

Ir/Sn dual-reagent catalysis towards highly selective alkylation of arenes and heteroarenes with benzyl alcohols

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Abstract. A catalytic combination of $[\text{Ir}(\text{COD})\text{Cl}]_2\text{-SnCl}_4$ efficiently promotes the reactions of arenes and heteroarenes with $1^\circ/2^\circ/3^\circ$ benzyl alcohols as the alkylating agents to afford the corresponding diarylmethane and triarylmethane derivatives in high yields. The scope and limitation of the reaction with respect to catalyst and substrates variation has been studied in detail.

Keywords. Organometallic; bimetallic; catalysis; alkylation; benzyl alcohol; iridium, tin.

1. Introduction

Even after 125 years since its discovery, Friedel–Crafts alkylation (FCA) reaction remains a fundamental tool towards the construction of carbon–carbon bond leading to various organic architectures of pharmaceutical and industrial relevance.¹ Indeed FCA continues to attract synthetic chemists due to its astonishing success with regard to versatility, scope, and applicability. Generally, Friedel–Crafts aromatic alkylation reactions are carried out in presence of stoichiometric amount of traditional Lewis acid or Brønsted acid using large excess of aromatics.¹ Emergence of catalytic rare earth metal triflates as water tolerant and recyclable Lewis acids has significantly improved upon many FCA processes.^{2–3} More recent reports show the successful use of monometallic transition metal catalysts as well.⁴ Thus in the classical and industrially useful FCA of aromatics with benzyl alcohols, the known catalytic systems include traditional FC catalysts, lanthanide/actinide triflates, $\text{H}_2\text{PtCl}_6 \cdot 6\text{H}_2\text{O}$, FeCl_3 , modified clays, and Nafion-H at 10–120% loading and a temperature of 80–120°C.^{1,3–5}

Recently the concept of heterobimetallic cooperative catalysis has been successfully explored in many organic transformations. This is mainly due to the fact that the incorporation of two metals in a single scaffold offers selective substrate binding, dual and

synergistic activation, as well as enhanced reactivity.⁶ Though in the last 10–15 years this concept has flourished in various corners of organic transformations, its efficacy was less explored in the vast areas of Friedel–Crafts reactions.

In practice, two design features exemplify a potential cooperative heterobimetallic motif. The first type is an intramolecular version involving a single catalyst in which two different metals are built on a single scaffold ($\text{M-L-M}'$ or $\text{L-M-M}'\text{-L}'$). The second type is an intermolecular version involving dual partners ($\text{M-L} + \text{M}'\text{-L}'$), both of which participate in the transition state^{6g} (figure 1). Irrespective of their types, these catalysts offer superior results in terms of efficiency and selectivity relative to the individuals.

In the course of our continuing effort to exploit the organic reactivity of bimetallic/dual reagent systems having transition metal (Tm) and tin (Sn) as partners,^{7–20} we had recently proposed a fascinating cooperative heterobimetallic catalysis concept. Ac-

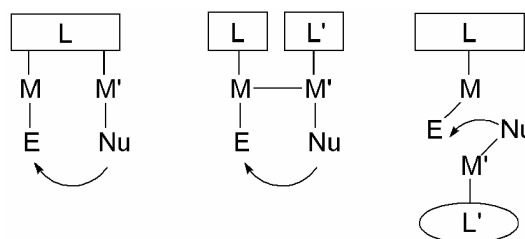


Figure 1. Intramolecular and intermolecular heterobimetallic catalysts.

