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Electrostatic catalysis by ionic aggregates: scope and limitations of $Mg(ClO_4)_2$ as acylation catalyst

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Abstract—Alkali and alkaline earth metal perchlorates exhibit electrostatic catalysis in the activation of anhydrides for the acylation reaction. Perchlorates with higher values of the charge-size function of the metal ion exhibit better catalytic activity following the order $Mg(ClO_4)_2$>$Ba(ClO_4)_2$>$LiClO_4$. Acylation of structurally diverse phenols, thiols, alcohols, and amines have been carried out with stoichiometric amounts of anhydride at room temperature under solvent free conditions in the presence of catalytic amount of $Mg(ClO_4)_2$. Sterically hindered and electron deficient phenols are efficiently acylated. Acylation with sterically hindered anhydrides such as iso-butyric, pivalic, and benzoic anhydrides are carried out with phenols and alcohols in excellent yields. Acid-sensitive alcohols are acylated in excellent yields without any competitive side reactions.

Acylated phenols, thiols, amines and alcohols serve as feed stock for the synthesis of drugs and pharmaceuticals and are usually prepared through acylation with anhydrides[1] due to their ease of deprotection.[1,2] However, the poor nucleophilic property of hydroxylic compounds, particularly phenols, necessitates the activation of the anhydride. Activation is commonly achieved by the use of nucleophilic agents such as DMAP[3] and Bu_3P[4] and Lewis acids such as $CoCl_2$,[5] $Sc(OTf)_3$,[6] $Sc(NTf_2)_3$,[7] TMSOTf,[8] $Bi(OTf)_3$,[9] $Cu(OTf)_2$,[10] $In(OTf)_3$,[11] $TaCl_5$,[12] zeolites,[13] clays,[14] Nafion-H,[15] yttria–zirconia,[16] and HBF_4–SiO_2.[17] Nevertheless, there remains a high demand for the development of better acylation methodology considering one or more of the limitations of the existing protocols such as longer reaction time, stringent conditions, use of halogenated solvents, use of hazardous materials (e.g. DMAP is highly toxic, Bu_3P is flammable and air sensitive), use of costly catalysts (e.g. the triflates), special efforts required to prepare the catalyst (e.g. $Bi(OTf)_3$, $Sc(NTf_2)_3$, Nafion-H, yttria–zirconia, HBF_4–SiO_2), need to use excess acylating agent, side reactions with acid-sensitive substrates and in some cases being applicable to alcohols only.

Although the triflates, in general, are claimed as the most effective catalysts, the larger negative H_0 value (−14.1) of TfOH[18] suggests that metal triflates should be very strong Lewis acids[19] and lead to competitive side reactions (e.g. rearrangement, dehydration etc.) for acid sensitive substrates. This is reflected in the observations that TMSOTf, $Sc(OTf)_3$, and $Bi(OTf)_3$ catalysed acetylation of tertiary alcohols necessitates the use of large excess of Ac_2O and low reaction temperature (e.g. −50 to −10°C) so as to minimize the potential side reactions. The high cost and susceptibility to aqueous medium of the metal triflates become a major concern for their industrial applications. We reasoned that as perchloric acid is weaker than TfOH, the use of metal perchlorate should circumvent the problem of side reactions for acid-sensitive substrates.

Wienstein et al.[20] observed that the ionisation of *p*-methoxyneophyl tosylate and a *p*-nitrobenzoate in a 0.1 M solution of $LiClO_4$ in ether is respectively 10^5 and 10^6 times faster than in ether itself. Pocker et al.[21] showed that the ionisation of TrCl in 5.5 M $LiClO_4$/ether occurs about 7.0×10^9 more rapidly than in ether. These unusual rate enhancements have been attributed to electrostatic catalysis in which the large Coulomb fields of the ions stabilise polar transition states and much of these data can be rationalised by mechanisms in which lithium ion functions as a Lewis acid catalyst.[22] Thus, we planned to exploit the electrostatic catalytic effect of ion aggregates in metal perchlorates and were delighted to see the recent report of use of $LiClO_4$ as acylation catalyst.[23] The role of metal perchlorates in activating the anhydride may be explained in Figure 1. Coordination of the cation of the perchlorate (ML_n) with the anhydride $(RCO)_2O$ should lead to the six membered transition state (**TS-I**) in which the anhydride becomes more susceptible to nucleophilic attack by $(R^1)ArXH$ leading to the formation of the acylated product, RCO_2H and ML_n. However, the

Keywords: acylation; electron deficient phenols; $Mg(ClO_4)_2$; solvent free conditions.

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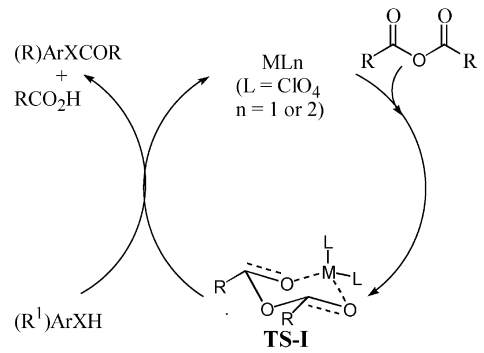


Figure 1. Role of metal perchlorates in activation of anhydride.

$LiClO_4$ catalysed reactions required prolonged time (4–48 h) and acylation of electron deficient (e.g. phenols) and sterically hindered substrates are carried out at higher temperature (ca. 40°C). The longer reaction time required for the $LiClO_4$ catalysed reactions necessitates the use of large excess (10 equiv.) of Ac_2O to suppress the potential side reactions with acid sensitive substrates. We thought that the larger value of the charge-size function[24] of Mg^{+2}, compared to that of Li^+, should enable $Mg(ClO_4)_2$ to coordinate with the anhydride more effectively under milder condition. It has been observed that the better coordinating capability of Mg^{+2} allows the formation of six membered Ireland transition state at room temperature resulting in stereoselective enolate generation during the deprotonation of carbonyl compounds with magnesium bis-diisopropylamide[25] whereas the corresponding enolate formation is carried out at low temperature (−78°C) in the presence of lithium diisopropylamide as the well organized six membered transition state formation is not feasible with Li^+ at room temperature due the relatively weak coordinating ability of Li^+.[26] Therefore we planned to exploit the electrostatic catalytic effect of $Mg(ClO_4)_2$ for the acylation reaction.[27]

