



Friedel–Crafts acylation reactions using metal triflates in ionic liquid

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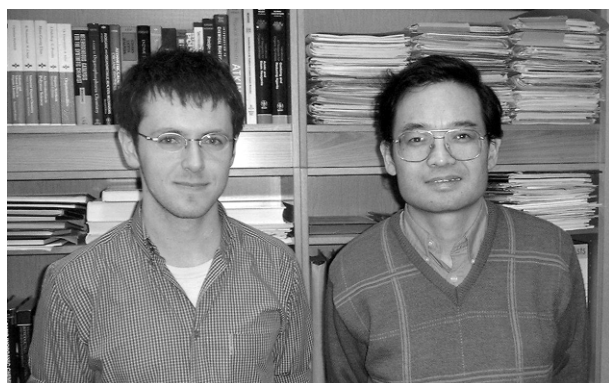
Aromatic electrophilic substitution reactions such as benzylation and acetylation catalysed by metal triflates have been conducted in an ionic liquid, [bmim][BF₄] (bmim = 1-butyl-3-methylimidazolium). Cu(OTf)₂ (OTf = trifluoromethanesulfonate) was found to be the most efficient catalyst used, affording quantitative conversion of benzoyl chloride and anisole to methoxybenzophenone within 1 h and with an *ortho/para* product ratio (*o/p*) of 4/96. The same reaction performed in the molecular solvents CH₃CN and CH₂ClCH₂Cl gave lower 1 h conversions of 64 and 73%, respectively, and a reduced *o/p* regioselectivity of 7/93 in both cases. The scope and limitations of the reaction and recyclability of the ionic liquid/catalyst system are presented.

Introduction

Ionic liquids, which are entirely composed of ions, can provide an ideal medium for reactions that involve reactive ionic intermediates.¹ Indeed, in our recent work on palladium-catalysed C–C coupling reactions in imidazolium ionic liquids, we have complemented the steadily growing family of reactions in which ionic liquids can promote unprecedented selectivities and enhanced reaction rates and such alternations could at least partly be attributed to the increased ability of ionic liquids to stabilise charged intermediates compared with conventional molecular solvents.² Consequently, our attention turned to Lewis acidic metal ion catalysed Friedel–Crafts reactions and the potential advantage of ionic liquids to immobilise such catalysts and stabilise the intermediary cations.

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Activation of C–H bonds, *via* aromatic Friedel–Crafts reactions, is an important means of adding functionality to simple carbon compounds and as such, is of great importance to many sectors of chemistry.³ In a typical Friedel–Crafts acylation reaction, an aromatic compound undergoes electrophilic substitution with an acylating agent in the presence of an acid catalyst (Lewis or Brønsted) to afford a ketone. However, when using the common Lewis acid catalyst, AlCl₃, a stable adduct compound is formed between the catalyst and the carbonyl oxygen of the ketone product. Thus, an over stoichiometric excess of AlCl₃ is required to achieve complete reaction.³ Copious quantities of inorganic waste materials are produced invoking associated environmental and economic impedimenta.

One of the earliest examples of catalytic reactions performed in room temperature ionic liquids were Friedel–Crafts reactions. The ionic liquid [emim]Cl–AlCl₃ (emim = 1-ethyl-3-methylimidazolium) was shown to demonstrate catalytic activity in Friedel–Crafts acylations and alkylations, amongst other reactions, acting both as catalyst and as solvent.⁴ Recently, Seddon has reported the Friedel–Crafts acylation of both activated and deactivated aromatics to proceed at ambient and subambient temperatures in [emim]Cl–AlCl₃, affording ketone products in high yield and regioselectivity in very short reaction times.⁵ Using the analogous [emim]I–AlCl₃ ionic liquid, Singer and coworkers have demonstrated the applicability of these solvent

Green Context

Friedel–Crafts acylation reactions represent one of the greatest challenges to green chemistry. Traditional methods generally employ large quantities of hazardous soluble Lewis acids, which are destroyed on work-up giving poor resource utilisation and large volumes of waste. For this reason new research aimed at more efficient and environmentally benign reactor systems is important. Here it is shown that relatively small amounts of metal triflates can catalyse some acylations reactions in ionic liquid solvents. Copper triflate is particularly effective. Unfortunately the reactions reported are limited to highly activated substrates but at least some value with these new systems is evident.

