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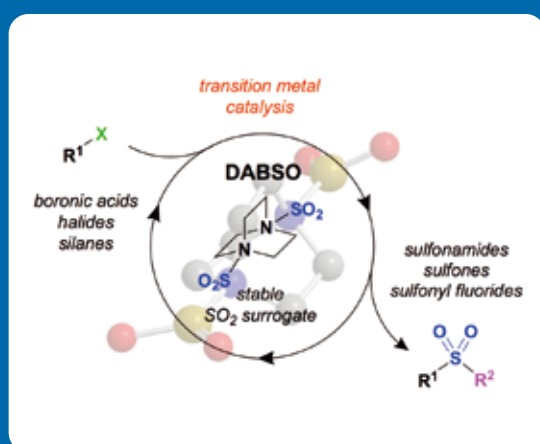R^1 $\overset{\overset{O}{\underset{\|}{}} \underset{\underset{O}{\|}}{S}}{}$ R^2

Research Article

DABCO-*bis*(sulfur dioxide), DABSO, as a Source of
Sulfur Dioxide in Transition Metal-Catalyzed Reactions

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Abstract: The *bis*-adduct of DABCO with sulfur dioxide, DABSO, has been shown to function as an effective surrogate for gaseous sulfur dioxide. DABSO is a stable, solid reagent. The use of DABSO has allowed the first efficient transition metal-catalyzed cross-coupling type reactions of sulfur dioxide to be achieved. Early reactions employed palladium catalysts in combination with aryl iodides and *N,N*-dialkyl hydrazines, to deliver *N*-aminosulfonamides as products. More recently, alternative aryl substrates such as aryl bromides and aryl boronic acids have been employed, and products such as sulfones and sulfonyl fluorides can now be prepared in an efficient manner. In addition to palladium, reactions have been reported that use copper, cobalt and iridium catalysts. This review considers the catalytic reactions that have been developed using DABSO as a reagent, and is structured by type of catalyst used, and further by the type of product obtained.

Keywords: sulfur dioxide, catalysis, sulfonamide, sulfone, transition metal

1. Introduction

Sulfur dioxide has a long history of use in organic synthesis as both a reagent and solvent. Pericyclic reactions, including cheletropic additions and ene reactions, as well as the combination with preformed organometallic reagents such as organolithiums and Grignard reagents, are two examples of the transformations for which sulfur dioxide is well known.[1] Despite an extensive literature covering these and related reactions, there were very few examples in the literature of sulfur dioxide being used as a reagent in combination with transition metal catalysts.[2] Notwithstanding the lack of literature precedent, we were interested in the development of cross-coupling type reactions in which sulfur dioxide would be incorporated. Our key breakthrough was the discovery that the *bis*-adduct of DABCO with sulfur dioxide, which we have named DABSO, functions as an effective surrogate[3] reagent for sulfur dioxide gas (Figure 1).[4] DABSO is a colorless crystalline solid that decomposes at 200 °C (DSC). DABSO is air stable and easily handled. It is usually stored under inert gas at room temperature.[5] Although we have shown that DABSO can function as a SO$_2$-surrogate in combination with preformed organometallics,[6] the focus of this review is the use of DABSO in transition metal catalysis.

O$_2$S·N⁀N·SO$_2$

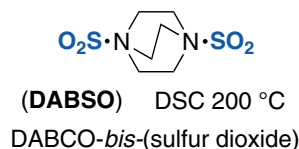(**DABSO**) DSC 200 °C
DABCO-*bis*-(sulfur dioxide)

Figure 1.

2. Palladium-Catalyzed Reactions
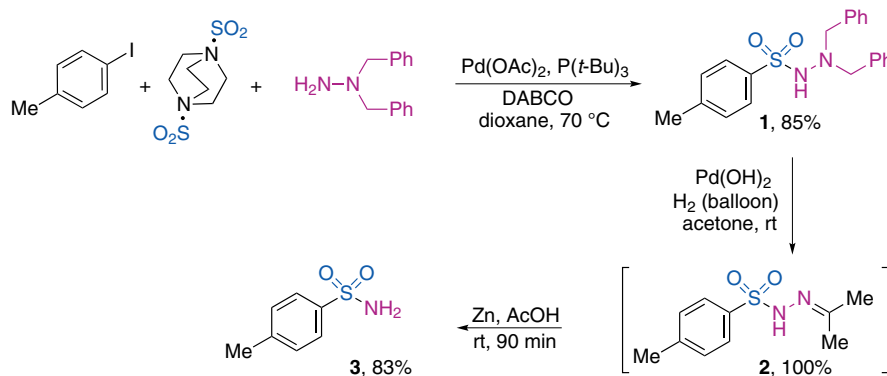
2-1. Sulfonamide Synthesis

The sulfonamide functional group features in a wide range of pharmaceuticals and agrochemicals, and as such these important motifs were the first class of compounds that we targeted. The successful chemistry allowed the union of aryl iodides, sulfur dioxide (provided from the reagent DABSO) and *N,N*-dialkylhydrazines, using a palladium(0) catalyst, to provide *N*-aminosulfonamides as the products.[7] Selected examples are shown in Scheme 1; variation of the aryl iodide component was readily achieved, and a broad range of functional groups could be tolerated. Heteroaryl iodides were also competent substrates, as were alkenyl iodides. The *N*-nucleophile was limited to *N,N*-dialkylhydrazines, but variation of the alkyl substituents of

the hydrazine was possible. All of the reactions were achieved using a catalyst generated from P(*t*-Bu)$_3$ (used as its HBF$_4$ salt)[8] and Pd(OAc)$_2$. The majority of reactions required only 0.6 equivalents of DABSO, demonstrating the excellent uptake of SO$_2$ during these reactions. Although this chemistry is limited in the scope of *N*-nucleophiles that can be employed, it does represent the first example of an efficient three-component cross-coupling type reaction that employs sulfur dioxide.