*For correspondence

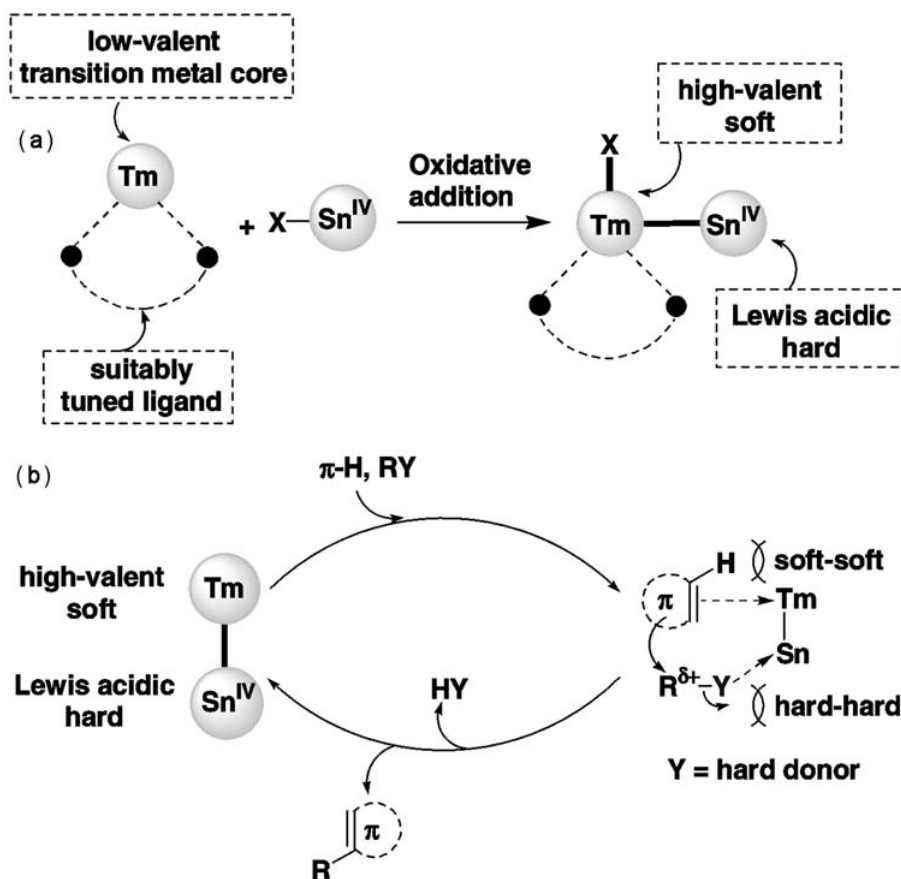


Figure 2. (a) Proposed model on the generation of cooperative Tm–Sn motif. (b) Proposed model on the reactivity of cooperative Tm–Sn motif.

According to our proposal, the oxidative addition of tin(IV) halides across a low-valent late transition metal organometallic partner would generate a high-valent Tm–Sn bimetallic scaffold (figure 2a).

This scaffold bears rather interesting stereoelectronic features, which can bring about catalytic reactivity in a cooperative fashion. These features include: (i) a high-valent and soft electrophilic late transition metal center (Tm) for the activation of soft nucleophiles such as a π -system, (ii) a hard Lewis acidic tin center (Sn^{IV}) for the activation of substrates having hard donor atoms and (iii) close proximity of Tm and Sn centers for proximal binding and subsequent coupling between different organic substrates (figure 2b).

We have been successful in bringing our proposed model into reality and communicated the first example of a heterobimetallic catalyst design within ‘Ir–Sn’ regime for the alkylation of aromatics with π -activated alcohols.²¹ A parallel investigation gave birth to new heterobimetallic transition metal–tin complexes.^{22–23} Subsequently, the concept has been extended towards

the activation of aldehydes, and ethers.^{24–25} Extensive kinetic and spectroscopic studies also led to meaningful insights from which we could propose a guide towards electronic tuning of the catalyst efficiency.²⁶

In this article, we present a comprehensive account from our detailed investigations on the Ir/Sn dual-reagent catalysed aromatic alkylation reactions with benzyl alcohols. The focus of this work is to critically look into the reaction from a synthetic viewpoint and assess the synthetic merit/limitation of the reaction with respect to catalyst and substrates.

2. Experimental

2.1 General methods

All preparations and manipulations were performed under a dry, oxygen-free argon atmosphere using standard vacuum lines and Schlenk techniques. All solvents, used for the synthesis, were dried and distilled by standard methods and previously deoxy-

generated in the vacuum line. Pre-coated silica gel 60F₂₅₄ was used for thin layer chromatography and silica gel 60–120 mesh was used for column chromatography. ¹H (200 MHz) and ¹³C NMR (54.6 MHz) spectra were recorded on Bruker-AC 200 MHz spectrometer. ¹H (400 MHz) and ¹³C NMR (100 MHz) spectra were recorded on Bruker-Avance II 400 MHz spectrometer at 300 K. Chemical shifts are reported in ppm from tetramethylsilane with the solvent resonance as the internal standard (in ¹H NMR spectra $\delta_{\text{H}} = 7.26$ ppm for CDCl₃ and in ¹³C NMR spectra $\delta_{\text{C}} = 77.0$ ppm for CDCl₃). Data are reported as follows: chemical shifts, multiplicity (*s* = singlet, *d* = doublet, *t* = triplet, *q* = quartet, *br* = broad, *m* = multiplet), coupling constant (Hz). Melting points are uncorrected.

IrCl₃·xH₂O, 1,5-cyclooctadiene and tin tetrachloride were commercially available. [Ir(COD)(μ -Cl)]₂ was prepared according to the literature procedure³⁴ and [Ir(COD)(μ -Cl)(SnCl₃)Cl]₂ was prepared according to the previously reported procedure.²¹

2.2 General procedure

A 10-mL Schlenk flask equipped with a magnetic bar was charged with [Ir(COD)(μ -Cl)]₂ (0.01 mmol), SnCl₄ (0.04 mmol), and arene (18.8 mmol). The flask was degassed with argon and placed into a constant temperature bath at 90°C. After the mixture was stirred vigorously for 5 min, the corresponding alcohol (1 mmol) was added to it, and the reaction was allowed to continue at 90°C. The reaction mixture was quenched with aqueous NH₄F solution and extracted with diethyl ether (4 × 25 mL). The combined extract was washed with water (2 × 10 mL), brine (2 × 10 mL), dried over anhydrous magnesium sulfate, and the solvent was removed under reduced pressure. The product was purified by column chromatography (Silica gel 60/120 mesh, eluent: pet ether or EtOAc/pet ether 1 : 9 (v/v)).

