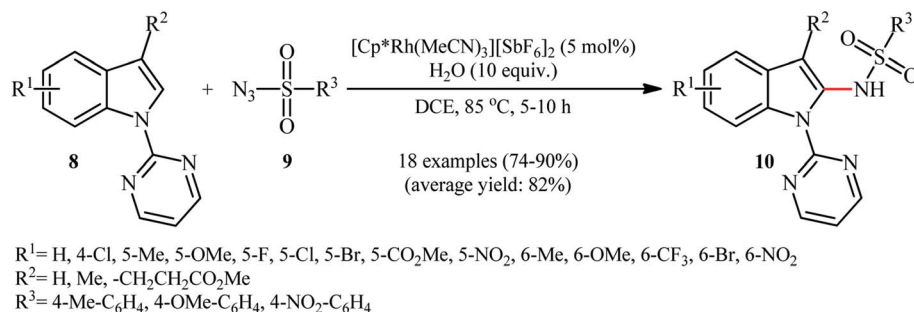
Scheme 2 Proposed mechanism for Rh-catalyzed sulfonamidation of phenylpyridines **5** with sulfonyl azides **6**.

$[\text{SbF}_6]_2$ and ten equivalents of water as an additive under an open air, tolerated various electron-rich and electron-poor functional groups on both coupling partners and provided the expected C2-sulfonamidated indoles **10** in good to excellent yields (Scheme 3). Noteworthy, no product was observed by replacing of pyrimidyl directing group with other groups (e.g., Me, Boc, Ac, Me_2NCO). NH-free indoles were also failed to participate in this reaction. It should be mentioned that the 2-pyrimidyl directing group can be easily removed through

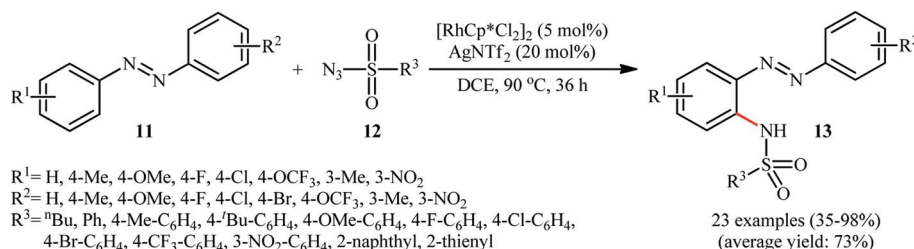
hydrolysis to yield the corresponding NH-free sulfonamidated indoles under alkaline conditions.

In 2014, Jia and Han disclosed that the treatment of azobenzenes **11** with sulfonyl azides **12** in the presence of 5 mol% of $[\text{RhCp}^*\text{Cl}_2]_2$ and 20 mol% of AgNTf_2 in DCE under an air atmosphere afforded the corresponding *ortho*-sulfonamidated azobenzene derivatives **13** in moderate to almost quantitative yields, ranging from 35% to 98% (Scheme 4).²² Some of the most important results obtained in this investigation are listed below: (i) the reaction was almost equally efficient for aromatic, heteroaromatic, and aliphatic sulfonyl azides; (ii) electron-rich azobenzenes compare to the electron-poor ones gave higher yield of the expected products; and (iii) unsymmetrical azobenzenes mainly gave the sulfonamidation products on the electron-rich aromatic rings. Concurrently, Xu and colleagues reported a similar strategy to construct *ortho*-sulfonamidated azobenzenes by using Cheng's standard reaction condition.²³ Although this methodology turned out to be highly efficient for the sulfonamidation of *ortho*- and *meta*-substituted azobenzenes, its application for the sulfonamidation of unsubstituted and *para*-substituted azobenzenes is restricted, since the selectivity of mono- and di-sulfonamidation products was generally poor.

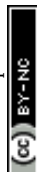
As a continuation of these studies, Peng and co-workers reported the steric hindrance controlled regioselective Rh-catalyzed direct C–H sulfonamidation of 2,4-diarylquinazolines **14** with sulfonyl azides **15** using Cheng's standard reaction condition (Scheme 5).²⁴ They showed that when the *meta* position of the phenyl ring at the 2-position of quinazolines was blocked by a substituent group, the mono-sulfonamidated products **16** were exclusively obtained without any of di-sulfonamidated product. Likewise, *ortho*-substituted

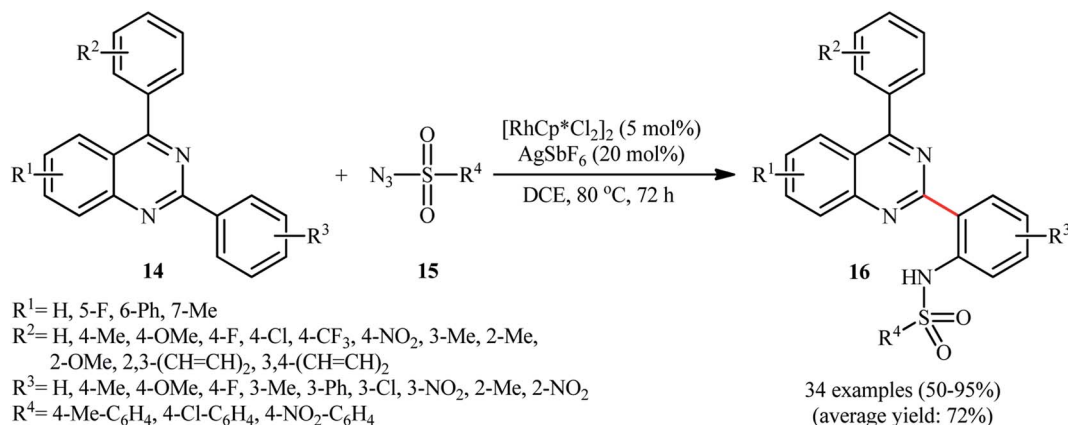


Scheme 3 Rh-catalyzed site-selective sulfonamidation of indoles **8** with sulfonyl azides **9**.