Access to the parent sulfonamides using this chemistry was possible if *N,N*-dibenzylhydrazine was used as the *N*-nucleophile. The initially formed *N*-aminosulfonamide **1** was treated with hydrogen gas over a Pd(OH)$_2$ catalyst in acetone as solvent. The *in situ* generated hydrazone **2** was then treated with zinc in acetic acid to provide the parent sulfonamide **3**.[7b]
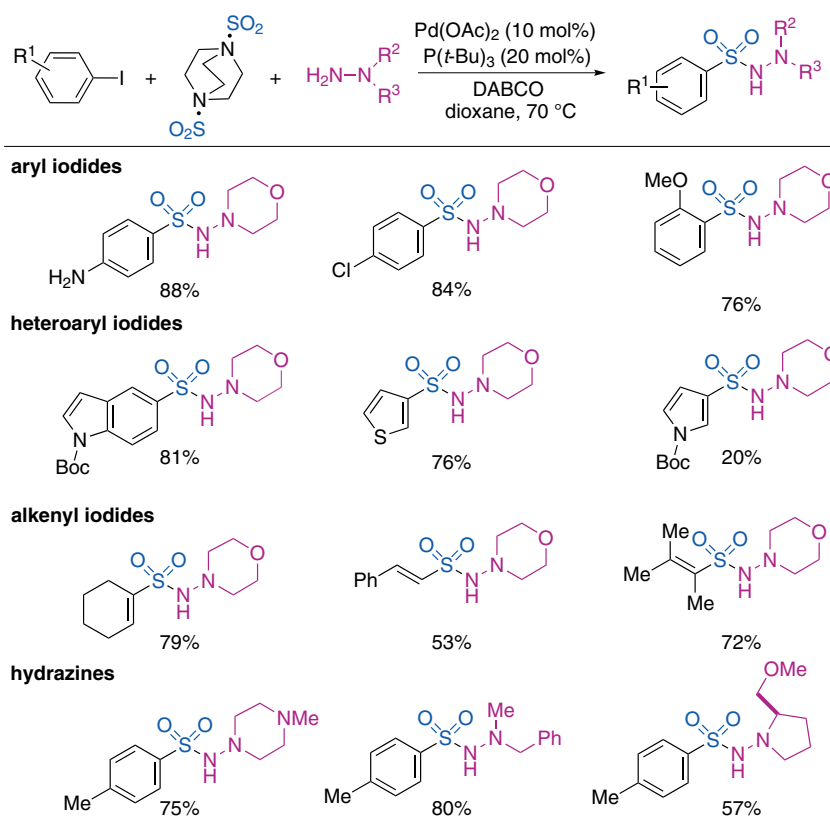
Scheme 1. Palladium-catalyzed *N*-aminosulfonamide synthesis from aryl iodides, DABSO and *N,N*-dialkylhydrazines
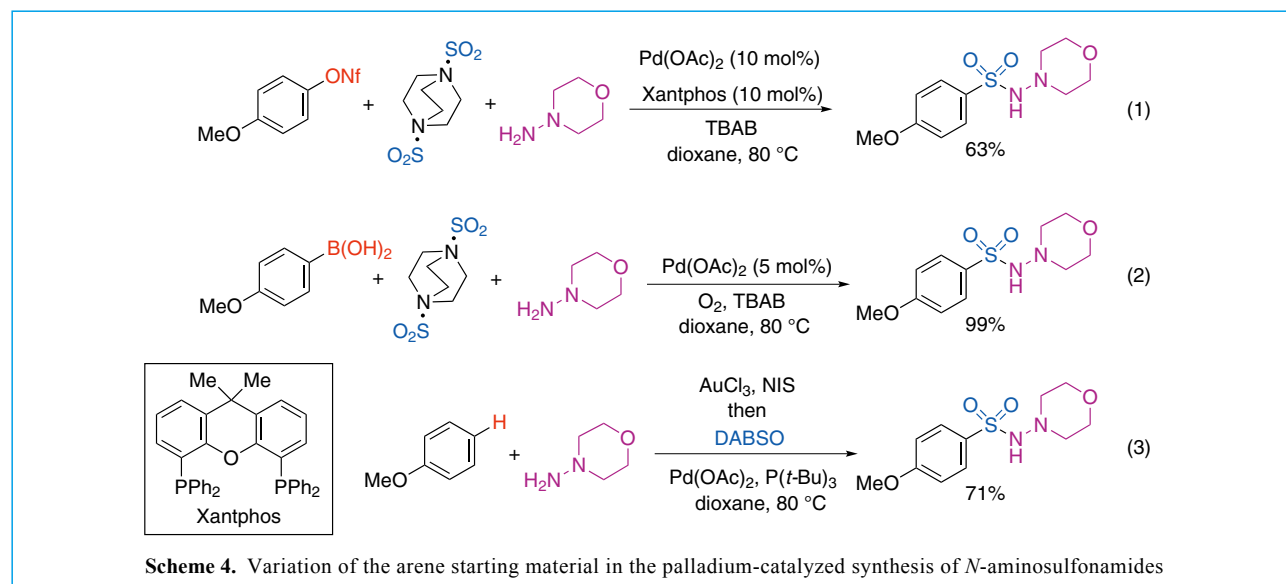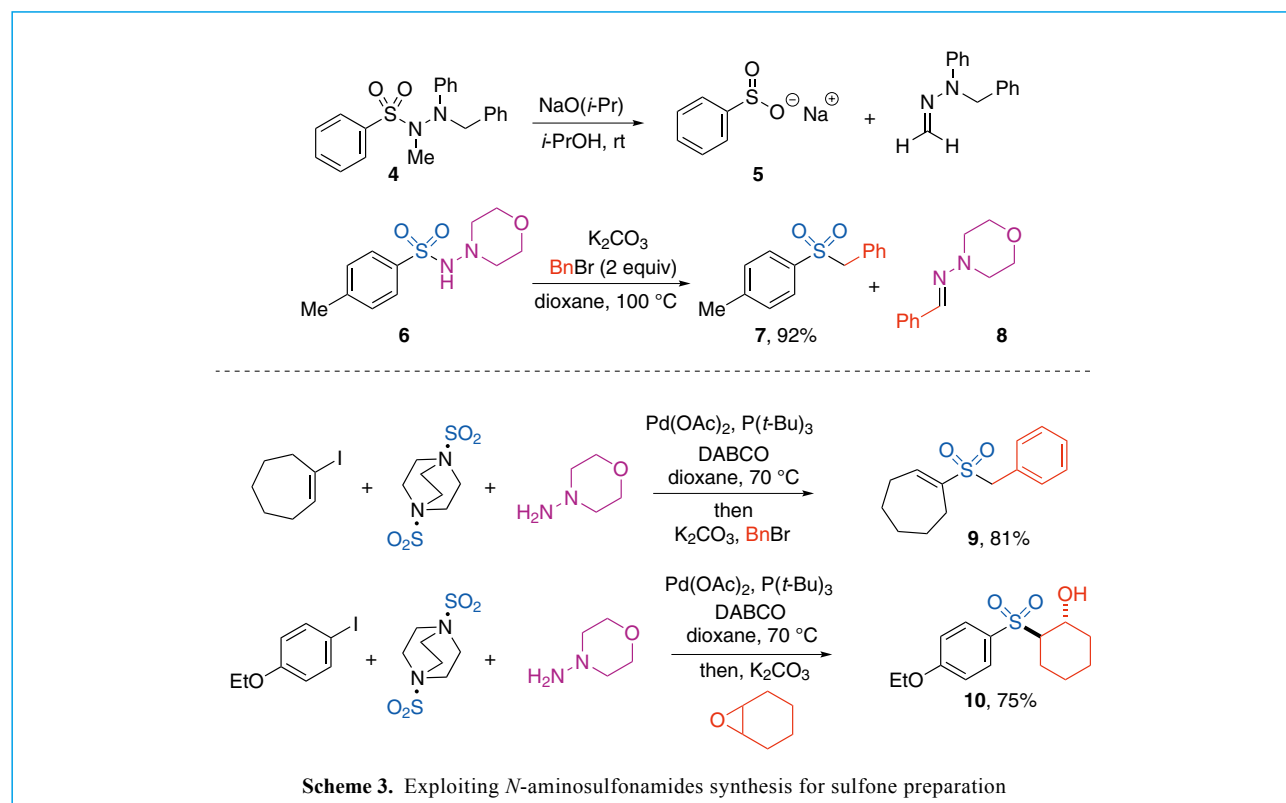

Scheme 2. Parent sulfonamide synthesis using *N,N*-dibenzylhydrazine as the nucleophile

Literature dating from 1957 had shown that N-aminosulfonamides can function as precursors to sulfinate salts. For example, when N,N,N-trialkylaminosulfonamide **4** was treated with an alkoxide base in isopropanol, sulfinate **5** was generated in good yield (Scheme 3).[9]

We were able to develop a version of this process that was applicable to the type of aminosulfonamides produced in Scheme 2. For example, following treatment of aminosulfonamide **6** with K_2CO_3 and two equivalents of BnBr, sulfone **7** was obtained in 92% yield.[10] The reactions proceed by initial alkylation of the aminosulfonamide N-atom, followed by deprotonation and elimination to generate an intermediate sulfinate and hydrazone byproduct **8**; the sulfinate salt reacts with the excess benzyl bromide to provide the desired sulfone.

This protocol could be extended to a one-pot process whereby the palladium-catalysed aminosulfonamide synthesis was combined with sulfinate formation/arylation. For example, an alkenyl iodide substrate provided sulfone **9**, while an aryl iodide substrate, in combination with an epoxide electrophile for the second step, provide β-hydroxysulfone **10**.

The Wu group at Fudan University has made significant contributions to the use of DABSO in synthesis. One of their first contributions was to show that aryl nonaflates (perfluorobutanesulfonates) could be used as substrates in place of aryl iodides in the synthesis N-aminosulfonamides.[11] The reactions used a modified catalyst system in which Xantphos was employed as the supporting ligand (Scheme 4, eq 1). This is an important extension as it allows phenols to be considered as
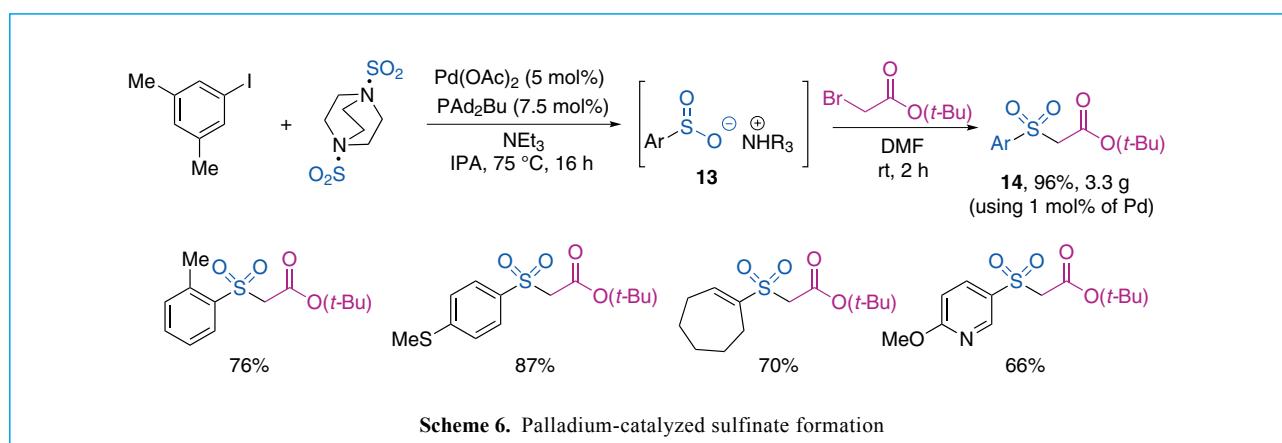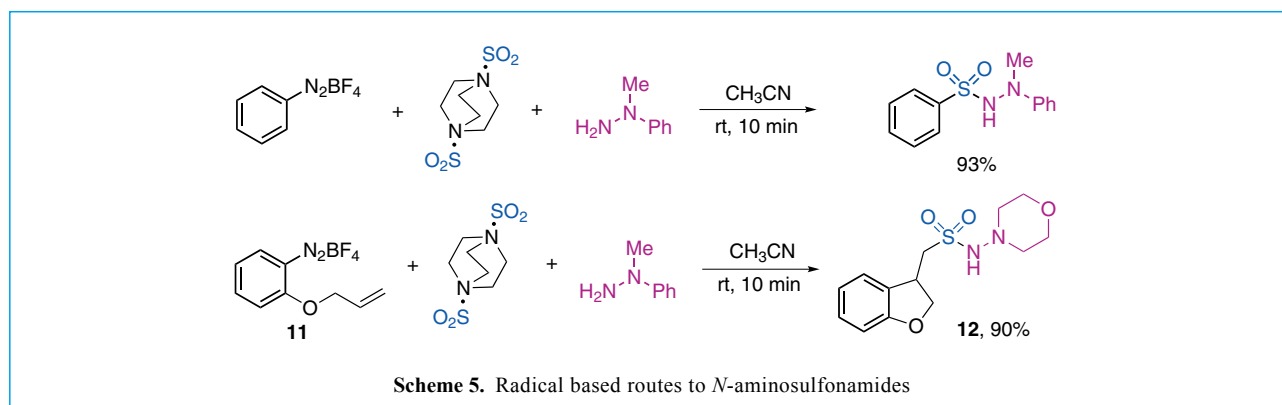