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systems to promote the acylation of organometallic compounds, with the ionic liquid again serving both as solvent and as active catalyst.⁶ More recently, Song *et al.* have shown that Friedel–Crafts alkylation of aromatics with simple alkenes can readily be performed, using Sc(OTf)₃ as catalyst in imidazolium ionic liquids such as [bmim][PF₆], which are easier to handle and are recyclable together with the catalyst.⁷

In conventional molecular solvents, Sc(OTf)₃ and a number of other Lewis acidic metal compounds have already proven to be attractive catalysts for Friedel–Crafts alkylation as well as acylation reactions and complete conversion to product can sometimes be achieved with catalyst concentrations < 1 mol%.⁸ In addition, their stability in aqueous phases makes them recyclable as active catalysts. Of particular note is that the activities of some of the catalysts such as Sc(OTf)₃ and In(OTf)₃ can significantly be enhanced by the addition of LiClO₄, which accelerates the reaction probably by helping the formation of reactive ionic species.⁹ The aim of the present work was to demonstrate the feasibility of Friedel–Crafts acylation catalysed by metal Lewis acids that are easily available and require no special caution to handle. In so doing, we anticipated that the ionic nature of the imidazolium ionic liquids could facilitate the reaction by providing stabilisation of reactive charged intermediates.

Results and discussion

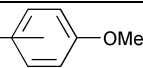
Four commercially available metal triflates were chosen for the study of Friedel–Crafts acylation reactions in [bmim][BF₄], namely Cu(OTf)₂, Zn(OTf)₂, Sn(OTf)₂ and Sc(OTf)₃. The benzylation of anisole was used as a test reaction to compare the catalytic ability of each metal triflate in turn. In a typical reaction, a mixture of benzoyl chloride (1 mmol) and anisole (5 mmol) was added to a mixture of catalyst (0.1 mmol) immobilised in [bmim][BF₄]. The reaction was performed at 80 °C under an atmosphere of dry argon. All four catalysts used provided 100% conversion of the benzoyl chloride to product after overnight reaction. However, Cu(OTf)₂ demonstrated the greatest activity of the four catalysts tested, affording quantitative conversion within 1 h, while Zn(OTf)₂ and Sn(OTf)₂ displayed moderately reduced activity, affording 1 h conversions of 87 and 74%, respectively, as evidenced by ¹H NMR and GC analysis of the crude product (Table 1). Sc(OTf)₃ was least active, producing a 1 h conversion of only 10%. This is somewhat surprising. Catalyst solubility was not a factor since

both Cu(OTf)₂ and Sc(OTf)₃ are highly soluble in [bmim][BF₄] under the reaction conditions employed. In addition a previous study revealed that Cu(OTf)₂ and Sc(OTf)₃ behave similarly in acylaminoalkylation and Friedel–Crafts alkylation in CH₂Cl₂.^{8e} Interestingly, we found that addition of CF₃CO₂H (0.5 mmol) increased the activity of the Sc(OTf)₃ catalysed reaction in [bmim][BF₄], improving the 1 h conversion from 10 to 47% with concomitant increase in regioselectivity from an *o/p* ratio of 16/84 to 6/94. However, no reaction occurred when CF₃CO₂H was used in the absence of Sc(OTf)₃, indicating that CF₃CO₂H is not catalysing the reaction but merely facilitating the Sc(OTf)₃ catalysed reaction as an additive. Hence, the established ease of recycle of Sc(OTf)₃,^{7,8} coupled with the means of increasing its catalytic performance as demonstrated here, may compensate for its lower activity compared with Cu(OTf)₂ in [bmim][BF₄]. Cu(OTf)₂ is also one of the most regioselective catalysts, as can be judged by the *o/p* ratios in Table 1. The benzylation of anisole was also attempted in the presence of other copper catalysts such as CuCl₂·2H₂O and Cu(OAc)₂·H₂O in the [bmim][BF₄] solvent. Both reactions failed to reach completion after 44 h, affording only 60 and 76% conversions, respectively, although CuCl₂·2H₂O showed greater catalytic activity in [bmim][BF₄] than in conventional solvents. CuCl₂·2H₂O and Cu(OAc)₂·H₂O were observed to be less soluble in [bmim][BF₄] than was Cu(OTf)₂. Thus the enhanced performance of the latter as catalyst in [bmim][BF₄] can be attributed both to favourable electronic properties and to increased solubility. Metal halides have been shown to be effective Lewis acids in the benzylation of 2-methoxynaphthalene at higher temperature in PhNO₂.^{8c} In establishing a standard reaction protocol, the benzylation of anisole was also performed at various temperatures in [bmim][BF₄]. The reaction became slower at lower temperature and no reaction occurred at room temperature.