All products gave satisfactory spectral data and were compared with authentic samples wherever possible. Compounds **3a–3g**^{35a–35g}, **3i–3o**^{35h–35n}, **3q–3x**^{35o–35v} and **3z**^{35w} are reported in the literature. The characterization data for the new compounds **3h**, **3p** and **3y** are given below.

2.2a Data for product 3h: Colourless oil; ¹H NMR (200 MHz, CDCl₃) δ (ppm) (*ortho* + *para* isomer) 1.12–1.26 (*m*, 6H, CH₂CH₃), 2.31 (*s*, 6H, CH₃), 2.56, 2.67 (*q*, 4H, CH₂CH₃), 3.91 and 3.99 (*s*, 4H,

4H, CH₂), 7.03–7.21 (*m*, 16H, Ph). ¹³C NMR (54.6 MHz, CDCl₃) δ (ppm) (*ortho* + *para* isomer) 14.8, 15.6, 20.9, 25.7, 28.4, 38.3, 41.1, 125.4–129.0 (many peaks), 130.2, 135.2, 137.8, 138.3, 138.6, 141.7, 142.3. Anal. (C₁₆H₁₈) calcd, C: 91.37, H: 8.63; found, C: 91.21, H: 8.69.

2.2b Data for product 3p: Colourless oil; ¹H NMR (200 MHz, CDCl₃) δ (ppm) 2.24 (*s*, 3H, CH₃), 4.00 (*s*, 2H, CH₂), 6.67–7.40 (*m*, 6H, Ph). ¹³C NMR (54.6 MHz, CDCl₃) δ (ppm) 20.4, 32.8, 115.3, 124.8, 127.0, 128.4, 129.1, 130.3, 131.3, 131.4, 132.4, 134.7, 136.5, 151.3. Anal. (C₁₄H₁₂Cl₂O) calcd. C: 62.94, H: 4.53; found, C: 62.76; H: 4.62.

2.2c Data for product 3y: Colourless oil; ¹H NMR (200 MHz, CDCl₃) δ (ppm) 2.08 (*s*, 3H, CH₃), 2.17 (*s*, 3H, CH₃), 5.19 (*s*, 1H, CH), 5.64 (*s*, 1H, =CH, furan ring), 7.12–7.31 (*m*, 10H, Ph). ¹³C NMR (54.6 MHz, CDCl₃) δ (ppm) 11.7, 13.6, 47.5, 107.7, 121.8, 126.2, 128.3, 128.8, 144.1, 145.8, 149.2. Anal. (C₁₉H₁₈O) calcd. C: 86.98, H: 6.92; found, C: 86.71, H: 7.01.

3. Results and discussions

3.1 Model studies

To test our concept of Tm/Sn bimetallic activity, firstly we carried out a model study on the benzylation of toluene **2a** with 4-methylbenzyl alcohol **1a** at 90°C. The dual-reagent combination involving 1 mol% of [Ir(COD)(μ -Cl)]₂ and 4 mol% of SnCl₄ promoted the desired alkylation giving rise to ditolylmethane **3a** (*o/p* 19/81) in 95% yield only after 15 min (table 1, entry 1). Under similar condition, reactions with lower loading of SnCl₄ (1–3 mol%) were not effective (entries 2–4). Attempt to carry out the model reaction at 55°C resulted in a very low turn-over and even after 2 h only 5% of benzylated product **3a** was obtained (entry 5). It is noteworthy that, individually either [Ir(COD)(μ -Cl)]₂ (1 mol%), IrCl₃ (1 mol%) or SnCl₄ (5 mol%) was poorly active (entries 6–8), and even a mere combination of IrCl₃ (1 mol%) and SnCl₄ (4 mol%) was also ineffective (entry 9) indicating the significant role of the Ir^{III}–Sn^{IV} core.

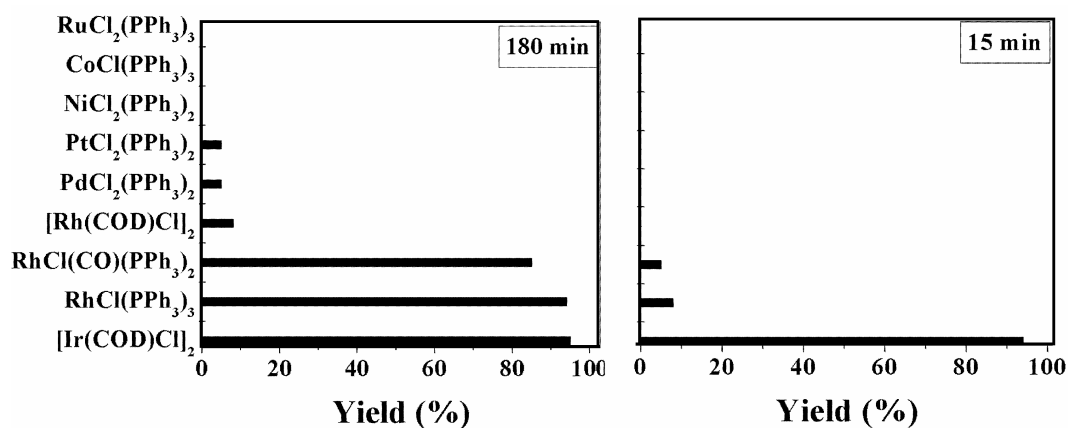
The importance of the Ir^{III}–Sn^{IV} core was further augmented when we tested the model reaction with a heterobimetallic catalyst namely [Ir(COD)(μ -Cl)(SnCl₃)Cl]₂ which promoted alkylation at only