Scheme 3. Exploiting N-aminosulfonamides synthesis for sulfone preparation

Scheme 4. Variation of the arene starting material in the palladium-catalyzed synthesis of N-aminosulfonamides

substrates for these reactions. The same group also demonstrated that aryl boronic acids could be employed as substrates (Scheme 4, eq 2).[12] This change to boronic acid substrates required the use of a Pd(II) catalyst and an oxidant, which was provided by an oxygen atmosphere. No phosphine ligand was required for these transformations. The Wu group demonstrated that an initial gold-catalyzed iodination, generating the iodoarene *in situ*, could be combined with the palladium-catayzed aminosufonylation, allowing simple arenes to function as the starting materials (Scheme 4, eq 3).[13] It should be noted that this is a two-step, one-pot process. All three of the transformations shown in Scheme 3, in which the arene starting material is varied, are still limited to the use of *N,N*-dialkylhydrazines as the *N*-nucleophiles. The Wu group has also introduced the use of potassium metabisulfate ($K_2S_2O_5$) as an alternative sulfur dioxide surrogate.[14] In their original report, aryl iodides were combined with $K_2S_2O_5$ and *N,N*-dialkylhydrazines using Pd(0) catalysis, to provide the expected *N*-aminosulfonamides.

The Wu group have been pioneers of the use of DABSO as a source of sulfur dioxide in radical-based processes, often under metal-free conditions. Although these reactions are beyond the scope of this review, their lead publication in this area is shown in Scheme 5.[15] The reactions employ aryl diazonium salts as aryl radical precursors, which can be combined with DABSO and an *N,N*-dialkylhydrazine to deliver *N*-aminosulfonamides as products. Importantly, these reactions are conducted at room temperature. A control reaction, using a substrate that features a tethered alkene (**11**), proceeded *via* cyclisation, ultimately providing *N*-aminosulfonamide **12** as the product, thus confirming the presence of radical intermediates.

2-2. Sulfinate Formation

The palladium-catalyzed preparation of *N*-aminosulfonamides, introduced in Scheme 2, established that SO_2 could be introduced in cross-coupling type reactions. However, the limitations with respect to the *N*-nucleophile result in the formation of specialized, not generally useful, products. In order to deliver a reaction of more utility we targeted the direct formation of sulfinate salts. This was achieved by replacing the *N*-nucleophile used in Scheme 2 with a hydride source, with the use of isopropanol being most effective; the general process is shown in Scheme 6.[16] Aryl iodides are combined with DABSO in isopropanol (this serves as both solvent and hydride source) using a Pd(0) catalyst generated from Pd(OAc)$_2$ and PAd$_2$Bu, with triethylamine as a base. The resulting sulfinates (**13**), can then be combined with a broad range of electrophiles, for example an alkyl halide, to provide the corresponding sulfone (**14**). When performed on gram scale the catalyst loading could be reduced to 1 mol%. Good variation of the aryl iodide substrate was possible, and alkenyl as well as heteroaryl variants could also be used (Scheme 6). A related reaction, which uses $K_2S_2O_5$ as the SO_2 source and sodium formate as the reductant, has been reported by scientists at Pfizer in the US.[17]

Scheme 5. Radical based routes to *N*-aminosulfonamides

**Scheme 6.** Palladium-catalyzed sulfinate formation

The utility of sulfinate salts is that they can be combined with a variety of alternative electrophiles to provide a correspondingly broad range of products. Selected examples of this approach, using sulfinate **13**, are shown in Scheme 7; the use of an epoxide provides β-hydroxy sulfone **15**, nucleophilic aromatic substitution delivers aryl-heteroaryl sulfone **16**, and chlorination followed by amine addition provides sulfonamide **17**.[16]