The reactivity and regioselectivity of Cu(OTf)₂ as catalyst in the benzylation of anisole in [bmim][BF₄] compares favourably with those observed in molecular solvents. Thus, in [bmim][BF₄], ketone was obtained quantitatively within 1 h with an *o/p* ratio of 4/96. In contrast, in CH₃CN and CH₂ClCH₂Cl, lower conversions and *o/p* ratios were obtained (Table 1), and the reaction performed in excess anisole required a much longer time to complete and led to two ketones with an *o/p* ratio of 10/90.¹⁰ However, for the other three catalysts, the results with the ionic liquid compare less favourably than those with the conventional solvents.

Due to its greater activity and ready availability, Cu(OTf)₂ was subsequently used to catalyse a range of Friedel–Crafts acylation reactions in [bmim][BF₄]. Whilst most reactions involving acyl halides went to completion within 1 h, all the reactions were performed overnight, due to slower acylation with related anhydrides (*vide infra*). Under such conditions GC and ¹H NMR analysis of the crude mixture showed a complete reaction for all the acylating agents. The ketone product was extracted with organic solvents. The results are summarised in Table 2. The benzylation of anisole derivatives furnished the ketones with good to excellent isolated yields (Table 2, entries 1–4). The benzylation of 3,5-dimethylanisole preferentially afforded the less hindered *ortho*-substituted product with an isomer distribution similar to that observed in conventional solvents (Table 2, entry 2).¹¹ The benzylation of the bulkier aromatic-substituted anisole derivative 2-methoxynaphthalene in [bmim][BF₄] produced 2-methoxy-1-naphthyl phenyl ketone exclusively (entry 3). This product is the kinetic product and, when formed under conventional reaction conditions, often undergoes isomerisation to give a mixture including 6-methoxy-2-naphthyl phenyl ketone, a precursor in the synthesis of Naproxen.^{8c} In [bmim][BF₄], isomerisation to this thermodynamically more stable product was not observed even after prolonged reaction, reminiscent of the acetylation of naphthylene, where the thermodynamically unfavoured 1-isomer

Table 1 Benzylation of anisole catalysed by metal triflates in [bmim][BF₄] and molecular solvents^a

PhOMe + PhCOCl		Catalyst	PhCO- 	
		Solvent		
		80 °C, 1 h		
Entry	Catalyst	Solvent	Conversion (%) ^b	<i>o/p</i> ^c
1	Cu(OTf) ₂	[bmim][BF ₄]	100	4/96
2	Zn(OTf) ₂	[bmim][BF ₄]	87	4/96
3	Sn(OTf) ₂	[bmim][BF ₄]	74	25/75
4	Sc(OTf) ₃	[bmim][BF ₄]	10	16/84
5	Cu(OTf) ₂	CH ₃ CN	64	7/93
6	Zn(OTf) ₂	CH ₃ CN	82	8/92
7	Sn(OTf) ₂	CH ₃ CN	80	7/93
8	Sc(OTf) ₃	CH ₃ CN	53	9/91
9	Cu(OTf) ₂	CH ₂ ClCH ₂ Cl	73	7/93
10	Zn(OTf) ₂	CH ₂ ClCH ₂ Cl	45	2/98
11	Sn(OTf) ₂	CH ₂ ClCH ₂ Cl	86	5/95
12	Sc(OTf) ₃	CH ₂ ClCH ₂ Cl	57	5/95

^a Ratio of anisole/benzoyl chloride = 5/1. ^b Conversion of benzoyl chloride, measured by ¹H NMR. ^c *ortho/para* Ratio measured by GC.

was predominantly obtained and the product did not rearrange when heated.⁵ Intriguingly, the benzylation of 2-methoxybiphenyl affords the substitution product 2-(2-methoxyphenyl)benzophenone exclusively in [bmim][BF₄], whereas benzylation occurring exclusively in the position *para* to the methoxy group is reported in the literature (entry 4).¹² Acetylation of anisole proceeded equally well, affording the *para* isomer as the only product detectable with GC (Table 2, entry 5).