In a model study, 2-hydroxynaphthalene (**1**) was treated with Ac_2O under various conditions (Table 1). The reaction is best carried out at room temperature under neat conditions with 1 equiv. of Ac_2O in the presence of 1 mol% of $Mg(ClO_4)_2$. Inferior results were obtained with $Mg(ClO_4)_2{\cdot}6H_2O$ and $Ba(ClO_4)_2$. $LiClO_4$ was found to be far less effective. The catalytic activities of the various metal perchlorates were found to be parallel to the order of their charge-size function values (Mg^{+2} 14.3, Ba^{+2} 7.6, and Li^+ 3.5).[24] Similar parallelism between the catalytic activity and charge-size function of these metal perchlorates was observed during the metal perchlorate catalysed Diels–Alder reaction.[28] However, $Mg(ClO_4)_2$–SiO_2 afforded comparable results but required a little longer time and $LiClO_4$–SiO_2 exhibited better catalytic activity compared to that of $LiClO_4$. Interestingly, $Mg(OTf)_2$ was found to be less effective compared to $Mg(ClO_4)_2$.

Table 1. Acylation of **1** with Ac_2O under various conditions

Entry	Activator	Ac_2O (equiv.)	Time (h)	Yield (%)[a,b]
1	$Mg(ClO_4)_2$	1	0.33	100
2	$Mg(ClO_4)_2$ $6H_2O$	1	0.33	75
3	$Mg(ClO_4)_2$–SiO_2	1	0.5	90
4	$Mg(OTf)_2$	1	0.5	86
5	$LiClO_4$	2	6	78
6	$LiClO_4$–SiO_2	2	20	65
7	$Ba(ClO_4)_2$	1	0.33	60

The substrate was treated with Ac_2O (1 equiv.) in the presence of the activator (1 mol%) at room temperature under solvent free conditions.
[a] Isolated yield of 2-acetoxynaphthalene.
[b] The unreacted **1** was recovered.

Table 2. Effect of Solvent During the $Mg(ClO_4)_2$ catalysed acylation of **1** with Ac_2O

Entry	Solvent	Time (h)	Yield (%)[a,b]
1	$MeNO_2$	1	5
2	MeCN	1	15
3	Et_2O	1	Trace
4	DCM	1	88
5	Toluene	1	80
6	Neat	0.33	100

The substrate was treated with Ac_2O (1 equiv.) in the presence of the $Mg(ClO_4)_2$ (1 mol%) at room temperature.
[a] Isolated yield of 2-acetoxynaphthalene.
[b] The unreacted starting material was recovered.

In order to establish that the catalytic effect of $Mg(ClO_4)_2$ was due to the electrostatic effect of the ionic aggregate, we carried out the acylation of **1** in various solvents under neat conditions in the presence of $Mg(ClO_4)_2$ (1 mol%) (Table 2). No appreciable acylation was observed in carrying out the reactions in coordinating solvents such as $MeNO_2$, MeCN, and Et_2O. Excellent results were obtained in non-coordinating solvents such as DCM and toluene. The loss of catalytic activity of $Mg(ClO_4)_2$ in coordinating solvents may be explained due to the lack of formation of **TS-I** as a result of competitive coordination of Mg^{+2} with the solvent. The retention of the catalytic activity in non-coordinating solvent supports the involvement of **TS-I**. This is reinforced by the fact that the acylation takes place at a slower rate in the presence of $Mg(ClO_4)_2{\cdot}6H_2O$ as the water molecules associated with the hydrated form of the catalyst allows the formation of a loose transition state.

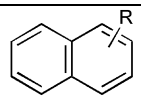
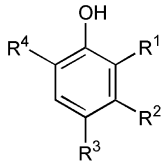
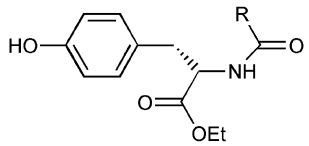
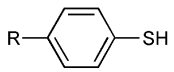
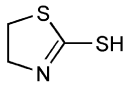
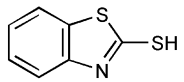
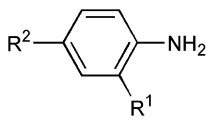
To establish that $Mg(ClO_4)_2$ can be claimed as a generalized acylation catalyst, **1** was treated with various acylating agents (Table 3). The reaction rate was found to be influenced by the steric and electronic factors around the anhydride carbonyl group. Thus the reactions with propionic and iso-butyric anhydrides (entries 3 and 4)

Table 3. $Mg(ClO_4)_2$ catalyzed acylation of **1** with various acylating agents

Entry	Acylating agent (equiv.)	Time (h)	Yield (%)[a,b]
1	Ac_2O (1)	0.33	100
2	AcCl (2)	1	50
3	$(H_3CCH_2CO)_2O$ (1)	1	97
4	$[(H_3C)_2CHCO]_2O$ (1)	1	98
5	$[(H_3C)_3CCO]_2O$ (1.5)	1	70[c]
6	$(PhCO)_2O$ (1)	1	76[d,e]
7	PhCOCl (1)	6	40

The substrate was treated with the acylating agent in the presence of $Mg(ClO_4)_2$ (1 mol%) under solvent free conditions at room temperature (except for entry 5).
[a] Isolated yield of the corresponding acylated product.
[b] The unreacted phenol was recovered.
[c] The reaction was carried out at 80°C.
[d] A 90% yield was obtained in carrying out the reaction in DCM.
[e] A 30% yield was obtained when the reaction was carried out in the presence of $LiClO_4$ (5 mol%).