Given the prevalence of sulfonamides in medicinal and agrochemistry, we wanted to adapt the sulfinate synthesis described above to provide a simple and efficient entry to these important functional groups. Accordingly, we adapted our earlier chemistry based on the use of pre-formed organometallic reagents,[6d] and were able to show that treatment of the *in situ* catalytically generated sulfinate intermediates with an aqueous solution of the relevant amine and bleach (NaOCl), provides the corresponding sulfonamides in high yield (Scheme 8).[18] The
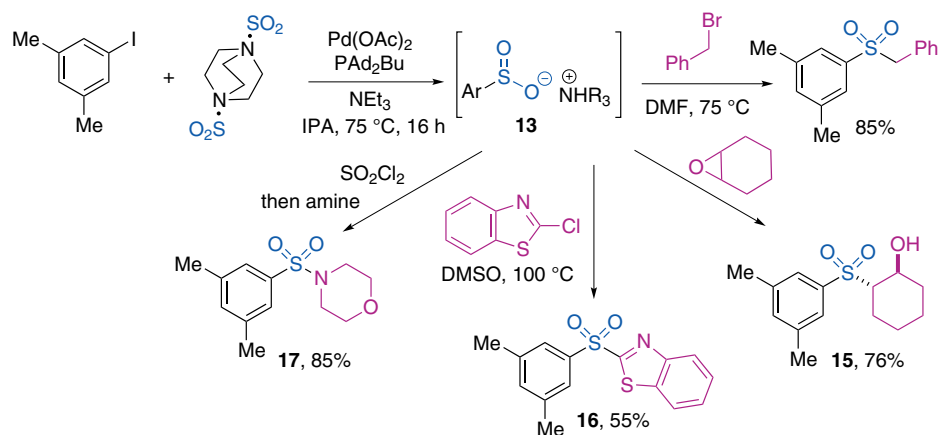
Scheme 7. Catalytically generated sulfinates as versatile intermediates in synthesis
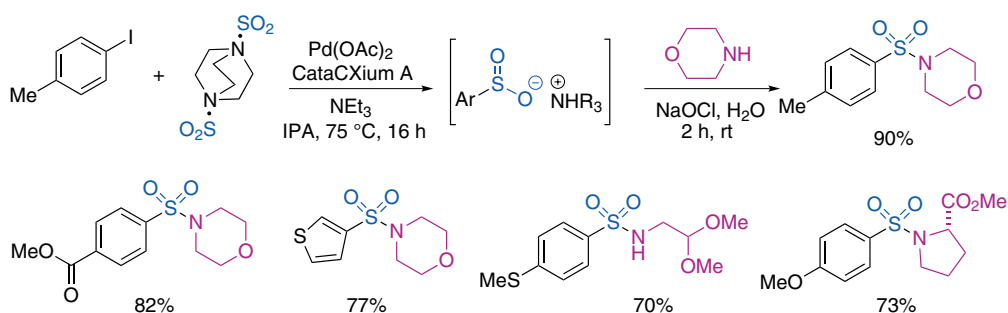
Scheme 8. Sulfonamide synthesis using *in situ* generated *N*-chloroamines
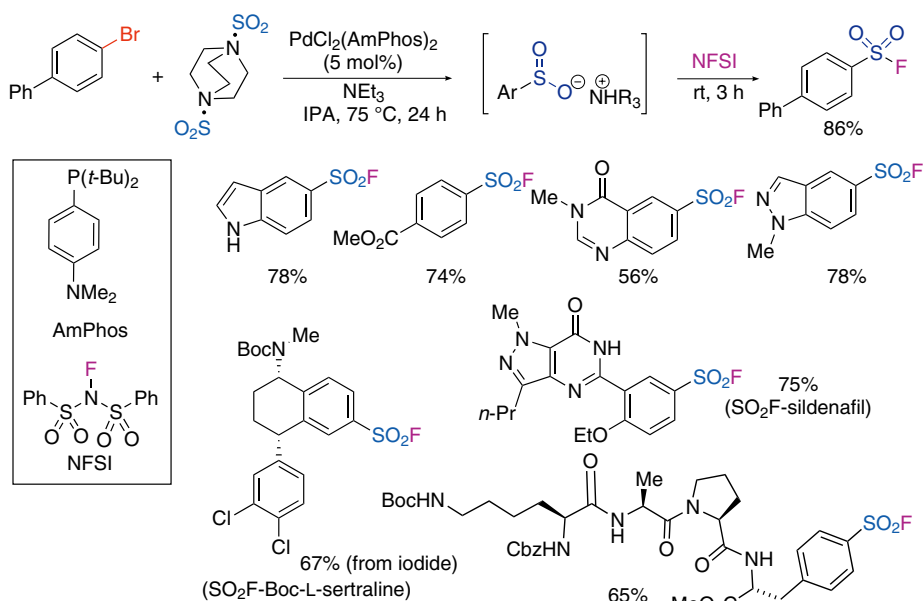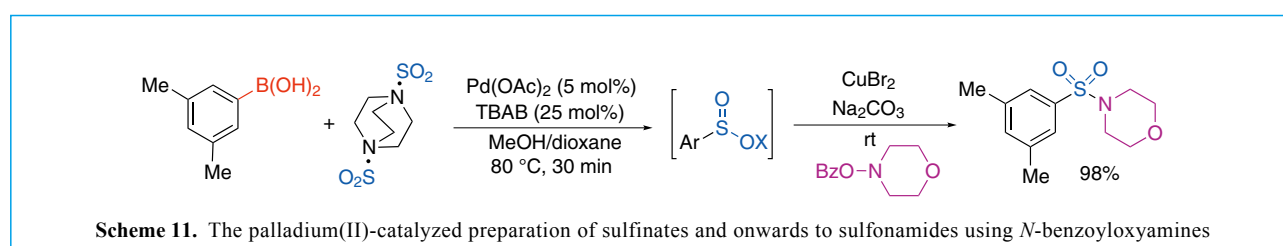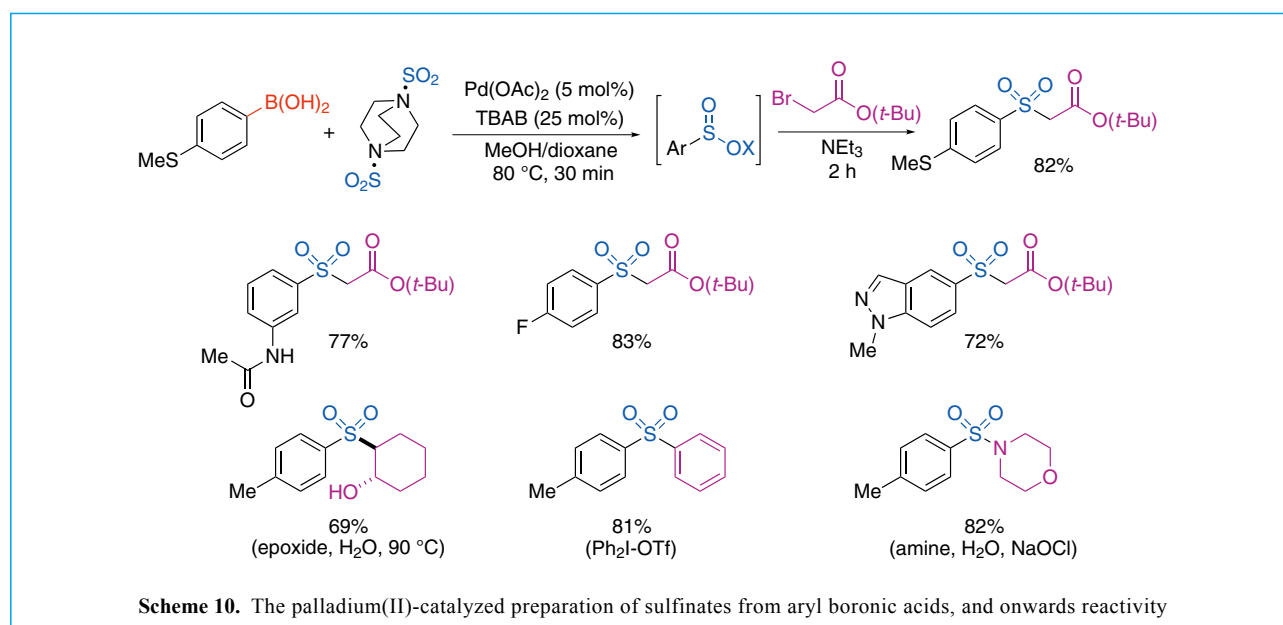

Scheme 9. The palladium-catalyzed preparation of sulfonyl fluorides from aryl halides

reactions proceed *via in situ* formation of the *N*-chloroamines. Broad variation of both the aryl iodide and amine component was possible, including the use of heteroaryl iodides, and well as amines bearing acid-sensitive functional groups. Amino acids could also be employed, and the corresponding sulfonamides were obtained with no erosion of enantiomeric excess.

The sulfinate syntheses shown in Schemes 6, 7, and 8 all employ (hetero)aryl iodide substrates. A re-evaluation of phosphine ligands allowed a new catalyst system, this time featuring the ligand AmPhos, to be used in combination with (hetero)aryl bromide substrates.[19] In a collaboration with scientists at Pfizer, this chemistry was showcased in the synthesis of a range of sulfonyl fluorides (Scheme 9). The *in situ* generated sulfinates are treated with NFSI, which is a source of F$^+$, and delivered the corresponding sulfonyl fluorides in good yields. Good variation of the aryl bromide was possible. Sulfonyl fluorides are important molecules for the design of covalent inhibitors, and as probe reagents in chemical biology applications; Scheme 9 also shows the preparation of several sulfonyl fluorides from halogenated pharmaceuticals, or pharmaceutical fragments that were prepared using this methodology.

To complement the Pd(0)-catalyzed sulfonylation procedures described above, we have also developed a Pd(II)-catalyzed protocol that employs aryl boronic acids as the substrates (Scheme 10).[20] The reaction conditions consist of Pd(OAc)$_2$ with tetrabutylammonium bromide (TBAB) in a methanol/dioxane solvent mixture at 80 °C. No phosphine ligands were required in the reactions. Complete conversion to sulfinate was achieved after just 30 minutes, at which point an electrophile could be added. As shown in Scheme 10, good variation of the starting aryl boronic acid, including heterocyclic variants was possible, and a variety of electrophiles could be introduced in the second step, allowing access to various sulfones as well as sulfonamides. A related transformation, which uses K$_2$S$_2$O$_5$ as the SO$_2$ source, has been reported by scientists at Pfizer in the US.[21]

The sulfonamide shown in Scheme 10 was prepared by the addition of an aqueous solution of the amine and NaOCl to the *in situ* generated sulfinate. The reaction proceeds *via* the *in situ* formation of the *N*-chloroamine which functions as an electrophilic amine component. Similar reactivity has been reported by Tu and co-workers, who used preformed *N*-benzoyloxyamines as electrophilic amine components in combination with a Cu(II) catalyst (Scheme 11).[22]

Scheme 10. The palladium(II)-catalyzed preparation of sulfinates from aryl boronic acids, and onwards reactivity

Scheme 11. The palladium(II)-catalyzed preparation of sulfinates and onwards to sulfonamides using *N*-benzoyloxyamines

3. Copper-Catalyzed Reactions

The Wang group were the first to report a copper-catalyzed process involving DABSO. They developed a variant of the aminosulfonamide synthesis shown in Scheme 1, but employed aryl triethoxysilanes as the substrates in combination with a Cu(II)-catalyst (Scheme 12).[23] Cu(OAc)$_2$ was employed as the catalyst, along with an oxygen atmosphere. The reactions were tolerant of a broad range of silanes, but the commercial availability of these reagents is limited. As with the related palladium-catalyzed reactions, the *N*-nucleophile is again limited to *N,N*-dialkylhydrazines.

The Wu group employed the same class of aryl substrate in a copper-catalyzed sulfone synthesis.[24] Their method involved the combination of aryl triethoxysilanes, DABSO, and an alkyl halide using Cu$_2$O as catalyst (Scheme 13).

The same group reported a copper-catalyzed preparation of benzothiophene-1,1-dioxides (Scheme 14). The chemistry involved the combination of *o*-alkynylboronic acids (**18**), with DABSO and a Cu(II) catalyst.[25] Reasonable variation of the substrate was possible, delivering the expected heterocycles in moderate to good yields.