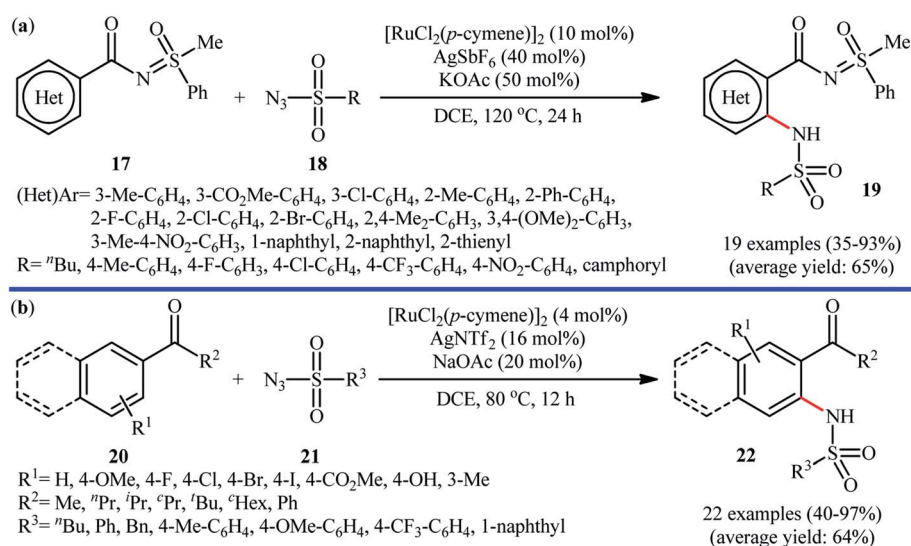


Scheme 4 Direct sulfonamidation of azobenzenes **11** with sulfonyl azides **12** catalyzed by $[\text{RhCp}^*\text{Cl}_2]_2$.





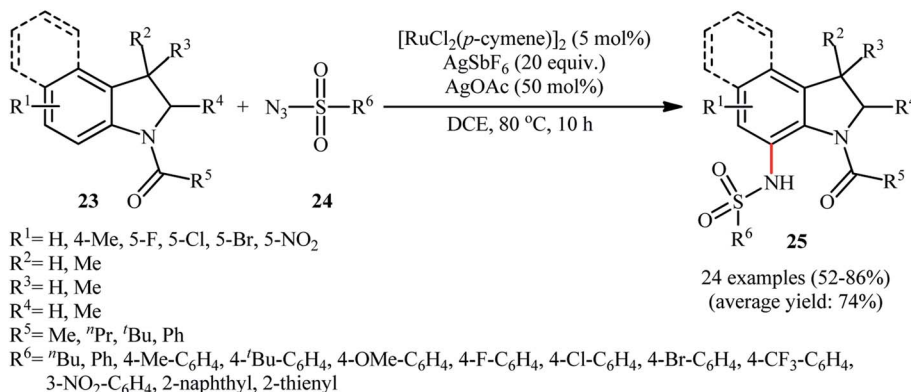
Scheme 5 Rh-catalyzed direct C–H sulfonamidation of 2,4-diarylquinazolines **14** with sulfonyl azides **15** developed by Peng.



Scheme 6 (a) Sulfoximine directed Ru-catalyzed C–H sulfonamidation of arenes **17** with sulfonyl azides **18**; (b) Ru-catalyzed synthesis of 2-sulfonamidated aromatic ketones **22** from ketones **20** and sulfonyl azides **21**.

substrates selectively afforded the corresponding mono-sulfonamidated products. By contrast, the substrates with a substituent at the *para* position resulted in a mixture of mono- and di-sulfonamidated products. Of note, different substituents

on the quinazoline ring failed to enhance the selectivity, albeit total yields were affected by the introduction of various substituents on this ring. Unfortunately, the exact mechanism of this transformation has not been elucidated yet.



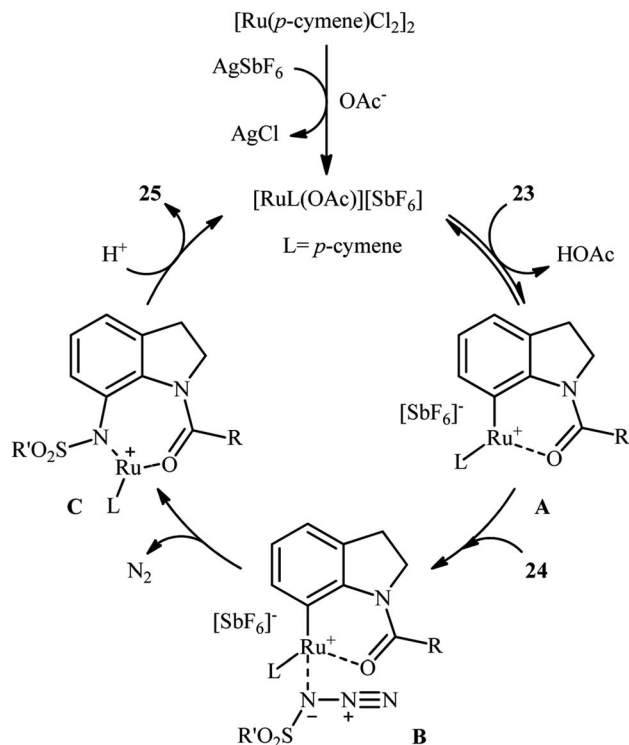
Scheme 7 Ru-catalyzed site-selective C–H sulfonamidation of *N*-carbonylated indolines **23** with sulfonyl azides **24**.