Table 4. $Mg(ClO_4)_2$ catalyzed acylation of phenols, thiols, and amines

Entry	Substrate	Time (h)	Yield (%)[a]
			
1	R=2-OH	0.33	100
2	R=1-OH	1	95
			
3	R^1=R^2=R^4=H; R^3=Me	0.25	98
4	R^1=R^2=R^4=H; R^3=OMe	0.25	98
5	R^1=R^3=R^4=Me; R^2=H	1	85
6	R^1=R^2=R^4=Me; R^3=H	1	90
7	R^1=R^4=^{t}Bu; R^3=Me; R^2=H	5	90[b]
8	R^1=R^2=R^4=H; R^3=Br	1	95[c]
9	R^1=R^2=R^4=H; R^3=Cl	1	90[c]
10	R^1=R^4=H; R^2=Me; R^3=Cl	0.25	95
11	R^1=R^2=R^4=H; R^3=COMe	1	90
12	R^1=R^3=R^4=H; R^2=COMe	0.5	90
13	R^1=COMe; R^2 =R^3=R^4=H	1	90
14	R^1=R^2=R^4=H; R^3=CO_2Me	1	90
15	R^1=R^2=R^4=H; R^3=CO_2Et	1	88
16	R^1=R^2=R^4=H; R^3=CO_2Pr^n	1	85
17	R^1=R^2=R^4=H; R^3=CO_2H	1	85
18	R^1=CO_2H; R^3=R^2=R^4=H	2	93
19	R^1=R^2=R^4=H; R^3=OH	0.16	100[d]
20	R^1=OH; R^2=R^3=R^4=H	0.25	90[d]
21	R^1=R^3=R^4=H; R^2=OH	0.08	94[d]
22	R^1=R^4=H; R^2=OH; R^3=COMe	0.5	97[d]
23	R^1=R^2=OH; R^3=R^4=H	0.25	100[e]
			
24	R=Me	2	95
25	R=Ph	3	90
			
26	R=H	1	95
27	R=Me	0.25	98
			
28		0.5	65
29		12	Nil
30	R^1=NO_2; R^2=H	0.5	89[f,g]
31	R^1=R^2=NO_2	2	70

The substrate was treated with Ac_2O (1 equiv. per OH/SH/NH_2 group except for entry 7) in the presence of $Mg(ClO_4)_2$ (1 mol%) under solvent free conditions at room temperature.

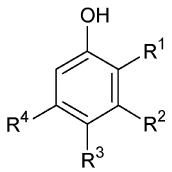
[a] Isolated yield of the corresponding acylated product.
[b] A 1.5 equiv. of Ac_2O was used.
[c] A 100% yield was obtained in carrying out the reaction at 80°C for 15 min.
[d] Isolated yield of the di-acetate.
[e] Isolated yield of the tri-acetate.
[f] A 50% yield was obtained during the Mg(OTf) catalysed reaction.
[g] No appreciable acylation was observed during the $LiClO_4$ catalysed reaction.

required longer time to afford comparable results. The large steric factor associated with pivalic anhydride necessitates the use of 1.5 equiv. of the anhydride and higher temperature (entry 5). The combined effect of steric and electronic factors in benzoic anhydride might be the reason for the inferior results (entry 6) obtained as compared to propionic and iso-butyric anhydrides. Comparison of the results of entries 1 vs 2 and 6 vs 7 reveal that the catalytic effect of $Mg(ClO_4)_2$ is operative with anhydrides and not with acid halides justifying the coordinating mechanism involving **TS-I** for activation of the anhydride.

To explore the generality and scope, structurally diverse phenols, thiols, and amines were subjected to acylation catalysed by $Mg(ClO_4)_2$ (Table 4). The reaction could be carried out with 1 equiv. of Ac_2O at room temperature. Di- and tri-hydroxy aromatic compounds afforded the di- and tri-acetates, respectively, in excellent yields (entry 19–23). Substrates bearing ketone, ester, and cyano functionalities[29] are smoothly acetylated and no competitive Fries rearrangements[30] are observed. Acetylation of optically active substrates were efficiently carried out without any detrimental effect on the optical purity (entries 24 and 25). The reaction was found to be highly influenced by the steric and electronic factors associated with the substrate. The distinct difference in the rate of acetylation with 2- and 1-hydroxynaphthalenes (entries 1 and 2) may be explained as the result of steric inhibition of approach of the electrophile by the *peri* hydrogen of 1-hydroxynaphthalene. Sterically hindered substrates require longer time (entries 5–7). The longer time required for substrates bearing halogen or carbonyl group (8,9,11,13–18) may be explained due to the decreased nucleophilic property of the respective phenol as a result of moderately electron withdrawing nature of the substituents. The presence of the methyl group (entry 10) counterbalances the electronic withdrawing effect of the chlorine in enabling the reaction rate to be unaltered. Comparison of the results of entries 11 and 12 clearly indicates the influence of the electronic effect of the substituent on the rate of acylation. The longer reaction required for entry 18 compared to that of entry 17 could be explained as the result of electrostatic repulsion by the *ortho* carboxylic acid group in addition to its electron withdrawing effect. The inferior result obtained with thiazoline (entry 28) compared to other thiols (entries 26 and 27) reveals the decrease of nucleophilicity of the thiozoline due to the resonance of the sulfur with the imine moiety. The participation of the lone pair electrons of the sulfur in the thiazole ring of benzothiazole (entry 29) to impart aromatic character induces a strong electron withdrawing property on the thiozole moiety thereby reducing the nucleophilicity of the sulfhydryl group. In general, the very good nucleophilic property of amines makes acylation very facile so that acylation may be carried out without the need for a catalyst. However, the steric and electronic effect of the *ortho* NO_2 in 2-nitroaniline (entry 30) makes the NH_2 less nucleophilic necessitating the presence of $Mg(ClO_4)_2$ to afford acylated product. The presence of the additional *para* NO_2 group in 2,4-dinitroaniline (entry 31) reduces the nucleophilicity further requiring longer time.

As the presence of a strong electronic withdrawing group reduces the nucleophilicity of the phenolic substrate

Table 5. $Mg(ClO_4)_2$ catalyzed acylation of electron deficient phenols

Entry	Substrate	Time (h)	Yield (%)[a,b]
			
1	R^1=R^2=R^4=H; R^3=CN	0.25	100 (88)
2	R^1=NO_2; R^2=R^3=R^4=H	0.5	60
3	R^1=R^2=R^4=H; R^3=NO_2	0.25	95 (96)
4	R^1=R^3=R^4=H; R^2=NO_2	0.25	98 (94)
5	R^1=NO_2; R^2=R^3=H; R^4=Me	0.5	60
6	R^1=R^4=H; R^2=Me; R^3=NO_2	0.5	100
7	R^1=NO_2; R^2=R^4=H; R^3=Me	0.5	70

The substrate was treated with Ac_2O (1 equiv.) in the presence of $Mg(ClO_4)_2$ (1 mol%) under solvent free conditions at 80°C (Method A).