Our laboratory has reported a Cu(I)-catalyzed synthesis of aryl sulfinates using aryl boronic acids as substrates (Scheme 15).[26] The chemistry employs the commercially available copper catalyst Cu(MeCN)$_4$BF$_4$ and relies on a 12 hour reaction to achieve complete sulfinate formation. Addition of a variety of electrophiles is possible, trapping the sulfinate, and providing sulfones, sulfonamides, and sulfonyl fluorides. This chemistry provides a copper variant of the palladium-catalyzed reactions presented in Scheme 10.
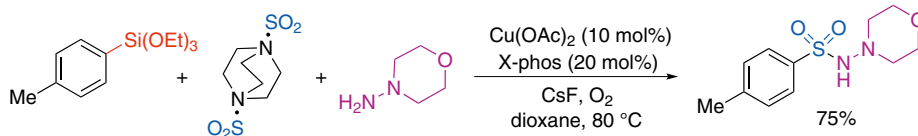
Scheme 12. The copper(II)-catalyzed preparation of *N*-aminosulfonamides using aryl triethoxysilanes
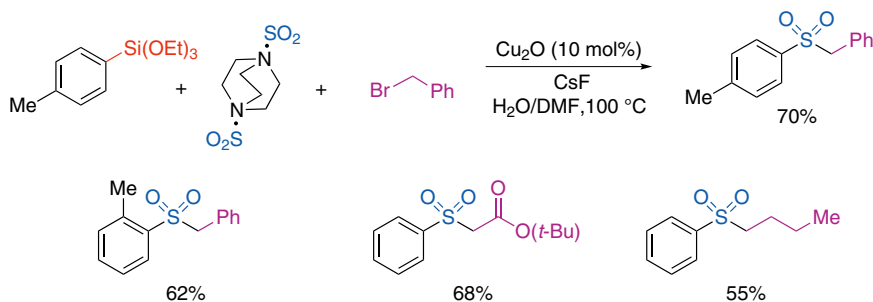

**Scheme 13.** The copper-catalyzed preparation of sulfones using aryl triethoxysilanes
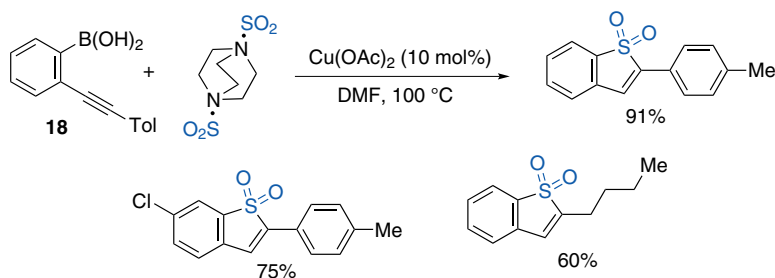
Scheme 14. The copper-catalyzed synthesis of benzothiophene-1,1-dioxides

Our laboratory was also able to exploit copper-catalysis in developing the first examples of a sulfonylative Suzuki-Miyaura cross-coupling (Scheme 16).[26] The reactions allowed the direct combination of aryl boronic acids, aryl halides and sulfur dioxide (provided from DABSO), and employ the same commercial copper catalyst, this time partnered with the indicated bipyridine ligand. Good variation of both the aryl iodide and aryl boronic acid was possible, including the use of heteroaryl variants, as well as alkenyl examples. This chemistry represents the first sulfonylative variant of any classic cross-coupling process.
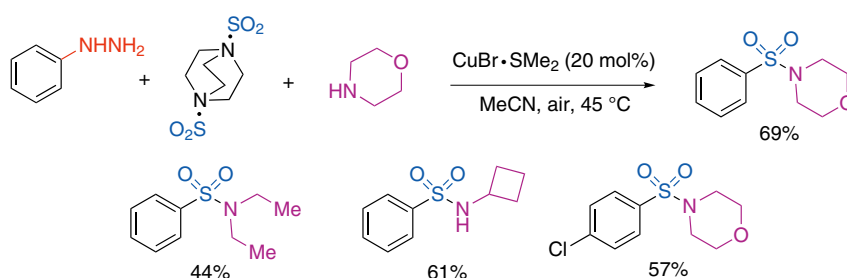
A copper-catalyzed direct sulfonamide synthesis has also been reported, and involves the coupling of aryl hydrazines, sulfur dioxide (from DABSO), and amines, using a CuBr catalyst and an air atmosphere (Scheme 17).[27] The chemistry involves the oxidative conversion of the aryl hydrazines to aryl radicals. This is a rare example of a direct sulfonamide synthesis, but is limited by the need to employ aryl hydrazines as the substrates.
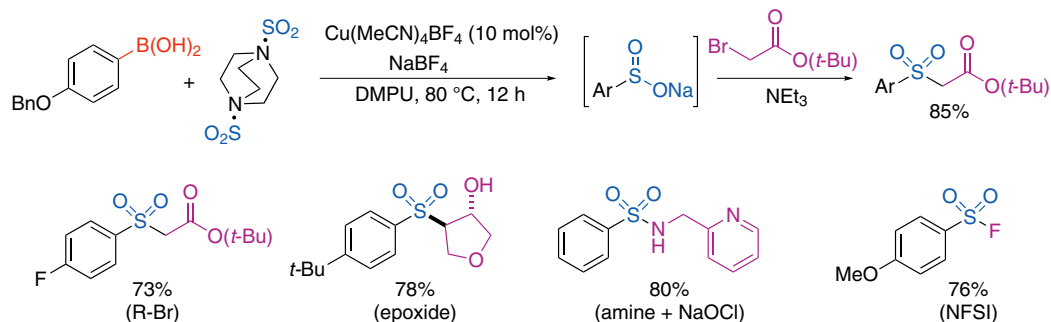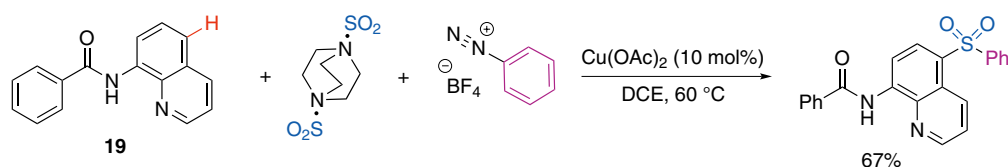
Scheme 15. The copper(I)-catalyzed sulfinate formation, and onwards to sulfones, sulfonamides and sulfonyl fluorides
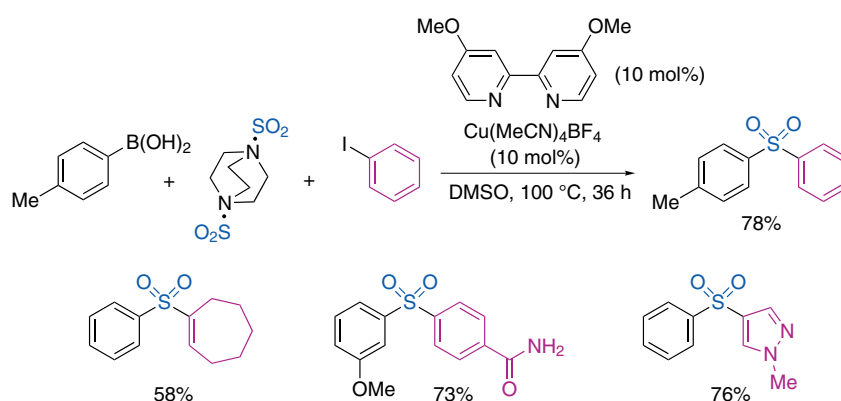
Scheme 16. The copper(I)-catalyzed sulfonylative Suzuki-Miyaura cross-coupling

Scheme 17. The copper(I)-catalyzed sulfonamide synthesis employing aryl hydrazine substrates

Scheme 18. The copper(II)-catalyzed C-H sulfonylation of 8-aminoquinoline amides

The final copper-catalyzed DABSO-based reaction we will consider is a recent report from the Wu group, and involves the sulfonylation of an aryl C-H bond (Scheme 18).[28] The chemistry is radical based, and involves the coupling of a quinolinyl-derived amide (**19**) with DABSO and an aryl diazonium salt using a Cu(II) catalyst. The targeted C-H functionalization products, diaryl sulfones, are obtained in moderate yields.

4. Miscellaneous Metal Catalysts

Although palladium and copper catalysts provide the majority of examples of DABSO, and alternative SO_2-surrogates, use in synthesis, there are a handful of reports that employ different metal catalysts. For example, The Toste group, in collaboration with scientists at Pfizer, have demonstrated that Au(I) complexes are effective catalysts for the addition of sulfur dioxide to aryl boronic acids.[29] They utilized this reactivity in a one-pot sulfone synthesis (Scheme 19, eq 1). Note, $K_2S_2O_5$ is used as the SO_2-source. Recently, a Au(I)-carbene complex has also been used in a closely related system.[30] The same overall transformation can also be promoted using a cobalt complex.[31] In this case, cobalt oxide is used in stoichiometric amounts, and promotes the union of aryl triethoxysilanes, DABSO and an alkyl halide (Scheme 19, eq 2).