Thus far, 10 mol% Cu(OTf)₂ had been used to catalyse the benzylation of anisole in [bmim][BF₄], which is the most common catalyst loading found in the literature.^{8a,b,e-g,10} Attempting to lower the amount of added catalyst, this reaction was conducted sequentially in the presence of 5 mol% and then 1 mol% Cu(OTf)₂. Reducing the amount of added catalyst from 10 mol% to 5 mol% did not alter the 1 h conversion, which was quantitative. However, further lowering to 1 mol% slowed the reaction noticeably; hence there was no detectable conversion after 1 h and only 84% conversion after 20 h.

The handling of acyl chlorides is generally disagreeable and as such their anhydride analogues were also investigated.¹³ Under conditions similar to those for the chlorides, acetic anhydride, benzoic anhydride and even the much more

hydrophobic heptanoic anhydride all underwent complete reactions with anisole, yielding the *para* isomers as the only or predominant product, albeit with moderate isolated yields (Table 2, entries 6–9). Worthy of note is the apparent difference between the Friedel–Crafts reactions of anhydrides and acyl chlorides in [bmim][BF₄]. Thus, ¹H NMR monitoring of the reaction of acetic anhydride with anisole showed only 19% conversion to ketone after 1 h, whereas quantitative conversion was observed, within the same time period, when the anhydride was replaced with acetyl chloride. Comparative to the above example, replacing benzoyl chloride with benzoic anhydride in the reaction with anisole decreased the 1 h conversion from 100% to less than 10%, although similar regioselectivities were achieved for both reactions (Table 2). In common solvents such as CH₂ClCH₂Cl and CH₃CN, the same reaction catalysed by Cu(OTf)₂ was similarly slow. Faster reactions were achieved only when excess anhydride was used as both the acylating agent and solvent.¹⁰

The low activity of Cu(OTf)₂ towards anhydrides is related to its behaviour in the ionic liquids. Unlike the reaction involving the acyl halides, the acylation by anhydrides in [bmim][BF₄] was always accompanied with immediate and ultimately quantitative formation of a pale blue precipitate, identified as

Table 2 Cu(OTf)₂ catalysed acylation of aromatic compounds in [bmim][BF₄]^a

Entry	Ar-H	RC(O)X	ArC(O)R	Yield (%) ^b	<i>o/p</i> ^c
1		PhCOCl		81	4/96
2		PhCOCl		91	63/37 ^d
3		PhCOCl		72	
4		PhCOCl		65	
5		MeCOCl		87	
6		Ac ₂ O		48	
7		(PhCO) ₂ O		46	6/94 ^d
8		(C ₂ H ₅ CO) ₂ O		55	
9		(C ₆ H ₁₃ CO) ₂ O		58	
10		PhCOCl		53	

^a For general reaction conditions, see Experimental. ^b Isolated yields. 100% *para* product unless stated otherwise. ^c *ortho/para* %Ratio by GC. ^d *ortho/para* With respect to OMe.

Cu(OAc)₂·H₂O by NMR, elemental analysis and comparison with an authentic sample, when using acetic anhydride. The formation of Cu(OAc)₂·H₂O in [bmim][BF₄] is caused by the trace amounts of water found in such hygroscopic ionic liquids and is driven by the insolubility of this resulting neutral species in the ionic liquid. The end result is lowering of the concentration of active Cu(II) species and thus the activity of the reaction in the ionic liquid. Consistent with this, when the [bmim][BF₄]/catalyst system was further dried by stirring in the presence of activated 4 Å molecular sieves for 3 h prior to the addition of acetic anhydride and anisole, the acetylation reaction was faster, affording a complete conversion to 4'-methoxyacetophenone after 1 h. Such trace amounts of water appear to be inconsequential towards the reactions of acyl halides in the same medium, probably due to differing behaviours of HCl and AcOH generated in the chloride and anhydride reactions in [bmim][BF₄] (*vide infra*).