3. Ruthenium-catalyzed reactions

Ruthenium is a rare transition metal placed in period V of the periodic table, adjacent to rhodium and is much cheaper than it. Therefore, it is reasonable to investigate the catalytic ability of this noble metal in direct C–H sulfonamidation of aromatic compounds with sulfonyl azides. In 2013, Sahoo and co-workers first reported the usefulness of ruthenium catalysts for such transformations.²⁵ They showed that the treatment of *ortho*- and *meta*-substituted *N*-benzoylated sulfoximines **17** with various aromatic and aliphatic sulfonyl azides **18** in the presence of $[\text{RuCl}_2(p\text{-cymene})]_2/\text{AgSbF}_6/\text{KOAc}$ combination as a catalytic system in DCE afforded the corresponding mono-sulfonamidated products **19** in modest to excellent yields and outstanding *ortho*-selectivity (Scheme 6a). However, *para*-substituted *N*-benzoylated sulfoximines provided a mixture of mono- and di-functionalized products with poor selectivity. The authors also successfully applied this strategy to the high yielding synthesis of ataciguat, a drug candidate for the treatment of aortic valve stenosis. They demonstrated that the methylphenyl sulfoximine directing group can be efficiently removed by hydrolysis of the final products under basic conditions (NaOH in $\text{MeOH}/\text{H}_2\text{O}$ at 60°C in 6 h), providing the corresponding anthranilic acid derivatives in excellent yields. Subsequently, the same authors broadened the substrate scope of their methodology to aromatic ketones.²⁶ In this report, thirty-three *N*-aryl sulfonamides were synthesized in relatively poor to excellent yields by means of 5 mol% of $[\text{RuCl}_2(p\text{-cymene})]_2$ and 20 mol% of AgSbF_6 in DCE at 100°C in the presence of 50 mol% of $\text{Cu}(\text{OAc})_2 \cdot \text{H}_2\text{O}$ as a base. In contrast to their previous work, *para*-substituted substrates were also furnished *ortho*-sulfonamidated products with high mono-selectivity. At the same time, Chang and colleagues reported independently a similar strategy for the preparation of 2-sulfonamidated aromatic ketones **22** from ketones **20** and sulfonyl azides **21** by using a catalytic amount of $[\text{RuCl}_2(p\text{-cymene})]_2$ in combination with AgNTf_2 and NaOAc (Scheme 6b).²⁷ Noteworthy, the authors proposed mechanism for this transformation is analogous to the one depicted for Rh-catalyzed reaction in Scheme 2. Shortly afterwards, by using a slightly modified catalytic system ($[\text{RuCl}_2(p\text{-cymene})]_2/\text{AgSbF}_6/\text{NaOAc}/\text{DCE}$, 60°C), Ackermann and co-workers described the formation of *N*-aryl sulfonamides from the corresponding hetero-aromatic (pyrimidine, pyridines, and pyrazole) directing-group-containing arenes and sulfonyl azides.²⁸ Following these works, other coordinating directing groups, such as benzo[d]thiazole,²⁹ 1,2,3-triazole,³⁰ and azo³¹ were also successfully utilized in this reaction.

Along this line, Zhu and co-workers elaborated a synthetic route to prepare sulfonamidated indolines **25** via a Ru-catalyzed site-selective C–H sulfonamidation of *N*-carbonylated indolines **23** with sulfonyl azides **24** (Scheme 7).³² The couplings took place in the presence of $[\text{RuCl}_2(p\text{-cymene})]_2$ (5 mol%), AgSbF_6 (20 mol%), AgOAc (50 mol%), at 80°C in DCE and selectively provided C7-functionalized products in moderate to high yields. Based on preliminary mechanistic investigations involving

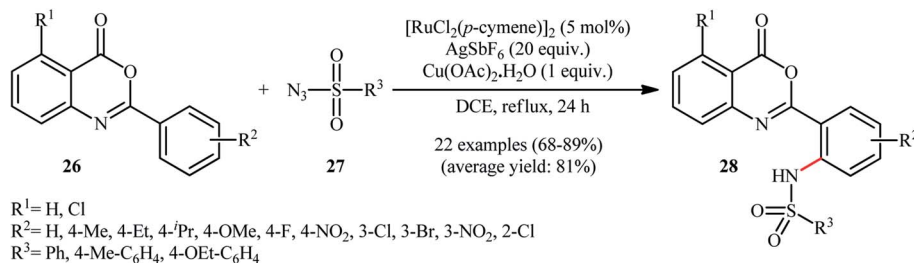


Scheme 8 Mechanistic proposal for the reaction in Scheme 7.