The Wu group has reported a second aryl C-H sulfonylation protocol, this time employing an iron catalyst (Scheme 20).[32] This radical process combines 2-napthols, DABSO, and aryl diazoniums salts, and delivers diaryl sulfone products in good yields. A simple $FeCl_3$ catalyst is employed. The final transformation we will consider is a recent report from the Wu group concerning thiophosphate synthesis. Aryl iodonium salts are used as the substrates and are combined with DABSO and diphenylphosphine oxide, in the presence of an iridium photocatalyst (Scheme 21).[33] Irradiation with visible light results in formation of the thiophosphonate **20**. This is an unusual example of DABSO use in which the SO_2 is reduced during the transformations.

5. Conclusions

The advent of DABSO (and other reagents) as an effective surrogate for sulfur dioxide gas has allowed the development of a range of transition metal catalyzed reactions that result in sulfur dioxide incorporation. Although early examples deliver rather esoteric products, more recent reactions deliver synthetically useful products. Palladium and copper based catalysts dominate the reactions that have been reported, but recent advances suggest that alternative metals could provide useful, and different, reactivity.
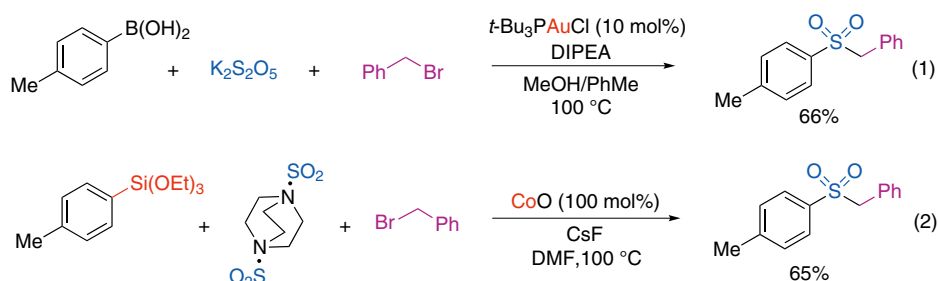
Scheme 19. Gold and cobalt mediated sulfone syntheses
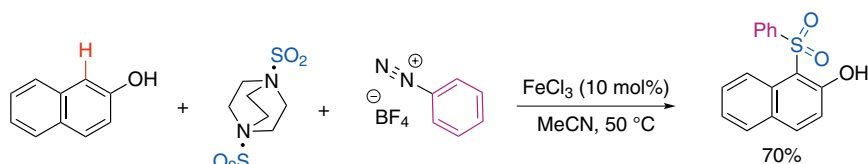
Scheme 20. Iron-catalyzed naphthol sulfonylation
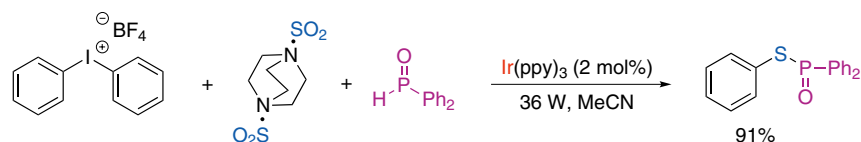
Scheme 21. Iridium-catalyzed thiophosphonate synthesis

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Introduction of the author:

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Michael Willis is a Professor of Chemistry at the University of Oxford. He received his undergraduate education at Imperial College London, and his Ph.D. from the University of Cambridge working with Prof. Steven Ley. After a postdoctoral stay with Prof. David Evans at Harvard University, he was appointed to a lectureship at the University of Bath in November 1997. In January 2007 he moved to the University of Oxford, where he is now a Professor of Chemistry and a Fellow of Lincoln College. His group's research interests are based on the development and application of new catalytic processes for organic synthesis, with a particular interest in transition metal catalysis. His work has been recognized by the award of recent prizes, including the Royal Society of Chemistry's 2014 Catalysis in Organic Chemistry Award, and the 2015 Pfizer, AstraZeneca, Syngenta, Process Chemistry Research Award.

TCI Related Products

B3960 　DABSO [= Bis(sulfur Dioxide)-1,4-diazabicyclo[2.2.2]octane Adduct] 　　　　　　1g　　5g
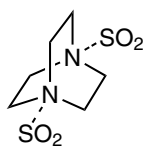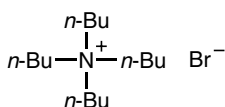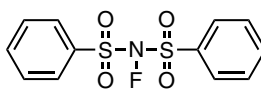
DABSO

D0134 　DABCO [= 1,4-Diazabicyclo[2.2.2]octane] 　　　　　　25g　100g　500g
P2480 　Potassium Disulfite 　　　　　　　　　　　　　　　　25g　500g
T0054 　TBAB (= Tetrabutylammonium Bromide) 　　　　　　25g　100g　500g
F0335 　NFSI [= *N*-Fluorobenzenesulfonimide] [Fluorinating Reagent] 　　　5g　　25g
C2204 　Cesium Fluoride 　　　　　　　　　　　　　　　　　25g　100g
A1424 　Palladium(II) Acetate 　　　　　　　　　　　　　　1g　　5g
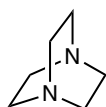
DABCO　　　　**TBAB**　　　　**NFSI**

P2161 　Palladium(II) Acetate (Purified) 　　　　　　　　　　　　　1g
T2666 　Tetrakis(acetonitrile)copper(I) Tetrafluoroborate 　　　1g　5g　25g
C2346 　Copper(II) Acetate Monohydrate 　　　　　　　　　25g　500g
B2709 　Xantphos [= 4,5-Bis(diphenylphosphino)-9,9-dimethylxanthene] 　1g　5g　25g
D4531 　Amphos [= (4-Dimethylaminophenyl)di-*tert*-butylphosphine] 　　1g　5g
D5038 　XPhos (= 2-Dicyclohexylphosphino-2',4',6'-triisopropylbiphenyl) 　1g　5g
D3886 　4,4'-Dimethoxy-2,2'-bipyridyl 　　　　　　　　　　1g　5g
T1946 　Ir(ppy)$_3$ [= Tris(2-phenylpyridinato)iridium(III)] (purified by sublimation) 　200mg
P1528 　Pearlman's Catalyst [= Palladium Hydroxide (contains Pd, PdO) on Carbon] (wetted with *ca*. 50% Water) 　10g　50g
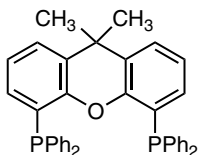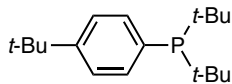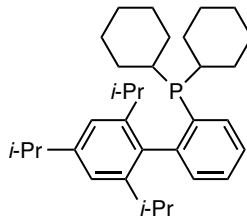
Xantphos　　　　**Amphos**　　　　**XPhos**　　　　**Ir(ppy)$_3$**

Highly Regioselective Organic Semiconducting Polymer: P3HT

P2513   Poly(3-hexylthiophene-2,5-diyl) (Mn.=*ca*. 40,000) (regioregular) (1)   100mg 500mg