The Friedel–Crafts benzylation reaction in [bmim][BF₄] was also extended to a series of toluene derivatives using Cu(OTf)₂. The benzylation of mesitylene led to quantitative conversion to product after overnight reaction (Table 2, entry 10). But the similar reaction with the less reactive toluene only afforded a 26% conversion, although with a high selectivity (*o/p* = 3/97), suggesting that Cu(II) is not acidic enough to generate highly reactive acylium ions, which could be formed by exchange of the chloride with triflate ion and by donor–acceptor interaction between the carbonyl oxygen and Cu(II).^{8g}

Attempts were made to recycle the solvent/catalyst system. The benzylation of anisole with benzoyl chloride under the conditions similar to those for Table 2 was run for three cycles, furnishing the methoxy substituted benzophenones with 86, 79 and 65% isolated yields, respectively, and an *o/p* ratio of 4/96 for all runs. The product was extracted with Et₂O; a second reaction was initiated after simple decanting of the organic layer and drying under vacuum for 30 min. It is thought that a gradual accumulation of HCl, possibly leading to formation of an increasing amount of CuCl₂, is responsible for the deactivation of the solvent/catalyst system towards subsequent reactions. Evidence for HCl formation is in detecting an acidic gas (pH ~ 2) emitted during the reaction. Dense white fumes were formed upon exposure of this acidic gas to concentrated ammonia solution, indicative of NH₄Cl.

As might be expected from previous studies,³ under the same reaction conditions used for forming C–C bonds, C–N and C–O bonds were readily formed and in high isolated yields. Thus, phenol and *m*-cresol formed their respective esters, and aniline formed benzanilide, with benzoyl chloride. Reaction with benzyl alcohol also proceeded but was not quantitative (Table 3).

Conclusions

In summary, the feasibility of metal triflates as Lewis acids for Friedel–Crafts acylations in an imidazolium ionic liquid has been demonstrated. Using Cu(OTf)₂ as catalyst, greater regioselectivities and enhanced rates of reaction can be achieved in [bmim][BF₄] compared with conventional solvent conditions for the Friedel–Crafts acylation of activated aromatic compounds. But deactivated aromatics and acylation by anhydrides give less satisfactory results. Recycling of the solvent/catalyst system was demonstrated when using Cu(OTf)₂. The faster rates associated with the copper catalyst could result from enhanced Lewis acidity of Cu(II) and/or easier generation of charged cations in the ionic liquid. However, the accelerating effect of ionic liquids, if any, varies with catalysts used, as exemplified by the other three triflates studied. The involvement of an active copper *N*-heterocyclic carbene species is less likely; the strong σ -donating capability of such a ligand would significantly reduce the Lewis acidity of Cu(II).^{14,15} The

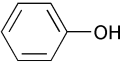
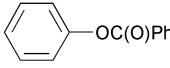
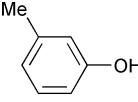
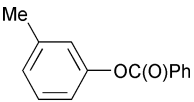
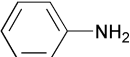
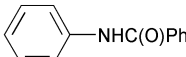
difference between ionic liquids and conventional molecular solvents is further highlighted by the easy precipitation of neutral Cu(OAc)₂·H₂O by anhydrides in [bmim][BF₄] but not in solvents such as CH₂ClCH₂Cl and CH₃CN. The insolubility of this Cu(II) species, which shows negligible activity towards the acylation of anisole using acetic anhydride in [bmim][BF₄], is an additional driving force toward the degradation of Cu(OTf)₂ not observed in solvents such as CH₂ClCH₂Cl and CH₃CN, showing that the physical and chemical properties of ionic liquids need to be more fully understood before their full potential can be realised.