kinetic isotope effect studies and radical trapping experiments, the authors suggested that this reaction proceeds through the following key steps (Scheme 8): (i) initial formation of active Ru(II) catalyst **A** via removing of the Cl^- ligand from the $[\{\text{RuCl}_2(p\text{-cymene})\}_2]$ complex by silver salt; (ii) coordination of the carbonyl oxygen of the indoline **23** to the Ru(II) catalyst **A** to give the metallacycle intermediate **B**; (iii) coordination of the azide group of the sulfonyl azide **24** to intermediate **B** to afford the Ru-species **C**; (iv) insertion of the sulfonamido moiety with evolution of N_2 gas into the intermediate **C** leads to the intermediate **D**; and (v) protonolysis of **D** to form the final product **25** and regenerates ruthenium complex **A**. The above-mentioned catalytic system was then utilized by Reddy's research group in the C8-selective sulfonamidation of 1-tetralones with sulfonyl azides.³³ Kim and co-workers also reported a similar strategy to construct 1-sulfonamido-xanthenes, 5-sulfonamido-chromones, and 5-sulfonamido-flavonoid derivatives by switching the additive to $\text{Cu}(\text{OAc})_2$ and solvent to DCM.³⁴

Very recently, Bakthadoss and co-workers illustrated a similar site-selective C–H sulfonamidation of oxobenzoxazine derivatives **26** with a range of aromatic sulfonyl azides **27** for the synthesis of *ortho*-sulfonamido oxobenzoxazine frameworks **28** using $[\text{RuCl}_2(p\text{-cymene})]_2$ as the catalyst, AgSbF_6 an additive and $\text{Cu}(\text{OAc})_2 \cdot \text{H}_2\text{O}$ as an oxidant (Scheme 9).³⁵ The results demonstrated that oxobenzoxazines possessing electron-withdrawing groups afforded higher yields compared to the electron-rich oxobenzoxazines and the reaction was equally efficient for both electron-neutral and electron-rich aryl sulfonyl azides. However, no examples were given with aliphatic and electron-



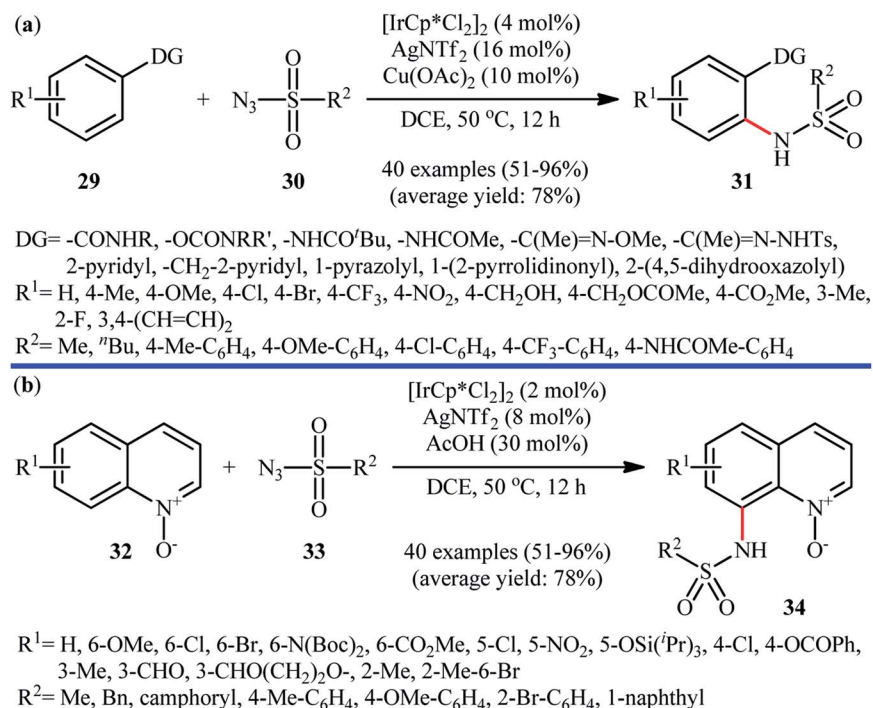
Scheme 9 Synthesis of *ortho*-sulfonamido oxobenzoxazine frameworks **28** reported by Bakthadoss.³⁵

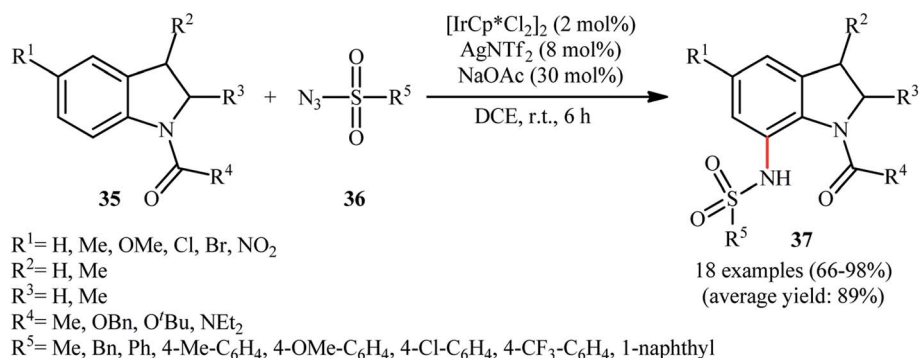
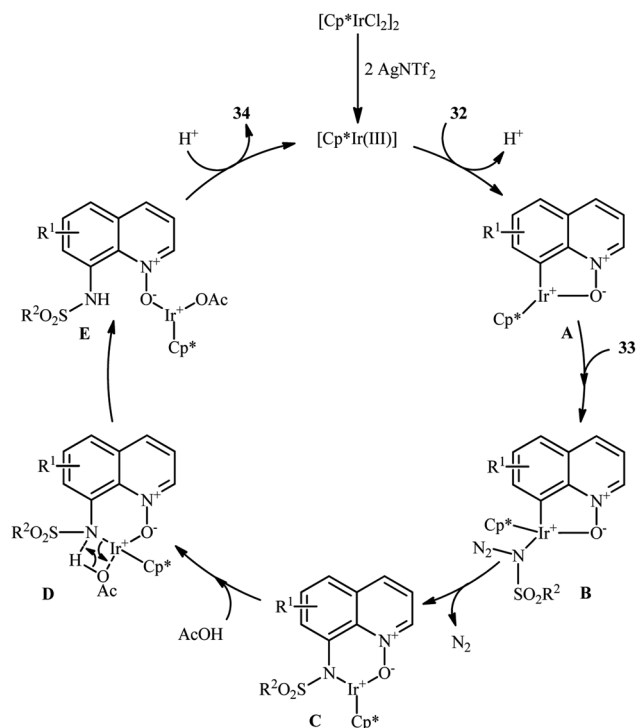
poor aromatic sulfonyl azides as the amide partners. To demonstrate the synthetic application of their methodology, the authors performed further late-stage functional group transformation reactions. They showed that hydrolysis of the synthesized compounds under basic conditions (*e.g.*, NaOH/acetone, KO^tBu/^tBuOH) or in the presence of HBr in AcOH provided the corresponding 2-(2-sulfonaminobenzamido)benzoic acids in excellent yields, while hydrolysis in the presence of NaOMe in refluxing MeOH gave 2-sulfonaminobenzoic acid derivatives in near quantitative yields.