Table 1. Alkylation of toluene with 4-methylbenzyl alcohol: Effect of catalyst^a.

Reaction scheme: 1a + 2a $\xrightarrow{\text{catalyst}}$ 3a

Entry	Catalyst (mol%)	Time (min)	Temp. (°C)	Yield of 3a (%) ^b
1	[Ir(COD)(μ -Cl)] ₂ (1%) + SnCl ₄ (4%)	15	90	95 (87)
2	[Ir(COD)(μ -Cl)] ₂ (1%) + SnCl ₄ (3%)	15	90	(23)
3	[Ir(COD)(μ -Cl)] ₂ (1%) + SnCl ₄ (2%)	15	90	(<10)
4	[Ir(COD)(μ -Cl)] ₂ (1%) + SnCl ₄ (1%)	15	90	(<10)
5 ^c	[Ir(COD)(μ -Cl)] ₂ (1%) + SnCl ₄ (4%)	120	55	5
6	[Ir(COD)(μ -Cl)] ₂ (1%)	360	90	0
7	IrCl ₃ (1%)	360	90	<1
8	SnCl ₄ (5%)	360	90	<1
9	IrCl ₃ (1%) + SnCl ₄ (4%)	360	90	2
10	[Ir(COD)(μ -Cl)(SnCl ₃)Cl] ₂ (1%)	360	90	45 (36)
11	Sc(OTf) ₃ (5%)	360	90	30 (29)

^aUnless otherwise stated, reaction conditions: 2a (18.8 mmol), 1a (1 mmol), catalyst (0.01 mmol), temp. 90°C. ^bDetermined by GC, isolated yield in parentheses. ^ctemp. 55°C

**Figure 3.** FCA Activity of various transition metal complexes with SnCl₄ as LA partner.

1 mol% catalyst loading affording 45% of ditolylmethane 3a along with 26% of 4-methylbenzaldehyde after 6 h (entry 10). It should also be noted that 5 mol% of scandium triflate, a well-known Lewis acid catalyst, afforded only 30% of the desired alkylated product (entry 11) in the present case.

The above results prompted us to test the activity of other 'Tm-Sn' motifs in the model reaction. In view of this, we screened a wide range of transition metal complexes (1 mol%) in combination with SnCl₄ (4 mol%). For each of the transition metal partners, the yield of the product at reaction time of 15 min and at 180 min has been shown in figure 3. As can be seen from the figure, promising activity was shown by RhCl(PPh₃)₃ and RhCl(CO)(PPh₃)₂, but

with much lower TOF value than 'Ir-Sn' catalyst. The oxidative addition of SnCl₄ to these complexes to generate high-valent Rh^{III}-Sn^{IV} core made them active in this reaction. On the other hand, PdCl₂(PPh₃)₂ and PtCl₂(PPh₃)₂ were found to be weakly active (up to 5% product) though the oxidative addition of SnCl₄ to these complexes are known to happen very smoothly. The probable reason might be the formation of inert complexes in these cases. We also noted that complexes CoCl(PPh₃)₃, RuCl₂(PPh₃)₃, and NiCl₂(PPh₃)₂ as catalyst were inactive for the present reaction.

An obvious question at this stage was to test whether cooperative activation of the most suitable partner iridium can be done by Lewis acidic hal-

ides/esters other than SnCl₄. Accordingly, benzylation of toluene was carried out with a dual-catalyst combination of [Ir(COD)(μ-Cl)]₂ (1 mol%) and the Lewis acid (4 mol%), representing each of the four groups in Olah's classification table.²⁷ Surprisingly, all of the combinations tested with AlCl₃, Sc(OTf)₃, InCl₃, TiCl₄, BF₃·OEt₂, SnCl₂, and ZnCl₂ failed (figure 4). An important realization from this study is the fact that a matching redox potential of the two metal partners is important to generate a high-valent hetero-bimetallic core via oxidative addition as in the case of 'Ir^{III}-Sn^{IV}'.

3.2 Extending the scope of the reaction

Utilizing the optimized parameters we tested the FCA reactivity of the dual-reagent combination Ir(I)/SnCl₄ (hereafter Ir/Sn) by conducting the reaction of various arenes (**2a–2l**), and heteroarenes (**2m–2q**) with 1°/2°/3° benzyl alcohols (**1a–1i**). Gratifyingly, in majority of the cases, the corresponding monoalkylated products were obtained in good to excellent yields (tables 2–4). Major highlights of the results thus obtained are discussed in detail below.