[a] Isolated yield of the corresponding acylated product.

[b] The figure in parenthesis is the corresponding yield in carrying out the reaction with Ac_2O (1 equiv.) in the presence of $Mg(ClO_4)_2$ (5 mol%) at room temperature for 1 h (Method B).

significantly, we planned to evaluate the catalytic efficiency of $Mg(ClO_4)_2$ during the acylation of phenols bearing strong electronic withdrawing groups such as NO_2 and CN (Table 5). Best results are obtained in using a 1 mol% of the catalyst at 80°C (Method A) or a 5 mol% of the catalyst at room temperature (Method B).

As a logical extension of this methodology, we further investigated the potential of $Mg(ClO_4)_2$ as a catalyst for the acylation of various alcohols (Table 6). Excellent chemoselectivity was observed in that secondary and tertiary alcohols did not experience any competitive dehydration (entries 5,6,9–11,15 and 17–23) and no rearrangement took

Table 6. $Mg(ClO_4)_2$ catalyzed acylation of alcohols

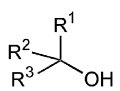
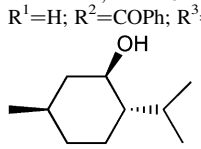
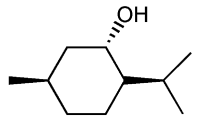
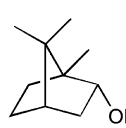
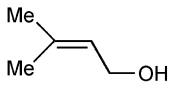
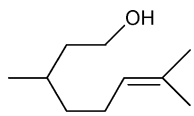
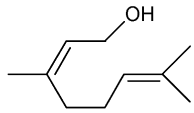
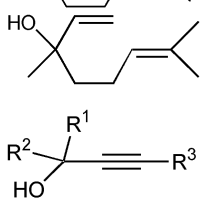
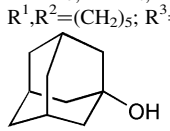
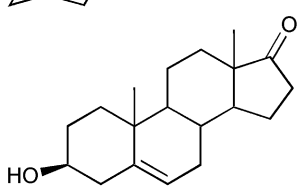
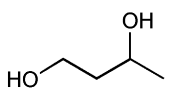
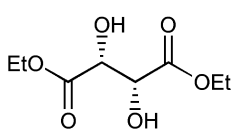
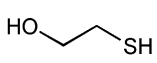
Entry	Substrate	Time (h)	Yield (%)[a]
			
1	R^1=R^2=H; R^3=Ph	0.25	100
2	R^1=R^2=H; R^3=H_2CPh	0.25	100
3	R^1=R^2=H; R^3=4-OMe-C_6H_4	0.25	63[b]
4	R^1=R^2=H; R^3=3,4-di-OMe-C_6H_3	0.25	62[c]
5	R^1=H; R^2=Me; R^3=Ph	0.25	95
6	R^1=R^2=R^3=Me	4	90
7	R^1=R^2=H; R^3=HC=CHPh	1	100[d]
8	R^1=H; R^2=COPh; R^3=Ph	1	89
9		0.5	100
10		0.5	100
11		1	100

Table 6 (*continued*)

Entry	Substrate	Time (h)	Yield (%)[a]
12		0.5	90
13		0.5	100
14		1	70
15		3	100[e]
16	R^1=R^2=R^3=H	0.5	100
17	R^1=R^2=Me; R^3=H	0.5	100
18	R^1=Me; R^2=Et; R^3=H	0.25	90
19	R^1,R^2=$(CH_2)_5$; R^3=H	0.5	100
20		0.33	100
21		0.5	90
22		1	95[f]
23		1	92[f]
24		1	87[f]

The substrate was treated with Ac_2O (1 equiv. per OH/SH except for entry 7 and 15) in the presence of $Mg(ClO_4)_2$ (1 mol%) under solvent free conditions at room temperature).

[a] Isolated yield of the corresponding acylated product.

[b] The GCMS data of the reaction mixture revealed the formation of 4,4′-dimethoxydibenzyl ether in 35% yield.

[c] The GCMS data of the reaction mixture revealed the formation of 3,3′,4,4′-tetramethoxydibenzylether in 30% yield.

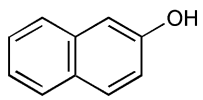
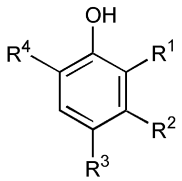
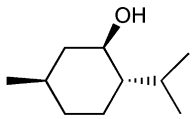
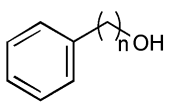
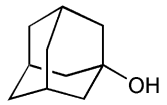
[d] The reaction was carried out with 2 equiv. of Ac_2O.

[e] The reaction was carried out with 3 equiv. of Ac_2O.

[f] Isolated yield of the corresponding di-acetate.

place for allylic and propargylic substrates (entries 7,12 and 15–19). However, 4-methoxybenzyl alcohol and 3,4-dimethoxybenzyl alcohol (entries 3 and 4) resulted in the formation of the corresponding dibenzyl ether in 35 and 30% yields, respectively, as revealed by the GCMS analyses of the reaction mixture. Optically active substrates were efficiently acylated without any detrimental effect on the optical purity (entries 9–11,21 and 23) demonstrating the mildness of the acylation process.

Table 7. $Mg(ClO_4)_2$ catalyzed benzoylation of phenols and alcohols

Entry	Substrate	Time (h)	Yield (%)[a]
1		0.5	82
			
2	$R^1=R^2=R^4=H$; $R^3=Cl$	0.75	85
3	$R^1=R^2=R^4=H$; $R^3=COMe$	0.75	75
4	$R^1=R^2=R^4=H$; $R^3=CN$	0.75	100
5	$R^1=R^2=R^4=H$; $R^3=NO_2$	0.75	80
6	$R^1=R^2=R^4=Me$; $R^3=H$	1	90
7	$R^1=R^3=R^4=Me$; $R^2=H$	1	80
8	$R^1=R^2=R^4=H$; $R^3=OH$	1	86[b]
9	$R^1=R^3=R^4=H$; $R^2=OH$	1	68[b]
10	$R^1=OH$; $R^2=R^3=R^4=H$	1	82[b]
11		0.5	80
			
12	$n=1$	0.5	80
13	$n=2$	0.5	85
14		1	70

The substrate was treated with $(PhCO)_2O$ (1 equiv. per OH group except for entries 8–10) in the presence of $Mg(ClO_4)_2$ (1 mol%) under solvent free conditions at 80°C.