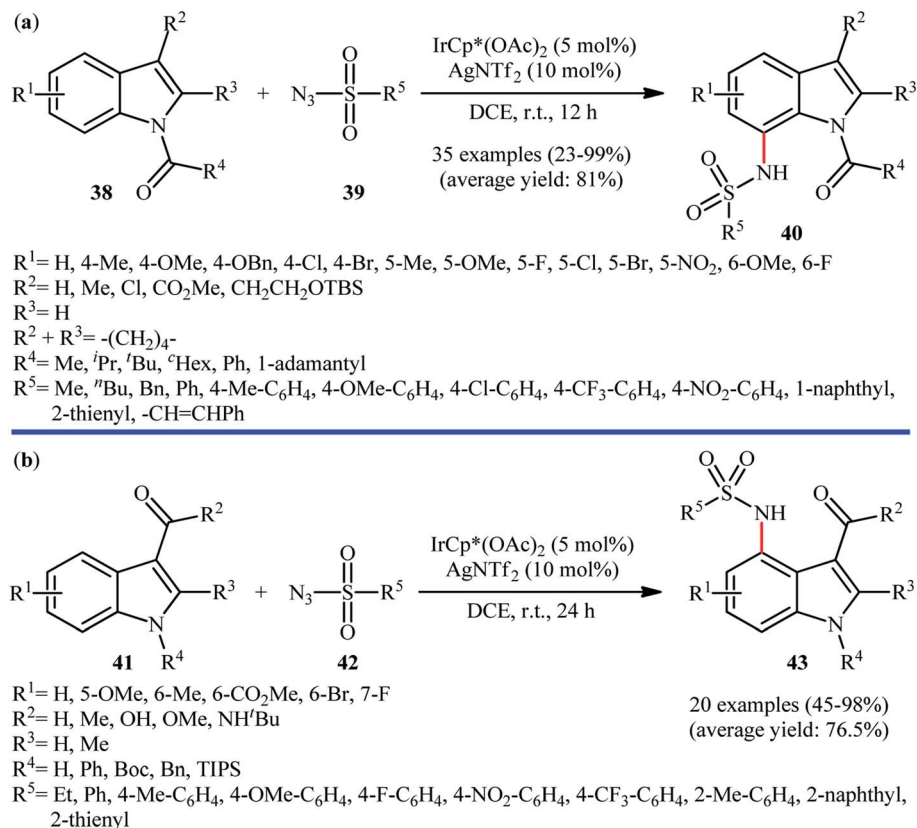
4. Iridium-catalyzed reactions

Of the large amount of published literature, without question, iridium was the most widely used catalyst for the synthesis of *N*-aryl sulfonamides *via* denitrogenative coupling of the corresponding aromatic compounds and sulfonyl azides.

In 2013, Chang and co-workers communicated the first example of iridium-catalyzed direct sulfonamidation of aromatic C–H bonds with sulfonyl azides.³⁶ They showed that a coordinating directing group (*e.g.*, amide, anilide, ketoxime, hydrazone, carbamate, 2-pyridine, 2-pyrazol, and 2-azoline derivatives) attached to the arene rings leads to sulfonamidated products at the *ortho* position, adjacent to these groups. Thus, by employing the combination of [IrCp*Cl₂]₂ with AgNTf₂ as an effective catalytic system, mono-selective amidation of aromatic compounds **29** with various aryl and alkyl sulfonyl azides **30** afforded the corresponding *ortho*-sulfonamidated arenes **31** in moderate to excellent yields (Scheme 10a). The protocol was compatible with various important functional groups such as fluoro, chloro, bromo, nitro, ether, ester, amide and aldehyde functionalities that are useful for further manipulation of products. Noteworthy, the protocol was also applicable for the site-selective amination of arenes with aryl azides. The same authors have next elegantly extended their methodology to

Scheme 10 (a) Ir-catalyzed *ortho*-selective sulfonamidation of aromatic compounds **29** with sulfonyl azides **30**; (b) Chang's synthesis of C8-sulfonamidated quinoline *N*-oxides **34**.