3.2a Reactivity of substituted 1°/2°/3° benzyl alcohols: The Ir/Sn catalysed alkylation reaction was found to be effective for a number of substituted 1°/2°/3° benzyl alcohols. Almost all the reactions involved full conversion (100%) of the starting alcohol to afford the corresponding benzylarenes in

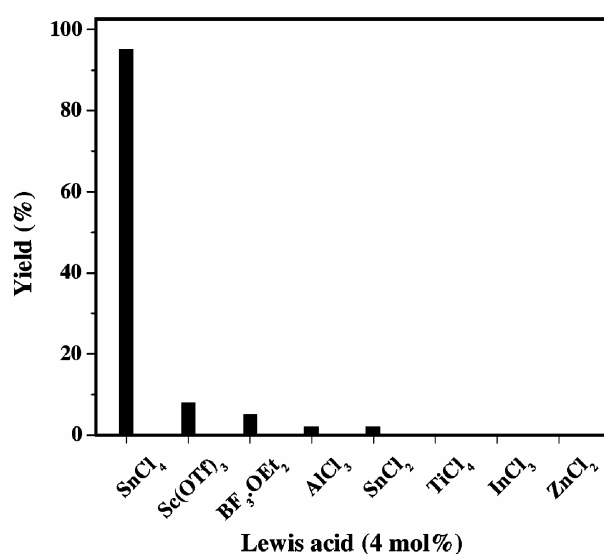


Figure 4. FCA activity of various Lewis acidic metal salts with [Ir(COD)(μ-Cl)]₂ as transition metal partner.

high selectivity and good yields. The reaction of benzyl alcohol **1b**, and *para*-substituted benzyl alcohols **1a** (*p*-Me), and **1c** (*p*-Cl) with toluene proceeded smoothly to give the corresponding diarylmethanes **3a–3c** in 70–95% yields with a mixture of regioisomers where the *p*-isomer predominated (table 2, entries 1–3). In case of 4-nitrobenzylalcohol **1d** the corresponding aldehyde was obtained as a major side product with concomitant lowering in yield of the benzylated product. Thus reaction of **1d** with *p*-xylene afforded the benzylated product **3d** in 41% isolated yield after 24 h (entry 4). We speculate that the high-valent Ir^{III}-Sn^{IV} core may be responsible for the partial oxidation of alcohol **1d** to aldehyde (table 1, entry 10). Reaction of 1,4-benzenedimethanol **1e** with *p*-xylene gave the desired product **3e** in 87% isolated yield, and as a single isomer (entry 5). Similarly, 2° and 3° benzyl alcohol **1f** and **1g** also reacted satisfactorily with toluene and anisole and the corresponding tri- and tetraarylmethane derivatives **3f** and **3g** were obtained in 71% and 65% yields, respectively (entries 6 and 7). In the case of toluene the *o*:*p* ratio was 20:80 (from ¹H NMR), while in the case of anisole single isomer was observed.

3.2b Reactivity of various arene systems: A variety of electron rich arenes could be employed in the present reaction, giving rise to the corresponding alkylated products in good to excellent yields (table 3). The reaction of benzyl alcohol **1b** and substituted benzyl alcohols such as 4-methylbenzyl alcohol **1a** and 2,4-dichlorobenzyl alcohol **1h** with toluene, ethylbenzene, *o*-xylene and *p*-xylene afforded the corresponding benzylated products **3b**, **3h–3k** in 82–95% yields (entries 1–5). Mesitylene, naphthalene and biphenyl were also reacted well with substituted benzyl alcohols such as 2-chlorobenzyl alcohol **1i** and 4-methylbenzyl alcohol **1a** to give the benzylated products **3l–3n** in 82–87% yields (entries 6–8). The reaction of anisole and *p*-cresol with benzyl alcohol **1b** and 2,4-dichlorobenzyl alcohol **1h** gave the corresponding benzylated products **3o** in 88% and **3p** in 75% isolated yields respectively (entries 9–10). Interestingly, even non-activated substrates like benzene, and bromobenzene afforded the desired products **3q** and **3s** in moderate to good yields ranging from 62–70% (entries 11 and 13). Reaction of 4-bromoanisole (less activated than anisole) with benzyl alcohol **1b** also gave the desired product **3r** in 69% isolated yield (entry 12).

Table 2. Reactivity of substituted 1°/2°/3° benzyl alcohols^a.