[a] Isolated yield of the corresponding benzoylated product.

[b] The reaction was carried out with 1.2 equiv. of $(PhCO)_2O$ per OH group.

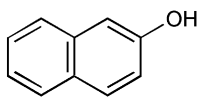
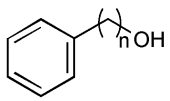
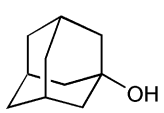
The strong Lewis acid character of the metal triflates makes them unsuitable for use in acylation of acid-sensitive substrates. This is exemplified by the necessity of use of large excess of Ac_2O and/or low temperature (−50 to −20°C) to suppress the competitive side reactions (e.g. dehydration and rearrangement) during the acylation of 1-ethynyl-1-cyclohexanol and 3-methyl-1-pentyn-3-ol. The superiority of $Mg(ClO_4)_2$ over the metal triflates during acylation of alcohols may be best demonstrated through comparison of the results of a few representative examples of acid-sensitive and sterically hindered substrates. Thus, the $Sc(OTf)_3$ catalysed[6] acetylation of linalool used Ac_2O as solvent at −20°C providing a 68% yield of the expected product along with a 8% yield of the rearrangement product and the TMSOTf catalysed[8] reaction failed to produce any expected product. Use of $Mg(ClO_4)_2$ resulted in 100% yield of the desired product with 3 equiv. of Ac_2O in the absence of solvent at room temperature without any concomitant formation of the rearranged product (entry 15, Table 6). Acetylation 1-ethynylcyclohexanol catalysed by $Sc(OTf)_3$, $Bi(OTf)_3$ and TMSOTf require 10 equiv. of Ac_2O and MeCN/DCM as co-solvent affording 94, 88, and 68% yields, respectively.[9b] On the contrary to these, a 100% yield of the product could be obtained with 1 equiv. of Ac_2O under neat conditions in the presence of $Mg(ClO_4)_2$ (entry 19, Table 6). Quantitative acylation of 3-methyl-1-pentyn-3-ol takes place with a stoichiometric amount of Ac_2O in the absence of solvent at room temperature under the catalytic influence of $Mg(ClO_4)_2$ (entry 18, Table 6) but the corresponding TMSOTf catalysed[8] reaction require 2 equiv. of Ac_2O in DCM at 0°C to afford 80% yield. Acetylation of sterically hindered *endo*-borneol involves the use of 10 equiv. of Ac_2O in THF for 7 h in the presence of TMSOTf and the corresponding $Bi(OTf)_3$ catalysed reaction uses 10 equiv. of Ac_2O in THF to afford a 99% yield in 7 h.[9b] In contrary, the $Mg(ClO_4)_2$ catalysed reaction afforded comparable results in 0.33 h with 1 equiv. of Ac_2O in the absence of solvent (entry 11, Table 6).

The phenyl group in benzoic anhydride makes it less susceptible to nucleophilic attack due to the steric and electronic effects of the phenyl ring. Thus, to evaluate the catalytic efficiency of $Mg(ClO_4)_2$ during the benzoylation reaction a few selected phenols and alcohols were treated with benzoic anhydride under the catalytic influence of $Mg(ClO_4)_2$ (Table 7).

As the increase of the steric crowding around the carbonyl group of the anhydride is expected to retard the nucleophilic attack at the anhydride, we planned to evaluate the efficiency of $Mg(ClO_4)_2$ during the treatment of phenols and alcohols with pivalic anhydride (Table 8).

In conclusions, $Mg(ClO_4)_2$ is an efficient catalyst for acylation of structurally diverse phenols, thiols, alcohols and amines. Acetylation, benzoylation, and pivalation of electron deficient phenols, sterically hindered phenols/alcohols,

Table 8. $Mg(ClO_4)_2$ catalyzed pivalation of phenols and alcohols

Entry	Substrate	Yield (%)[a,b]
1		97 (95)[c]
		
2	$n=1$	85 (80)
3	$n=2$	87 (82)
4		85 (90)
5		72 (80)

The substrate was treated with pivalic anhydride (1.5 equiv. per OH group) in the presence of $Mg(ClO_4)_2$ (1 mol%) under solvent free conditions at 80°C for 1 h.

[a] Isolated yield of the corresponding pivalate.

[b] The figures in parenthesis are the yield of the corresponding reaction carried out in DCM at room temperature for 3 h.

[c] A 78% yield was obtained in carrying out the reaction at room temperature under neat conditions for 1 h.

and acid-sensitive alcohols are carried out efficiently under solvent free conditions. The low cost and with increasing environmental concern[31] the solvent free condition employed in the present method will make it 'environmentally friendly' and potentially useful for industrial applications.

Finally, it may be mentioned that the potential explosiveness of perchlorates, when heated in the presence of combustible substances at high temperature,[32] has prevented their industrial use[33] especially when large amounts of these compounds are involved and therefore care should be taken while handling perchlorates under such conditions. However, some perchlorate salts have high thermal stability.[33] For example, $LiClO_4$ is thermally stable at or above its melting point of 247°C and can be dried under vacuum at 160°C for prolonged period (~50 h).[34] No LD_{50}/LC_{50} information of $Mg(ClO_4)_2$ is known relating to normal routes of occupational exposure,[35] and the LD_{50} (intraperitoneal mouse) value of 1500 mg/kg[36] does not make it particularly poisonous. Thus, in the present work the requirement of catalytic quantities of $Mg(ClO_4)_2$, its use mostly in the absence of combustible substances (e.g. solvent), and the mild reaction conditions employed (room temperature to 80°C i.e. far below the melting point of 251°C of magnesium perchlorate) should circumvent the problem of potential hazard associated with perchlorates and make the methodology suitable for large scale synthesis.