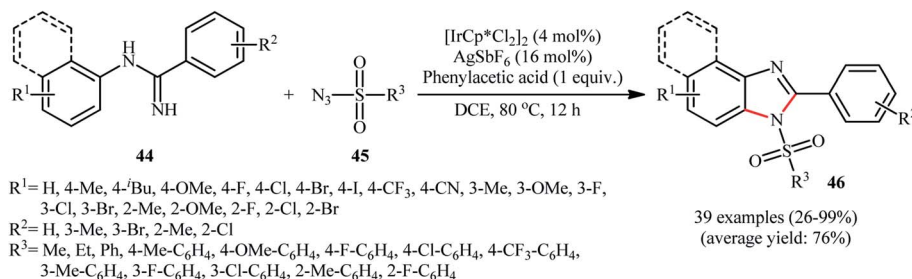
Scheme 13 (a) Synthesis of C7-sulfonamidated indoles **40** reported by Chang; (b) You's synthesis of C4-sulfonamidated indoles **43**.

Table 1 Directing group-assisted $[\text{IrCp}^*\text{Cl}_2]_2$ -catalyzed *ortho*-selective sulfonamidation of aromatic compounds with sulfonyl azides

Entry	Conditions	Directing group	N.E. ^a	Yield (%)		Ref.
				Range	Average	
1	AgNTf ₂ , HOAc, Li ₂ CO ₃ , DCE, 80 °C	–CO ₂ H	26	40–99	81	44
2	AgBF ₄ , AgOAc, ball milling, 30 Hz	–CONHR	18	42–97	76	45
3	Ag ₂ CO ₃ , HOAc, DCE, 80 °C	–SO ₂ NHR	21	71–95	83.5	46
4	AgNTf ₂ , DCE, r.t.	–CH=N ⁺ (O [–])R	28	27–99	87	47
5	AgNTf ₂ , DCE, r.t.	–CH=NTs	21	46–95	75	48
6	AgSbF ₆ , DCE, 80 °C	2-Amino-pyrimidine	21	57–99	87.5	49
7	AgNTf ₂ , PivOH, DCE, 60 °C		29	15–97	73	50
8	AgNTf ₂ , CF ₃ CH ₂ OH, 80 °C		27	67–99	90	51
9	AgSbF ₆ , AcOH, DCE, 80 °C	2-Quinazolinonyl	13	45–90	78	52
10	AgNTf ₂ , AgTFA, DCE, 100 °C		21	56–98	81	53

^a Number of examples.





Scheme 14 Synthesis of 1-(sulfonyl)-2-aryl-1*H*-benzo[*d*]imidazoles **46** from *N*-phenylbenzimidamides **44** and sulfonyl azides **45** through a C–H activation, sulfonamidation and annulation cascade.

(*e.g.*, carboxylate, amide, sulfonamide, imine, nitron, triazole *N*-oxide, benzo[*d*]isothiazole 1,1-dioxide, pyrimidine, quinazolinone and tetrazine) with sulfonyl azides (Table 1).^{44–53}

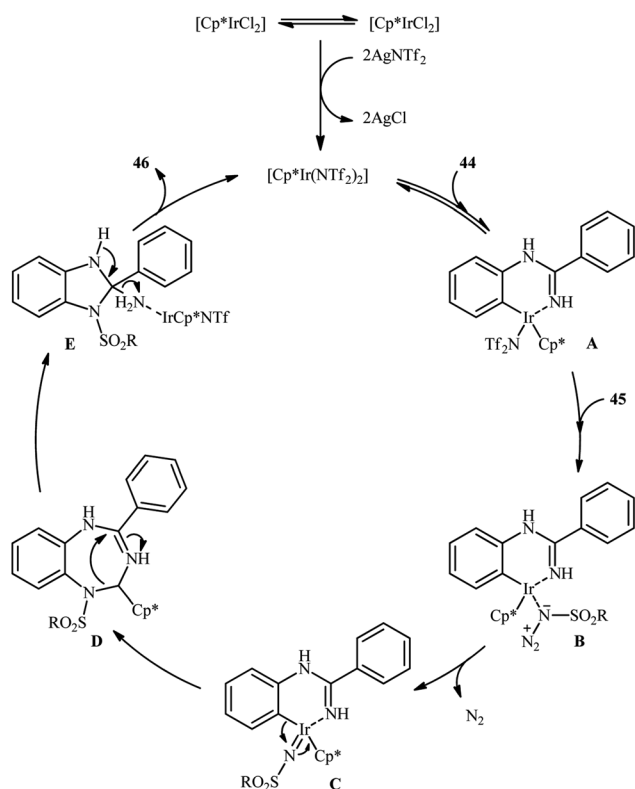
An important contribution to this field was reported by Cui and co-workers in 2017.⁵⁴ They showed that treatment of *N*-phenylbenzimidamide derivatives **44** with sulfonyl azides **45** in the presence of [IrCp*Cl₂]₂/AgNTf₂/phenylacetic acid combination in DCE afforded the corresponding 1-(sulfonyl)-2-aryl-1*H*-benzo[*d*]imidazoles **46** through C–H activation, sulfonamidation and annulation cascade (Scheme 14). Moderate to high yields, excellent regioselectivity, and broad substrate scope were the advantages, mentioned for this strategy. The suggested reaction mechanism for this transformation is displayed in Scheme 15. The reaction starts with the formation of active

catalyst, [Cp*Ir(NTf₂)₂]₂, through anion exchange. Next, coordination of *N*-phenylbenzimidamide **44** to this catalyst and subsequent cyclometalation generates iridacyclic intermediate **A**, which after coordination with azide **45** affords the intermediate **B**. Subsequently, elimination of N₂ from this intermediate produces iridium carbene species **C** that, after migratory insertion of the Ir–Ar bond into the carbene unit gives intermediate **D**. The Ir–N(sulfonamide) bond then undergoes migratory insertion into the C–N(imide) bond to form amide species **E**. Finally, elimination of the active Ir(III) catalyst and one molecule of NH₃ from intermediate **E** upon protonolysis affords the expected 1-(sulfonyl)-2-aryl-1*H*-benzo[*d*]imidazole product **46**.