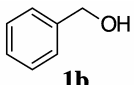
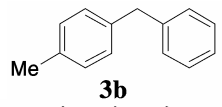
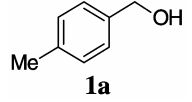
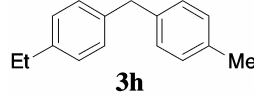
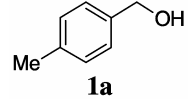
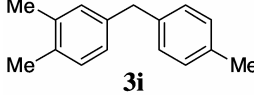
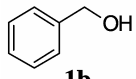
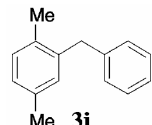
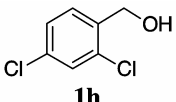
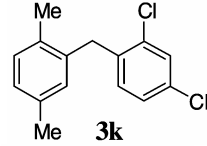
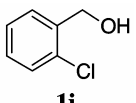
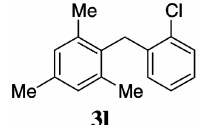
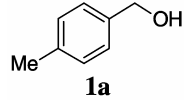
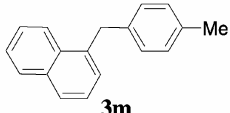
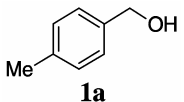
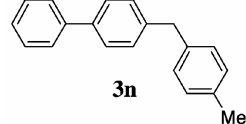
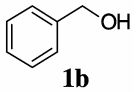
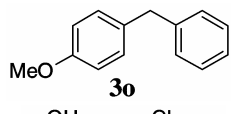
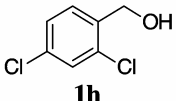
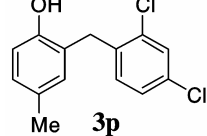
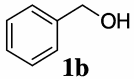
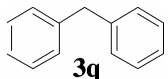
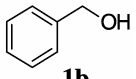
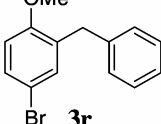
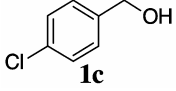
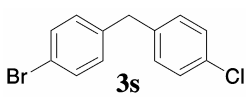
#	Arene	Alcohol	Time	Yield (%)	Major product	Regioisomer (<i>o/p</i>) ^b
1	Toluene 2a	 1b	20 min	95	 3b	30 : 70
2	Toluene 2a	 1a	15 min	87	 3a	15 : 85
3	Toluene 2a	 1c	30 min	86	 3c	40 : 60
4	<i>p</i> -Xylene 2b	 1d	24 h	41	 3d	–
5	<i>p</i> -Xylene 2b	 1e	3 h	87	 3e	–
6	Toluene 2a	 1f	30 min	71	 3f	20 : 80
7	Anisole 2c	 1g	6 h	65	 3g	–

^aReaction conditions: arene **2** (18.8 mmol), alcohol **1** (1 mmol), [Ir(COD)Cl]₂ (0.01 mmol), SnCl₄ (0.04 mmol), temp. 90°C. ^bfrom ¹H NMR

3.2c Reactivity of various heteroarene systems: We further probed the efficacy of the present Ir/Sn catalysed alkylation reaction in case of heteroarenes. In majority of the cases studied, the corresponding products were obtained in good

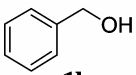
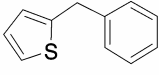
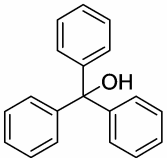
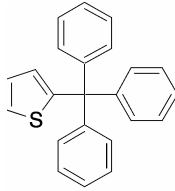
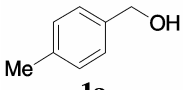
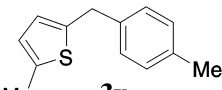
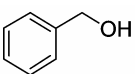
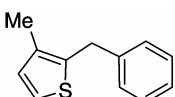
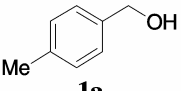
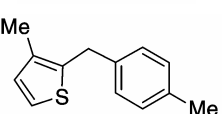
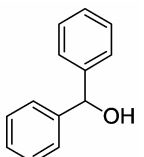
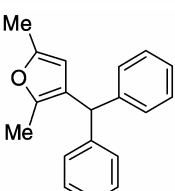
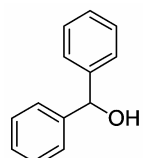
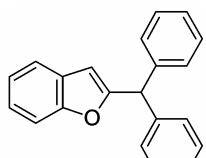
to excellent yields (table 4). Thus 1° benzyl alcohols such as 4-methylbenzyl alcohol **1a** and benzyl alcohol **1b** reacted well with thiophene, 2-methylthiophene, and 3-methylthiophene and the corresponding alkylated products **3t**, **3v–3x** were

Table 3. Reactivity of various arene systems^a.