1. Experimental

The ^1H and ^{13}C NMR spectra were recorded on Bruker Avance DPX 300 (300 MHz) spectrometer in $CDCl_3$ using TMS as internal standard. The IR spectra were recorded on Nicolet Impact 400 spectrometer as KBr pellets for solid and neat for liquid samples. The reactions were monitored by TLC (silica gel-G) and Shimadzu QP 5000 GCMS. Wherever, necessary, inert atmosphere for carrying out the reaction was maintained using dry nitrogen or argon using flame dried glasswares. Evaporation of solvents was performed at reduced pressure, using a Buchi rotary evaporator.

1.1. General procedure for acylation. Representative procedure for acetylation

2-Hydroxynaphthalene (**1**) (360 mg, 2.5 mmol) was treated with Ac_2O (0.24 mL, 2.5 mmol) in the absence of solvent at room temperature for 15 min under magnetic stirring in the presence of $Mg(ClO_4)_2$ (5.6 mg, 0.025 mmol, 1 mol%). The reaction mixture was extracted with DCM to afford the product (465.5 mg, 100%), which was in full agreement with the spectral data (mp, IR, ^1H NMR and EIMS) of an authentic sample of 2-acetoxynaphthalene.[37b]

1.2. Representative procedure for pivalation

2-Hydroxynaphthalene (**1**) (360 mg, 2.5 mmol) was treated with $(^tBuCO)_2O$ (0.51 mL, 3.75 mmol) in the absence of solvent at 80°C for 1 h under magnetic stirring in the presence of $Mg(ClO_4)_2$ (5.6 mg, 0.025 mmol, 1 mol%). The reaction mixture was extracted with DCM to afford the product (428 mg, 75%), which was in full agreement with the spectral data (mp, IR, ^1H NMR and EIMS) of an authentic sample of 2′-naphthyl 2,2,2-trimethylacetate.[38]

1.3. Representative procedure for benzoylation

4-Nitrophenol (348 mg, 2.5 mmol) was treated with $(PhCO)_2O$ (565 mg, 2.5 mmol) in the absence of solvent at 80°C for 45 min under magnetic stirring in the presence of $Mg(ClO_4)_2$ (5.6 mg, 0.025 mmol, 1 mol%). The reaction mixture was extracted with DCM to afford the product (486 mg, 80%), which was in full agreement with the spectral data (mp, IR, ^1H NMR and EIMS) of an authentic sample of 4-nitrophenyl benzoate.[39]

The ^1H NMR and IR spectra of the following compounds were in complete agreement with those of the authentic samples: 2-naphthyl acetate,[37b] 2-naphthyl propionate,[40] 2′-naphthyl 2,2-dimethylacetate,[41] 2-naphthyl benzoate,[42] 1-naphthyl acetate,[37b] 4-methylphenyl acetate, 4-methoxyphenyl acetate,[14] 2,4,6-trimethylphenyl acetate,[9b] 2,6-di-*tert*-butyl-4-methyl phenyl acetate,[6] 4-bromophenyl acetate,[10] 4-chlorophenyl acetate,[39] 4-acetoxyacetophenone,[42] methyl-4-acetoxybenzoate,[37b] 4-acetoxybenzoic acid,[37b] 2-acetoxybenzoic acid,[37b] benzene-1,2-diyl diacetate,[9d] benzene-1,3-diyl diacetate,[37b] benzene-1,4-diyl diacetate,[37b] benzene-1,2,3-triyl triacetate,[42] *N*,*O*-diacetyl-L-tyrosine ethyl ester,[43] *N*-benzoyl-*O*-acetyl-L-tyrosine ethyl ester,[43] *S*-phenyl thioacetate,[37b] *S*-(4-methyl)phenyl thioacetate,[5] 2-nitroacetanilide,[42] 2,4-dinitroacetanilide,[42] 4-cyanophenyl acetate,[44] 2-nitrophenyl acetate,[9d] 3-nitrophenyl acetate,[14] 4-nitrophenyl acetate,[37b] 4-methyl-2-nitrophenyl acetate,[45] benzyl acetate,[37b] 2-phenethyl acetate,[9a] 1-phenethyl acetate,[6] 3,4-dimethoxybenzylacetate,[46] *tert*-butyl acetate,[14] cinnamyl acetate,[9d] 2-acetoxy-2-phenylacetophenone,[9a] (1*R*)-(−) menthyl acetate,[10] (−)-bornyl acetate,[29a] 2-butene-3-methyl-1-yl acetate,[47,48] β-citronellyl acetate,[42] geranyl acetate,[37a] linalyl acetate, 2-propyn-1-yl acetate,[42] 3-butyne-2-methyl-2-yl acetate,[13] 1-pentyne-3-methyl-3-yl acetate,[8] 1-ethynylcyclohexyl-1-yl acetate,[6] 1-adamantanyl acetate,[9a] 3β-acetoxy-5-androsten-17-one,[49] 1, 3-diacetoxybutane,[10b] 1-acetoxy-ethane-2-thioacetate,[14,16] 4-chlorophenyl benzoate,[39] 4-acetylphenyl benzoate,[39] 4-cyanophenyl benzoate,[39] 4-nitrophenyl benzoate,[39] 2,4,6-trimethyphenyl benzoate,[6b] benzene-1,2-diyl dibenzoate,[9d] benzene-1,3-diyl dibenzoate,[9d] benzene-1,4-diyl dibenzoate,[9d] (1*R*)-(−) menthyl benzoate,[9b] benzyl benzoate,[9b] 2-phenethyl benzoate,[9b] benzyl pivalate,[9b] 2-phenethyl pivalate,[9b] (−)-bornyl pivalate,[9b] 1-adamantanyl pivalate.[9d] Newly generated physical data of the acylated products, prepared following reported procedures, are given below.

1.4. Physical data

1.4.1. 1-Adamantyl benzoate (Table 7, entry 14).[50] IR (KBr) 1706 cm^{-1}; ^1H NMR δ 1.66 (s, 6H), 2.26 (s, 9H), 7.38–7.4 (m, 2H), 7.50–7.54 (m, 1H), 7.98 (d, J=6.8 Hz, 2H).