Recently, Das and Samanta disclosed the synthesis of C3-sulfonamidated isoquinolones **49** in modest to excellent yields and complete regioselectivity from the corresponding 2-pyridyl protected isoquinolones **47** through sulfonamidation with sulfonyl azides **48** in the presence of catalytic quantities of [IrCp*Cl₂]₂ and AgSbF₄, with 50 mol% of NaOAc as an additive (Scheme 16).⁵⁵ Interestingly, when the pyridyl group was switched to H or methyl group, the C8-sulfonamidated isoquinolones **50** were obtained as the sole products. This interesting directing group regiocontrolled reaction was also worked well with different other azides like benzoyl azide, diphenyl phosphoryl azide, and azidoformate. However, phenyl azide and benzyl azide did not furnish the desired products.

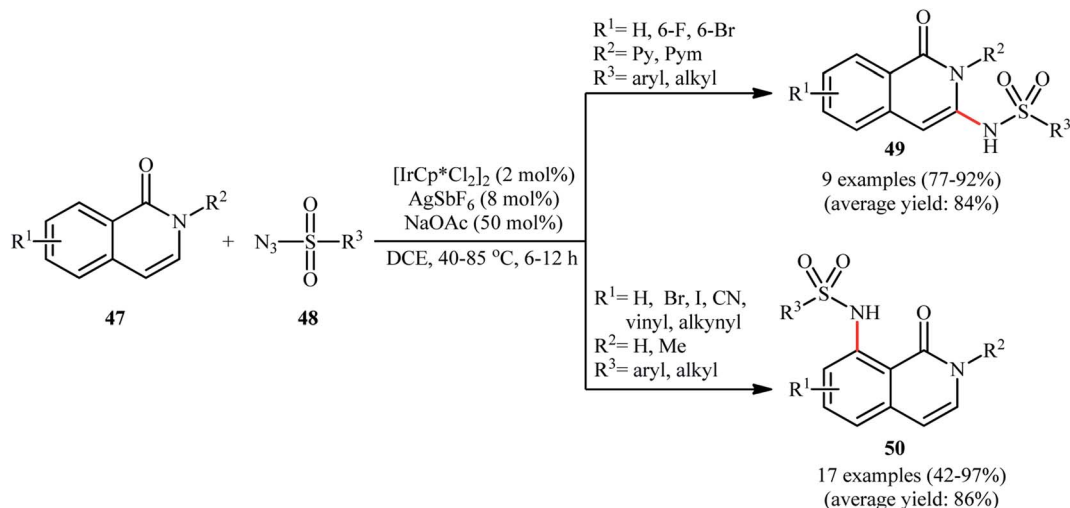
5. Palladium-catalyzed reactions

Despite wide utility of palladium catalysts in numerous C–H bond functionalization reactions,⁵⁶ the reported examples of the direct sulfonamidation of C–H bonds with sulfonyl azides using this versatile transition metal are scarce. In fact, only one example of such a reaction was reported in the literature thus far. In this investigation, Hu, Luo, and Zhu described the regioselective introduction of a sulfonamide group at the C-3 position of indoles using Pd(TFA)₂ as a catalyst and sulfonyl azides as the nitrogen source.⁵⁷ A screening of reaction variables indicated that PPh₃, H₂O, and *m*-xylene were the most effective ligand, additive, and solvent, respectively. With these optimized reaction conditions, a variety of C3-sulfonamidated indoles **53** were obtained in moderate to excellent yields from the corresponding 2-arylindoles **51** and sulfonyl azides **52** (Scheme 17).

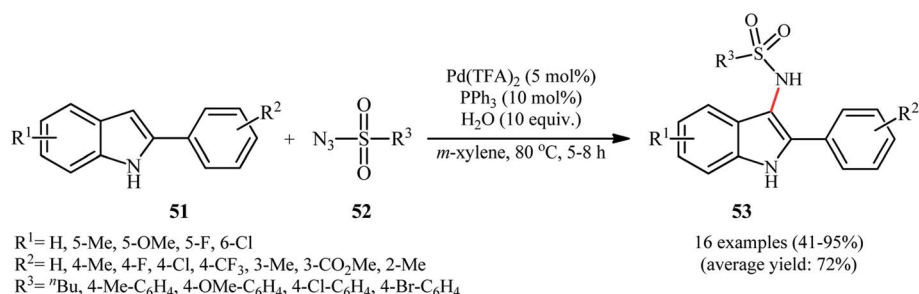


Scheme 15 Proposed mechanistic pathway for construction of 1-(sulfonyl)-2-aryl-1*H*-benzo[*d*]imidazoles **46**.





Scheme 16 Ir-catalyzed regiocontrolled C3/C8-sulfonamidation of isoquinolones **47** with sulfonyl azides **48**.