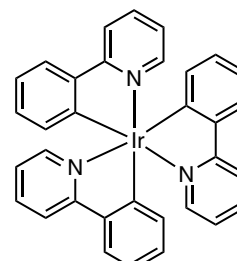Poly(3-hexylthiophene) (P3HT, **1**) is widely useful in organic electronics research fields, and is a representative material of soluble organic semiconducting polymers. The performance of electronic materials is typically dependent on the quality of the material. Among them, purity and molecular weight are important factors for the material performance. **1** was synthesized by a direct arylation polymerization (DArP)[1,2] and features a highly regioselective structure with a consistent average molecular weight and polydispersity index. In addition, **1** is useful for solution process-able organic solar cells,[3,4] perovskite solar cells,[5] and organic transistor research,[6] due in part to its high solubility.
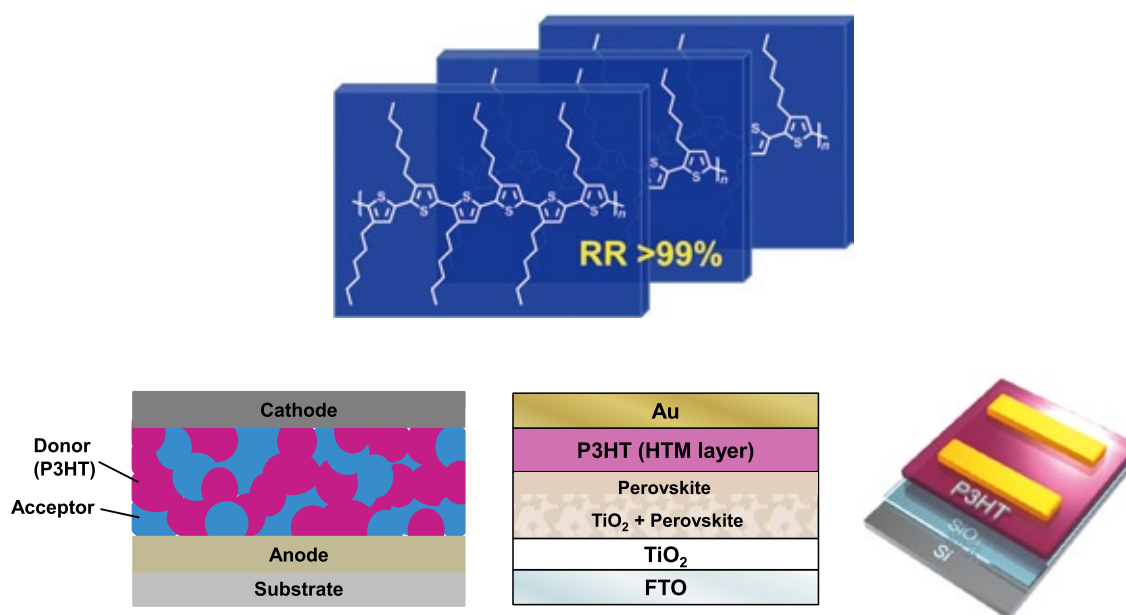

Figure 1. Organic Photovoltaics (OPV)   **Figure 2.** Perovskite Solar Cell (PSC)   **Figure 3.** Organic Transistor (OFET)

This material was produced by collaboration with Prof. Fumiyuki Ozawa
at Institute for Chemical Research, Kyoto University.

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Non-Aqueous Redox Flow Battery Material with High Current Density: MEEPT

M3068 10-[2-(2-Methoxyethoxy)ethyl]-10*H*-phenothiazine (1) 10g
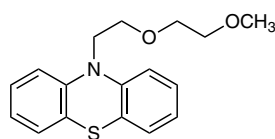
MEEPT (**1**)

Odom *et al.* have recently developed 10-[2-(2-methoxyethoxy)ethyl]-10*H*-phenothiazine (MEEPT, **1**) which features a redox active phenothiazine core and an alkoxy chain to increase solubility in non-aqueous media. **1** acts as a catholyte material for a non-aqueous redox flow battery (RFB), and is miscible with non-aqueous organic solvents to provide electrolyte solutions with high concentration. In addition, **1** shows high current density and long duration cycling for further development of a non-aqueous RFB.[1]
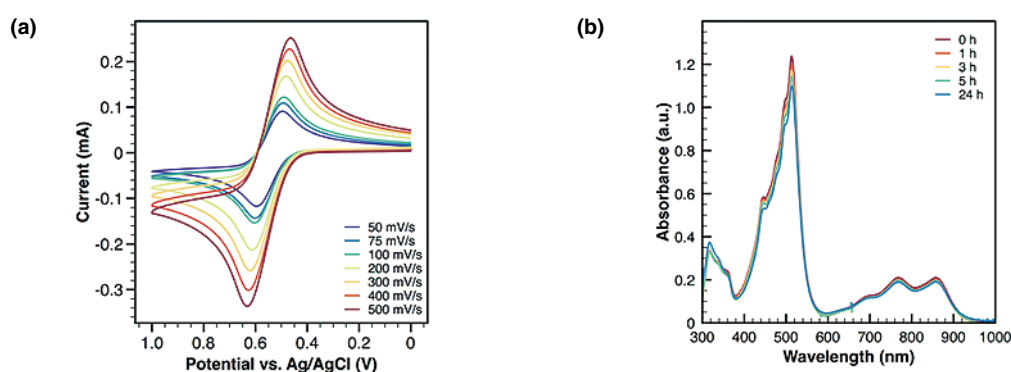
(a)

(b)

Figure 1. Electrochemical and Spectral Properties of MEEPT/MEEPT+

(a) Cyclic voltammogram of MEEPT at 10 mM in 0.1 M TBAPF$_6$ in DCM recorded at scan rates from 10 to 500 mV/s. (b) UV-vis spectra of MEEPT-SbCl$_6$ at 0.15 mM in acetonitrile for up to 24 h after dissolution. (These graphical materials were provided by Prof. Odom.)

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1) High current density, long duration cycling of soluble organic active species for non-aqueous redox flow batteries
    J. D. Milshtein, A. P. Kaur, M. D. Casselman, J. A. Kowalski, S. Modekrutti, P. L. Zhang, N. H. Attanayake, C. F. Elliott, S. R. Parkin, C. Risko, F. R. Brushett, S. A. Odom, *Energy Environ. Sci.* **2016**, *9*, 3531.

TCI Related Products

M1531	4-Methacryloyloxy-2,2,6,6-tetramethylpiperidine 1-Oxyl Free Radical	1g	5g
H0865	4-Hydroxy-2,2,6,6-tetramethylpiperidine 1-Oxyl Free Radical (= TEMPOL)	5g	25g
B5642	Bis(2,2,6,6-tetramethyl-4-piperidyl-1-oxyl) Sebacate	1g	5g
A1343	4-Amino-2,2,6,6-tetramethylpiperidine 1-Oxyl Free Radical	1g	5g
V0137	2,2'-(2-Vinylanthracene-9,10-diylidene)dimalononitrile	1g	5g
V0136	2,2'-(2-Vinylanthracene-9,10-diylidene)bis(1,3-dithiole)	100mg	500mg

Glossary: Redox flow battery

Redox flow batteries (RFB) have long duration cycling by charge/discharge, which may have applications for grid level energy storage. RFB may be useful for large energy storage by increasing battery scale; however, it cannot be compact due to low energy density. Aqueous RFB's using vanadium ion and water-soluble organic active materials in particular have received much attention.[1,2] Alternatively, organic solvents (e.g. acetonitrile, carbonate) can be expected to improve solubility of organic active materials to increase energy density.[3]

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Lead Acetate Anhydrous Forming Perovskite under Anhydrous Condition

L0315 Lead(II) Acetate [for Perovskite precursor] (1)   1g 5g 25g

Perovskite solar cells have received much attention due to their increased efficiency, and are anticipated to be fabricated at lower costs in the future. The light absorbing layer in the solar cell consists of lead perovskites. It is well known that high quality perovskite precursor boosts the solar cell efficiency with reproducibility.[1] Recently, the use of a lead acetate precursor was reported for several perovskite researches. Anhydrous lead acetate (**1**) allows for dry perovskite solar cell production, although lead acetate trihydrate is typically what is available. Lead acetate affords fast crystal growth of perovskites, and provides ultrasmooth pin-hole free perovskite film.[2-7]

$$Pb(OAc)_2 \quad + \quad 3CH_3NH_3I \quad \longrightarrow \quad CH_3NH_3PbI_3 \quad + \quad 2CH_3NH_3(OAc)$$

1   ***Perovskite***

$$2CH_3NH_2 + 2AcOH$$

Scheme 1. Proposed formation mechanism of $CH_3NH_3PbI_3$ from $Pb(OAc)_2$ [2]

References

1) Reproducible fabrication of efficient perovskite-based solar cells: X-ray crystallographic studies on the formation of $CH_3NH_3PbI_3$ layers
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2) PCE >10%: Effect of different lead precursors on perovskite solar cell performance and stability
   F. K. Aldibaja, L. Badia, E. Mas-Marzá, R. S. Sánchez, E. M. Barea, I. Mora-Sero, *J. Mater. Chem. A* **2015**, *3*, 9194.
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   W. Zhang, M. Saliba, D. T. Moore, S. K. Pathak, M. T. Hörantner, T. Stergiopoulos, S. D. Stranks, G. E. Eperon, J. A. Alexander-Webber, A. Abate, A. Sadhanala, S. Yao, Y. Chen, R. H. Friend, L. A. Estroff, U. Wiesner, H. J. Snaith, *Nat. Commun.* **2015**, *6*, 6142.
5) PCE >18%: High-performance inverted planar heterojunction perovskite solar cells based on lead acetate precursor with efficiency exceeding 18%
   L. Zhao, D. Luo, J. Wu, Q. Hu, W. Zhang, K. Chen, T. Liu, Y. Liu, Y. Zhang, F. Liu, T. P. Russell, H. J. Snaith, R. Zhu, Q. Gong, *Adv. Funct. Mater.* **2016**, *26*, 3508.
6) PCE >13%: Pinhole-free perovskite films for efficient solar modules
   W. Qiu, T. Merckx, M. Jaysankar, C. Masse de la Huerta, L. Rakocevic, W. Zhang, U. W. Paetzold, R. Gehlhaar, L. Froyen, J. Poortmans, D. Cheyns, H. J. Snaith, P. Heremans, *Energy Environ. Sci.* **2016**, *9*, 484.
7) PCE >14%: Chlorine incorporation for enhanced performance of planar perovskite solar cell based on lead acetate precursor
   J. Qing, H.-T. Chandran, Y.-H. Cheng, X.-K. Liu, H.-W. Li, S.-W. Tsang, M.-F. Lo, C.-S. Lee, *ACS Appl. Mater. Interfaces* **2015**, *7*, 23110.