1.4.2. 3-Methyl-4-nitrophenylacetate (Table 5, entry 6).[51] IR (neat) 1766 cm^{-1}; ^1H NMR δ 2.33 (s, 3H), 2.62 (s, 3H), 7.08–7.11 (m, 2H), 8.06 (d, J=9.55 Hz, 1H); ^{13}C

NMR δ 20.3, 20.6, 119.8, 125.3, 126.1, 135.6, 145.9, 153.4, 168.3; EIMS (*m/z*) 195 (M^+), 43 (100).

1.4.3. 3-Acetylphenylacetate (Table 4, entry 12).[52] IR (neat) 1767, 1687 cm^{-1}; ^1H NMR δ 2.33 (s, 3H), 2.60 (s, 3H), 7.68 (s, 1H), 7.31 (d, *J*=8.0 Hz, 1H), 7.45–7.48 (m, 1H), 7.83 (d, *J*=8.0 Hz, 1H); ^{13}C NMR δ 20.6, 26.3, 121.1, 125.4, 126.1, 129.3, 138.1, 150.6, 168.9, 196.8; EIMS (*m/z*) 178 (M^+), 121 (100).

1.4.4. 4-Methoxybenzylacetate (Table 6, entry 3).[40] IR (neat) 1720 cm^{-1}; ^1H NMR δ 2.05 (s, 3H), 3.78 (s, 3H), 5.02 (s, 2H), 6.87 (d, *J*=8 Hz, 2H), 7.27 (d, *J*=8 Hz, 2H); ^{13}C NMR δ 20.9, 55.1, 64.7, 113.6, 129.3, 130.3, 159.0, 170.9; EIMS 180 (M^+), 121 (100).

1.4.5. 4-Chloro-3-methyl-phenylacetate (Table 4, entry 10).[39] IR (neat) 1764 cm^{-1}; ^1H NMR δ 2.28 (s, 3H), 2.36 (s, 3H), 6.97 (s, 1H), 6.87 (d, *J*=8.5 Hz, 1H), 7.32 (d, *J*=8.5 Hz, 1H); ^{13}C NMR δ 20.1, 20.9, 120.2, 123.8, 129.6, 131.3, 137.3, 148.9, 169.3; EIMS (*m/z*) 184 (M^+), 142 (100).

1.4.6. 1,3-diacetoxybutane (Table 6, entry 22).[10b] IR (neat) 1740 cm^{-1}; ^1H NMR δ 1.25 (d, *J*=6.2 Hz, 3H), 1.90 (m, 2H), 2.1 (s, 6H), 4.11 (t, *J*=6.3 Hz, 2H), 5.01 (q, *J*=6.3 Hz, 1H); ^{13}C NMR δ 19.9, 20.7, 21.1, 34.6, 60.6, 67.7, 170.4, 170.8.

The following acylated products were not reported in the literature.

1.4.7. 2,3,6-Trimethylphenyl acetate (Table 4, entry 6). Oil. IR (neat) 1761 cm^{-1}; ^1H NMR δ 2.04 (s, 3H), 2.16 (s, 3H), 2.23 (s, 3H), 2.31 (s, 3H), 6.93 (s, 2H); ^{13}C NMR δ 12.4, 16.1, 19.6, 20.3, 127.1, 127.5, 128.4, 135.4, 147.9, 168.8; EIMS (*m/z*) 178 (M^+), 135 (100). CHN Anal. calcd for $C_{11}H_{14}O_2$: C 74.15, H 7.86. Found: C 74.45, H 7.66.

1.4.8. 2-Acetylphenyl acetate (Table 4, entry 13). Light yellow crystal, mp 89–92°C; IR (KBr) 1756, 1684 cm^{-1}; ^1H NMR δ 2.32 (s, 3H), 2.52 (s, 3H), 7.10 (d, *J*=8.0 Hz, 1H), 7.28 (t, *J*=7.6 Hz, 1H), 7.50 (t, *J*=7.7 Hz, 1H), 7.78 (d, *J*=7.8 Hz, 1H); ^{13}C NMR δ 20.9, 29.1, 123.6, 125.8, 130.1, 130.5, 133.2, 148.8, 169.2, 197.3; EIMS (*m/z*) 178 (M^+), 43 (100). CHN Anal. calcd for $C_{10}H_{10}O_3$: C 67.42, H 5.62. Found: C 67.75, H 5.50.

1.4.9. Ethyl-4-acetoxybenzoate (Table 4, entry 15). Oil. IR (neat) 1762, 1717 cm^{-1}; ^1H NMR δ 1.38 (t, *J*=7.1 Hz, 3H), 2.30 (s, 3H), 4.35 (q, *J*=7.1 Hz, 2H), 7.15 (d, *J*=8.6 Hz, 2H), 8.06 (d, *J*=8.6 Hz, 2H); ^{13}C NMR δ 14.1, 20.9, 61.0, 121.4, 127.8, 131.0, 154.1, 165.8, 168.8; EIMS (*m/z*) 208 (M^+), 121 (100). CHN Anal. calcd for $C_{11}H_{12}O_4$: C 63.46, H 5.76. Found: C 63.8, H 6.14.

1.4.10. *n*-Propyl-4-acetoxybenzoate (Table 4, entry 16). Oil. IR (neat) 1762, 1717 cm^{-1}; ^1H NMR δ 1.02 (t, *J*=7.4 Hz, 3H), 1.73–1.89 (m, 2H), 2.3 (s, 3H), 4.26 (t, *J*=7.4 Hz, 2H), 7.18 (d, *J*=8.6 Hz, 2H), 8.01 (d, *J*=8.6 Hz, 2H); ^{13}C NMR δ 10.4, 21.1, 22.0, 66.6, 121.5, 128.0, 131.0, 154.1, 165.9, 168.9; EIMS (*m/z*) 222 (M^+), 43 (100). CHN Anal. calcd for $C_{12}H_{14}O_4$: C 64.86, H 6.36. Found: C 64.8, H 6.34.