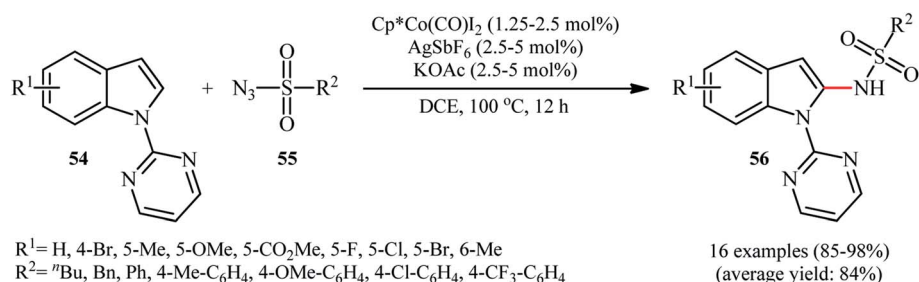
Scheme 17 Pd-catalyzed C-H sulfonamidation of indoles **51** with sulfonyl azides **52**.

Indole itself did not take part in the reaction and therefore no other C2-unsubstituted indoles were examined in the protocol. In order to evaluate the function of ligand, the authors conducted the reaction under the identical conditions by omitting PPh_3 and found no product was detected. However, the exact role of the ligand has not been elucidated yet.

6. Cobalt-catalyzed reactions

Cobalt-based catalytic systems have played key roles in organic synthesis over decades, due to the high catalytic activity, low-cost and toxicity of this earth-abundant transition metal.⁵⁸

The first and only example of Co-catalyzed direct sulfonamidation of aromatic C-H bonds with sulfonyl azides was described by Matsunaga and Kanai in 2014.⁵⁹ The authors reported that indoles **54** bearing a pyrimidine ring as the directing group could undergo a smooth site-selective sulfonamidation with various aryl and alkyl sulfonyl azides **55** in the presence of $\text{Cp}^*\text{Co}(\text{CO})\text{I}_2/\text{AgSbF}_6/\text{KOAc}$ combination as a catalytic system to give the corresponding C2-amidated products **56** in high to excellent yields (Scheme 18). Of note, Cp^*CoI_2 -dimer was also found to promote this denitrogenative coupling reaction, albeit at lower efficiency. However, other commercially available cobalt-catalysts such as $\text{Co}(\text{acac})_3$, $\text{Co}_2(\text{CO})_8$, $\text{Co}(\text{NH}_3)_6\text{Cl}_3$, CoI_2



Scheme 18 Co(III)-catalyzed C2-selective C-H sulfonamidation of indoles **54** with sulfonyl azides **55**.

also useful for C2-selective sulfonamidation of indoles using pyrimidine as the directing group. High to excellent yields, broad substrate scope, and scalability were the main advantages, mentioned of this process. However, the requirement of elevated reaction temperature limited the range of application of this protocol, more or less.

The next year, the same authors applied their manganese catalyst for the sulfonamidation of a diverse range of aromatic oximes **63** with sulfonyl azides **64** by using imidazolium ionic liquid [Hmim]OTf as the solvent (Scheme 21).⁶² This time, no additive was used and the couplings were performed under relatively milder conditions. Importantly, MnBr(CO)₅/[Hmim]OTf system could be easily separated from the final reaction mixture and reused for at least five times with tangible decrease in its catalytic activity. In addition, the reaction could be easily scaled up and performed on a multi-gram quantity without further optimization.

9. Summary and outlook

Sulfonamides belong to an important class of organosulfur compounds as they display an array of biological activities including antimicrobial, antiretroviral, anticonvulsant, anti-diabetic, antitumor, and anti-depressant activities. Interestingly, seventy-two FDA-approved drugs contain this privileged structural motif in their structure and up to 25% of them are *N*-(hetero)arylated derivatives. Therefore, development of facile and efficient procedure for their synthesis from easily available starting materials that meet the objectives of green chemistry is always interesting.

The direct functionalization of C–H bonds represents one of the most atom-economical and environmentally friendly approaches to molecular construction. This methodology enables unprecedented, single-step access to a broad range of carbon–carbon and carbon–heteroatom bonds directly from C–H bonds that are unreactive under traditional methods. In this review, recent advances and developments on the synthesis of biologically important *N*-(hetero)aryl sulfonamides through the transition-metal catalyzed direct sulfonamidation of (hetero)aromatic C–H bonds with easily available sulfonyl azides have been discussed. It is shown that various *N*-aryl and *N*-heteroaryl sulfonamides are readily accessible by using this approach in a straightforward modular way where non-toxic nitrogen gas forms as the sole by-product. Of note, majority of the reactions covered in this review were performed under atmospheric environment and some of them were easily scaled up to the gram levels under relatively mild conditions. These results clearly indicate the potential application of this route of *N*-(hetero)aryl sulfonamide synthesis in industry.

Despite great achievements over the past few years in this fast-growing research area, many challenges remain to be solved. For instance, most of the catalysts used herein are late transition metal catalysts such as Rh, Ru, Ir based-catalysts. Given cost and sustainability concerns, there is a significant need for the development of first-row transition metal-based catalysts. Moreover, despite numerous recent published works on the usefulness of transition metal nanoparticles as highly

efficient and reusable catalysts for various C–H functionalization reactions, there have been no reports of the applicability of such catalysts in the titled reactions till date. Thus, the exploration of metallic nanocatalysts for this page of *N*-aryl sulfonamide are highly desirable in terms of cost and environmental benefits. In addition, almost all of the reactions covered in this review employed directing groups for controlling the site-selectivity. However, the requirement of installing and then removing this groups limited the range of application of this synthetic strategy and therefore, of course, catalyst-controlled site-selective processes should be explored.

Conflicts of interest

There are no conflicts to declare.

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