TCI Related Products

L0279	Lead(II) Iodide (99.99%, trace metals basis) [for Perovskite precursor]	1g	5g	25g	100g	1kg
L0288	Lead(II) Bromide [for Perovskite precursor]			1g	5g	25g
L0291	Lead(II) Chloride (purified by sublimation) [for Perovskite precursor]				1g	5g
L0292	Lead(II) Chloride [for Perovskite precursor]			1g	5g	25g
M2556	Methylamine Hydroiodide (MAI), (Water <100 ppm) [for Perovskite precursor]	1g	5g	25g	100g	
F0974	Formamidine Hydroiodide (FAI), (Water <100 ppm) [for Perovskite precursor]			1g	5g	25g

Ready-to-use 4-Nitrophenyl Phosphate Solution for ELISA

N1109   4-Nitrophenyl Phosphate (Ready-to-use solution) [for ELISA] (1)   100mL

1 is supplied as a ready-to-use solution containing 4-nitrophenyl phosphate (pNPP) for ELISA. When **1** reacts with alkaline phosphatases, yellow colored soluble products appear. After terminating the reaction by adding NaOH aqueous solution, the absorbances of the reaction product are measured at 405 nm.

Direction for Use

The following steps are for a 96-well plate format.
1.   Bring **1** to room temperature and mix it gently.
2.   Add 100 μL of **1** to each well.
3.   Incubate the plate at room temperature for 30 minutes.
4.   To terminate the reaction, add 100 μL of 1 mol/L NaOH to each well.
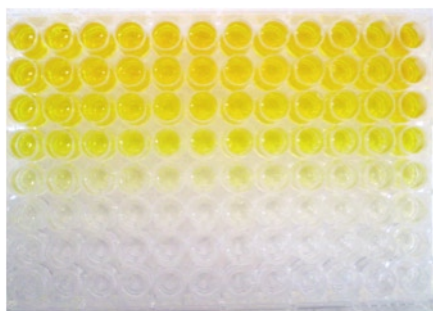5.   Within 1 hour of terminating the reaction, measure the absorbance of each well at 405 nm.

Figure 1. Example of use with a 96-well plate

Reference

1)   A. Voller, D. E. Bidwell, A. Bartlett, *Bull. World Health Organ.* **1976**, *53*, 55.

TCI Related Products

D4005	Disodium 4-Nitrophenyl Phosphate Hexahydrate [for Biochemical Research]	1g	5g
S0542	Sodium Hydroxide (1 mol/L in Water)		500mL

Anti-αGal Polyclonal Antibody that can Detect the αGal Epitope(Galα1-3Gal)

A3123　Anti-αGal Polyclonal Antibody (Chicken) (1)　　　　　　　1 vial

　　Anti-αGal antibody exists as a natural antibody in humans. Binding of this antibody to αGal antigens (αGal epitope) expressed on porcine xenograft surfaces are a major factor for determining engraft survival. Recently, it has been observed that therapeutic antibodies and cell processing material for reproductive medicine contain the αGal epitope, which indicates the importance of rapid detection of αGal epitope.

　　The anti-αGal polyclonal antibody (**1**) has high specificity similar to the anti-αGal monoclonal antibody, and it specifically recognizes the α1-3Gal structure (Figure 1).
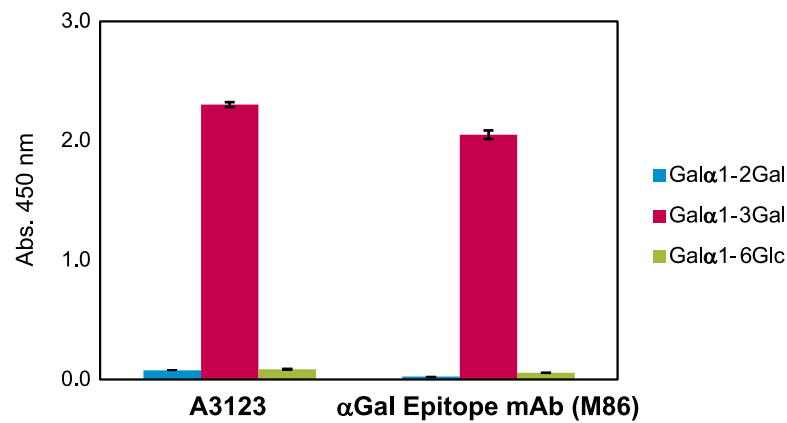

Figure 1. Specific binding to αGal antigens by anti-αGal monoclonal antibody
Glycoconjugates coated on ELISA plates. Results following epitope and anti-αGal antibodies incubation.
1st Ab were detected using appropriate secondary antibodies.

This product is for research purpose only.

TCI Related Products

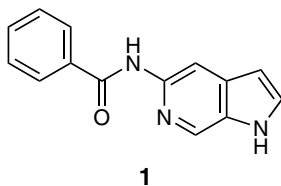A3144 Anti-αGal Polyclonal Antibody Biotin Conjugate　　　　　　　　　　1 vial
A3195 Anti-αGal Chicken Polyclonal Antibody HRP Conjugate　　　　　　　1 vial

OCT4 Activator

O0490   OAC1 (1)   10mg 50mg

1

OAC1 (**1**) was identified through high-throughput screening of a small molecule library as an OCT4-activating compound.[1] **1** enhanced reprogramming efficiency of induced pluripotent stem (iPS) cells. Furthermore, **1** was used for direct-reprogramming of mouse fibroblasts into functional astrocytes.[2]

1 also enhanced *ex vivo* expansion of human umbilical-cord blood hematopoietic stem and progenitor cells.[3] Homeobox protein, HOXB4, is essential for the **1**-mediated expansion.

This product is for research purpose only.

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    W. Li, E. Tian, Z.-X. Chen, G. Sun, P. Ye, S. Yang, D. Lu, J. Xie, T.-V. Ho, W. M. Tsark, C. Wang, D. A. Horne, A. D. Riggs, M. L. R. Yip, Y. Shi, *Proc. Natl. Acad. Sci. USA* **2012**, *109*, 20853.
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    E. Tian, G. Sun, G. Sun, J. Chao, P. Ye, C. Warden, A. D. Riggs, Y. Shi, *Cell Rep.* **2016**, *16*, 781.
3) Activation of OCT4 enhances *ex vivo* expansion of human cord blood hematopoietic stem and progenitor cells by regulating HOXB4 expression
    X. Huang, M.-R. Lee, S. Cooper, G. Hangoc, K.-S. Hong, H.-M. Chung, H. E. Broxmeyer, *Leukemia* **2016**, *30*, 144.

AMP-Activated Protein Kinase (AMPK) Inhibitor

D5394   Dorsomorphin (1)   10mg 50mg

1
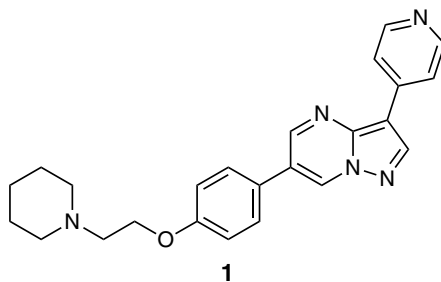
Dorsomorphin (**1**) is a potent inhibitor of AMP-activated protein kinase (AMPK).[1] AMPK is inhibited by **1** with Ki = 109 nM. However, **1** does not significantly inhibit structurally related kinases, including spleen tyrosine kinase (SYK), zeta-chain-associated protein kinase (ZAPK), protein kinase A (PKA), protein kinase Cθ (PKCθ), and Janus kinase (JAK).

Additionally, **1** inhibits bone morphogenetic protein (BMP) signaling.[2] **1** promotes self-renewal of human embryonic stem cells (hESCs).[3] Interestingly, **1** can support stem cell self-renewal over the long term (five or more passes).

This product is for research purpose only.

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2) Dorsomorphin inhibits BMP signals required for embryogenesis and iron metabolism
    P. B. Yu, C. C. Hong, C. Sachidanandan, J. L. Babitt, D. Y. Deng, S. A. Hoyng, H. Y. Lin, K. D. Bloch, R. T. Peterson, *Nat. Chem. Biol.* **2008**, *4*, 33.
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    R. Gonzalez, J. W. Lee, E. Y. Snyder, P. G. Schultz, *Angew. Chem. Int. Ed.* **2011**, *50*, 3439.

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