#	Arene	Alcohol	Time	Yield (%)	Major product	Regioisomer (<i>o/p</i>) ^b
1	Toluene 2a	 1b	20 min	95	 3b	30 : 70
2	Ethyl benzene 2d	 1a	20 min	88	 3h	35 : 65
3	<i>o</i> -Xylene 2e	 1a	15 min	88	 3i	—
4	<i>p</i> -Xylene 2b	 1b	15 min	95	 3j	—
5	<i>p</i> -Xylene 2b	 1h	1 h	82	 3k	—
6	Mesitylene 2f	 1i	15 min	87	 3l	—
7 ^c	Naphthalene 2g	 1a	20 min	83	 3m	90 : 10 (<i>α/β</i>)
8 ^c	Biphenyl 2h	 1a	30 min	84	 3n	—
9	Anisole 2c	 1b	5 min	88	 3o	35 : 65
10	<i>p</i> -Cresol 2i	 1h	11 h	75	 3p	—
11	Benzene 2j	 1b	30 min	70	 3q	—
12	4-Bromo anisole 2k	 1b	30 min	69	 3r	—
13	Bromo benzene 2l	 1c	1 h	62	 3s	40 : 60

^aReaction conditions: arene **2** (18.8 mmol), alcohol **1** (1 mmol), [Ir(COD)Cl]₂ (0.01 mmol), SnCl₄ (0.04 mmol), temp. 90°C. ^bfrom ¹H NMR. ^carene (10 mmol), alcohol (1 mmol)

Table 4. Reactivity of various heteroarene systems^a.

#	Heteroarene	Alcohol	Time	Yield (%)	Major product	Regioisomer ^b
1	Thiophene 2m	 1b	15 min	95	 3t	65 : 35 (2/3)
2	Thiophene 2m	 1g	6 h	86	 3u	–
3	2-Methyl thiophene 2n	 1a	15 min	85	 3v	60 : 40 (2/3)
4	3-Methyl thiophene 2o	 1b	15 min	78	 3w	49 : 17 : 34 (2/3/5)
5	3-Methyl thiophene 2o	 1a	15 min	82	 3x	52 : 10 : 35 (2/3/5)
6	2,5-Dimethyl furan 2p	 1f	10 min	99	 3y	–
7 ^c	Benzo[b] furan 2q	 1f	15 min	79	 3z	–

^aReaction conditions: heteroarene **2** (18.8 mmol), alcohol **1** (1 mmol), [Ir(COD)Cl]₂ (0.01 mmol), SnCl₄ (0.04 mmol), temp. 90°C. ^bfrom ¹H NMR. ^cheteroarene (1 mmol), alcohol (1 mmol), 1,2-dichloroethane as solvent

obtained in 78–95% yields as a mixture of regioisomers at 2- and 3- or 2-, 3- and 5-positions (entries 1 and 3–5). Reaction of thiophene with triphenyl methanol **1g** gave the tetraarylmethane derivative **3u** in 86% yield and as a single regioisomer (entry 2). Reaction of diphenyl methanol **1f** with 2,5-dimethylfuran, and benzo[b]furan afforded the triarylmethane derivatives **3y** and **3z** in 79% and 99% yields, respectively (entries 6 and 7). In

these cases also formation of single isomer was observed.

3.3 Limitations of the present Ir/Sn catalyst

In spite of the successful applications of the present Ir/Sn dual-reagent catalyst towards a range of 1°/2°/3° benzyl alcohols as well as various arenes and heteroarenes, there are some limitations with re-

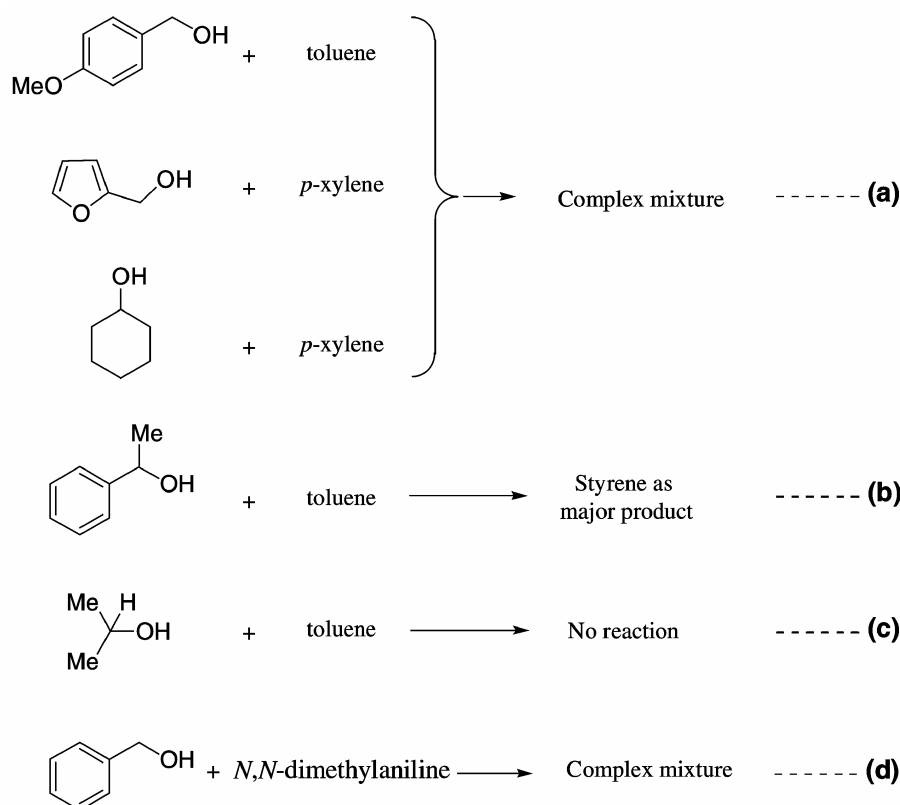


Figure 5. Limitations of Ir/Sn catalyst in benzylation reactions.

spect to alcohols and arenes. These are pointed below (figure 5).