Experimental

All reactions were carried out in oven-dried glassware under an atmosphere of dry argon. [bmim][BF₄] was prepared according to a published procedure, vacuum-dried and stored under an atmosphere of dry argon.¹⁶ Anisole and toluene were freshly distilled from calcium hydride under dinitrogen immediately prior to use. All other chemicals were purchased from commercial suppliers and were used as received. Reaction progress was monitored by ¹H NMR and GC analysis; [bmim][BF₄] was removed by passing the reaction sample through a pad of silica gel and flushing with solvent. Alternatively, ¹H NMR analyses of samples containing [bmim][BF₄] were run in acetone-*d*₆. Products were purified by chromatographic separation. Characterisation of ketone products was *via* NMR, C/H analysis, melting points (where appropriate) and MS with reference to literature values.

A typical reaction procedure is given for the acylation by acyl chlorides. A round-bottomed flask was charged with Cu(OTf)₂ (36.2 mg, 0.1 mmol). After drying under vacuum for 1 h with stirring and flushing several times with dry argon, [bmim][BF₄] (2 ml) was added. The mixture was stirred at 80 °C for 10 min until homogenous. After cooling to ambient temperature, benzoyl chloride (0.141 g, 1 mmol) and anisole (0.541 g, 5 mmol) were added. The reaction was stirred at 80 °C under an atmosphere of dry argon. Upon completion of the reaction, the organics were extracted with Et₂O. When recycling the solvent/catalyst system, fresh acylating agent and aromatic were added following prior drying of the solvent/catalyst system for 30 min at 80 °C under vacuum. The combined organic extracts were washed with water, aqueous NaHCO₃ and brine. After removing the solvent, the product was purified by flash chromatographic separation (eluent: light petroleum (bp 40–60 °C)/ethyl acetate = 10/1). Selected analytic data are given for the following compounds.

Table 3 C–O and C–N bond formation under Friedel–Crafts conditions in [bmim][BF₄]^a

Entry	Ar–H	Product	Yield, (%) ^b
1			67
2			86
3			81

^a Reaction conditions were the same as those for the benzylation of anisole. ^b Isolated yields.

4-Methoxybenzophenone^{8a}

¹H NMR (400 MHz, CDCl₃): δ 3.78 (s, OCH₃, 3H), 6.90 (d, *J* = 8.9 Hz, 3-/5-H, 2H), 7.41 (m, 3'-/5'-H, 2H), 7.50 (m, 4'-H, 1H), 7.72 (d, *J* = 6.9 Hz, 2'-/6'-H, 2H), 7.78 (d, *J* = 8.9 Hz, 2-/6-H, 2H); ¹³C{¹H} NMR (100 MHz, CDCl₃): δ 55.89, 113.95, 128.58, 130.12, 130.55, 132.28, 132.96, 138.68, 163.62, 195.96; Anal. Calc. for C₁₄H₁₂O₂: C, 79.26; H, 5.66. Found: C, 79.28; H, 5.66%.

2-Methoxy-4,6-dimethylbenzophenone/4-methoxy-2,6-dimethylbenzophenone¹¹

¹H NMR (400 MHz, CDCl₃): δ 2.10 (s, 4-CH₃ and 2-/6-CH₃), 2.35 (s, 6-CH₃), 3.61 (s, OCH₃), 3.74 (s, OCH₃), 6.61 (m, 3-/5-H), 7.35–7.60 (m), 7.75–7.85 (m); ¹³C{¹H} NMR (100 MHz, CDCl₃): δ 19.32, 22.10, 55.94, 112.06, 113.43, 128.92, 129.73, 129.79, 132.79, 133.63, 133.94, 138.05, 138.11, 200.83; Anal. Calc. for C₁₆H₁₆O₂: C, 80.01; H, 6.73. Found: C, 80.29; H, 6.98%.

2-Methoxy-1-naphthyl phenyl ketone^{8c}

Mp 122–123 °C; ¹H NMR (400 MHz, CDCl₃): δ 3.82 (s, 3H), 7.33–7.44 (m, 5H), 7.49–7.58 (m, 2H), 7.83–7.87 (m, 3H), 7.96 (d, *J* = 9.0 Hz, 1H); ¹³C{¹H} NMR (100 MHz, CDCl₃): δ 56.54, 113.09, 122.92, 124.05, 124.09, 127.39, 128.11, 128.28, 128.57, 128.77, 129.62, 131.17, 131.69, 133.47, 137.91, 154.07, 197.79; Anal. Calc. for C₁₈H₁₄O₂: C, 82.45; H, 5.38. Found: C, 82.37; H, 5.38%.