The reaction of 4-methoxybenzyl alcohol and 2-furyl methanol with toluene resulted in a complex mixture (figure 5a). Even the reaction of 4-methoxybenzyl alcohol with toluene at lower temperatures (0 to -78°C) gave the same result. Further studies are warranted to look into the plausible involvement of Lewis-acidic metal catalysed dehydration, β -hydrogen elimination, oxidative cleavage and polymerization reactions. The reaction of cyclic saturated alcohol such as cyclohexanol led to the formation of a complex mixture (figure 5a). Reactions of a 2° benzyl alcohol containing β -hydrogen such as 1-phenylethanol with toluene as aromatic partner did not give the corresponding alkylated product. TLC and ^1H NMR monitoring indicated disappearance of the starting alcohol, and the formation of corresponding olefin (figure 5b). 1-Phenylethanol having β -hydrogen atom undergoes fast dehydration in the presence of the strong Lewis acidic catalyst yielding styrene as the major product. Interestingly, secondary aliphatic alcohol such as *iso*-propanol remained unaffected under the reaction conditions (figure 5c). This is be-

cause our catalyst system was found to be active for only π -activated alcohols. Also noteworthy is the fact that attempted reaction of benzyl alcohol with *N,N*-dimethylaniline as aromatic partner failed to give the desired alkylated product and resulted in the formation of undefined mixture (figure 5d). Here the arene, *N,N*-dimethylaniline might deactivate the catalyst system due to Lewis acid-Lewis base interaction.

3.4 Importance of the diarylmethane products

The present methodology may be viewed as an efficient procedure for the synthesis of various types of benzyl arenes and heteroarenes. It may be noted that the diarylmethane motif is an integral part of a number of biologically active compounds and pharmaceuticals such as piritrexim, trimethoprim, avrainvilleol, papaverine, beclobrate, or letrozole (figure 6).²⁸ They are also utilized for the preparation of fluorenyl-based electroactive and photoactive oligomers and polymers, which have wide applications in nonlinear optics, electroluminescence, and optical information storage etc.²⁹ Diarylmethane motifs have

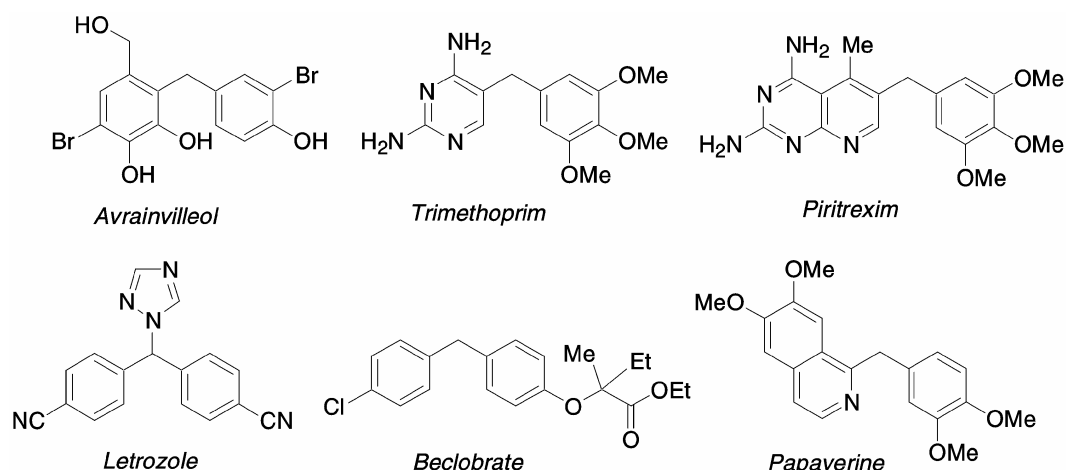


Figure 6. Representative bioactive diarylmethanes and analogues.

been used as supramolecular building blocks in various calix[4]arenes, resorcinol cyclic tetramers, carcerands, etc. The conformational flexibility of these moieties provides versatile binding pockets for a number of different guest molecules ranging from metal ions and large aromatic molecules.³⁰ Benzyltoluene and isomeric mixtures thereof are useful additives in (a) electrical insulating oils for high-voltage transformers/power capacitors³¹ and in (b) emulsions of termiticides, which show good penetration, and emulsion stability.³² Diphenylmethane, benzyltoluene and related aromatic hydrocarbons are essential constituents of crude oils, and high-octane fuels for aircraft engines.³³

4. Conclusion

In summary, we have demonstrated here an Ir/Sn dual-reagent catalyst combination for the alkylation of a wide variety of electron-rich as well as non-activated arenes and heteroarenes by 1°/2°/3° benzyl alcohols. The bimetallic nature of the reaction is also established.

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