2-(2-Methoxyphenyl)benzophenone¹²

Mp 94–96 °C; ¹H NMR (400 MHz, CDCl₃): δ 3.85 (s, OCH₃, 3H), 7.01 (d, *J* = 8.6 Hz, 1H), 7.25–7.55 (m, 8H), 7.76–7.87 (m, 4H); ¹³C{¹H} NMR (100 MHz, CDCl₃): δ 56.22, 110.92, 127.78, 128.49, 128.63, 129.93, 130.14, 130.68, 131.01, 132.13, 132.32, 133.61, 137.90, 138.67, 160.52, 195.94; Anal. Calc. for C₂₀H₁₆O₂: C, 83.34; H, 5.59. Found: C, 83.17; H, 5.59%.

1-(4-Methoxyphenyl)ethanone^{8a}

¹H NMR (400 MHz, CDCl₃): δ 2.56 (s, CH₃, 3H), 3.88 (s, OCH₃, 3H), 6.94 (d, *J* = 8.9 Hz, 3-/5-H, 2H), 7.94 (d, *J* = 8.9 Hz, 2-/6-H, 2H); ¹³C{¹H} NMR (100 MHz, CDCl₃): δ 26.64, 55.81, 114.07, 114.34, 130.78, 130.94, 131.22, 163.88, 197.06; Anal. Calc. for C₉H₁₀O₂: C, 71.98; H, 6.73. Found: C, 71.90; H, 6.77%.

1-(4-Methoxyphenyl)propan-1-one¹⁷

¹H NMR (400 MHz, CDCl₃): δ 1.20 (t, *J* = 7.7 Hz, CH₃, 3H), 2.95 (q, *J* = 7.7 Hz, CH₂, 2H), 3.85 (s, OCH₃, 3H), 6.94 (m, 2H), 7.96 (m, 2H); ¹³C{¹H} NMR (100 MHz, CDCl₃): δ 8.82, 31.79, 55.82, 113.73, 114.04, 130.38, 130.60, 130.88, 163.68, 199.94; Anal. Calc. for C₁₀H₁₂O₂: C, 73.14; H, 7.38. Found: C, 73.42; H, 7.43%.

1-(4-Methoxyphenyl)heptan-1-one¹⁸

¹H NMR (400 MHz, CDCl₃): δ 0.90 (br, CH₃, 3 H), 1.32 (m, CH₂, 6H), 1.72 (m, CH₂, 2H), 2.91 (br, CH₂, 2H), 3.88 (s, OCH₃, 3H), 6.93 (d, *J* = 8.8 Hz, 3-/5-H, 2H), 7.95 (d, *J* = 8.8 Hz, 2-/6-H, 2H); ¹³C{¹H} NMR (100 MHz, CDCl₃): δ 14.45, 22.94, 25.00, 29.51, 32.08, 38.72, 55.84, 114.04, 130.58, 130.71, 163.68, 199.71; Anal. Calc. for C₁₄H₂₀O₂: C, 76.31; H, 9.17. Found: C, 76.49; H, 9.22%.

2,4,6-Trimethyl-benzophenone¹⁹

¹H NMR (400 MHz, CDCl₃): δ 2.08 (s, CH₃, 6H), 2.32 (s, CH₃, 3H), 6.89 (s, CH, 2H), 7.42 (m, 3'-/5'-H, 2H), 7.56 (m, 4'-H,

1H), 7.81 (d, *J* = 7.2 Hz, 2'-/6'-H, 2H); ¹³C{¹H} NMR (100 MHz, CDCl₃): δ 19.74, 21.53, 129.02, 129.19, 129.61, 133.89, 134.63, 137.39, 138.08, 138.88, 201.05; Anal. Calc. for C₁₆H₁₆O: C, 85.67; H, 7.20. Found: C, 85.57; H, 7.26.

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