1.4.11. 2,4-Diacetoxy acetophenone (Table 4, entry 22). Oil. IR (neat) 1770, 1688 cm^{-1}; ^1H NMR δ 2.31 (s, 3H), 2.34 (s, 3H), 2.54 (s, 3H), 6.96 (d, *J*=2.1 Hz, 1H), 7.10 (dd, *J*=2.1, 8.5 Hz, 1H), 7.84 (d, *J*=8.5 Hz, 1H); ^{13}C NMR δ 21.1, 29.3, 117.3, 119.1, 128.0, 131.3, 150.0, 153.9, 168.3, 169.0, 196.3; EIMS (*m/z*) 236 (M^+), 43 (100). CHN Anal. calcd for $C_{12}H_{12}O_5$: C 61.02, H 5.08. Found: C 61.15, H 5.05.

1.4.12. 5-Methyl-2-nitrophenylacetate (Table 5, entry 5). Oil. IR (neat) 1775 cm^{-1}; ^1H NMR δ 2.37 (s, 3H), 2.44 (s, 3H), 7.03 (s, 1H), 7.18 (d, *J*=8.2 Hz, 1H), 8.02 (d, *J*=8.2 Hz, 1H); ^{13}C NMR δ 20.3, 20.9, 125.2, 125.3, 127.0, 138.9, 143.7, 146.6, 168.4; EIMS (*m/z*) 195 (M^+), 43 (100). CHN Anal. calcd for $C_9H_9NO_4$: C 55.38, H 4.6, N 7.17. Found: C 54.99, H 4.54, 6, N 7.12.

1.4.13. 2-Mercaptothiazolylacetate (Table 4, entry 28). Oil. IR (neat) 1694 cm^{-1}; ^1H NMR δ 2.76 (s, 3H), 3.35 (t, *J*=7.55 Hz, 2H), 4.59 (t, *J*=7.53 Hz, 2H); ^{13}C NMR δ 26.6, 27.9, 55.3, 87.9, 201.6; EIMS (*m/z*) 152 (M^+), 43 (100). CHN Anal. calcd for $C_5H_7NOS_2$: C 37.2, H 4.34, N 8.69, S 39.6. Found: C 37.2, H 4.31, N 8.54, S 39.6.

1.4.14. Isomenthyl acetate (Table 6, entry 10). Oil. $[\alpha]_D^{25}$=+30 (*c*=10, C_6H_6); IR (neat) 1708 cm^{-1}; ^1H NMR δ 0.85 (d, 3H, *J*=7 Hz), 0.93 (m, 6H), 1.24–1.87 (m, 9H), 2.03 (s, 3H), 4.99–5.05 (m, 1H); ^{13}C NMR δ 18.9, 20.4, 20.8, 21.4, 26.2, 27.5, 29.9, 35.8, 45.8, 71.6, 170.6; EIMS (*m/z*) 138 (M−57), 43 (100). CHN Anal. calcd for $C_{12}H_{22}O_2$: C 72.73, H 11.11. Found: C 72.67, H 11.02.

1.4.15. Diacetoxy diethyl tartarate (Table 6, entry 23). White crystal, mp 65–68°C; $[\alpha]_D^{25}$=−4.8 (*c*=1, DCM), −4.0 (*c*=1, EtOH); IR (KBr) 1759 cm^{-1}; ^1H NMR δ 1.27 (t, *J*=7 Hz, 6H), 2.17 (s, 6H), 4.25 (q, *J*=7 Hz, 4H), 5.71 (s, 2H); ^{13}C NMR δ 14.0, 20.2, 62.2, 70.5, 165.7, 169.5. CHN Anal. calcd for $C_{12}H_{18}O_8$: C 49.66, H 6.21. Found: C 49.50, H 6.53.

1.4.16. 2,3,6-Trimethylphenyl-benzoate (Table 7, entry 6). White crystal, mp 55–58°C; IR (KBr) 1734 cm^{-1}; ^1H NMR δ 2.08 (s, 3H), 2.15 (s, 3H), 2.27 (s, 3H), 6.99 (s, 2H), 7.50 (t, *J*=7.5 Hz, 2H), 7.63 (t, *J*=7.4 Hz, 1H), 8.25 (d, *J*=7.2 Hz, 2H); ^{13}C NMR δ 12.6, 16.3, 19.8, 127.2, 127.4, 127.64, 128.5, 129.3, 130.1, 133.5, 135.6, 148.1, 164.5; EIMS (*m/z*) 240 (M^+), 105 (100). CHN Anal. calcd for $C_{16}H_{16}O_2$: C 80.00, H 6.67. Found: C 80.22, H 6.52.

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References

1. (a) Greene, T. W.; Wuts, P. G. M. *Protective Groups in Organic Synthesis*; Wiley: New York, 1999. (b) Hanson, J. R. *Protective Groups in Organic Synthesis*; Blackwell Science: Malden, MA, 1999.

2. (a) Chakraborti, A. K.; Nayak, M. K.; Sharma, L. *J. Org. Chem.* **2002**, *67*, 1776–1780. (b) Chakraborti, A. K.; Nayak, M. K.; Sharma, L. *J. Org. Chem.* **2002**, *67*, 2541–2547. (c) Chakraborti, A. K.; Sharma, L.; Sharma, U. *Tetrahedron* **2001**, *57*, 9343–9346. (d) Chakraborti, A. K.; Nayak, M. K.; Sharma, L. *J. Org. Chem.* **1999**, *64*, 8027–8030.
3. Steglich, W.; Hofle, G. *Angew. Chem., Int. Ed. Engl.* **1969**, *8*, 981.
4. Vedejs, E.; Diver, T. S. *J. Am. Chem. Soc.* **1993**, *115*, 3358–3359.
5. (a) Iqbal, J.; Srivastava, R. *J. Org. Chem.* **1992**, *57*, 2001–2007. (b) Ahmed, S.; Iqbal, J. *Tetrahedron Lett.* **1986**, *27*, 3791–3794.
6. (a) Ishihara, K.; Kubota, M.; Kurihara, H.; Yamamoto, H. *J. Am. Chem. Soc.* **1995**, *117*, 4413–4414. (b) Ishihara, K.; Kubota, M.; Kurihara, H.; Yamamoto, H. *J. Org. Chem.* **1996**, *61*, 4560–4567.
7. Ishihara, K.; Kubota, M.; Yamamoto, H. *Synlett* **1996**, 265–266.
8. (a) Procopiou, P. A.; Baugh, S. P. D.; Flack, S. S.; Inglis, G. G. A. *J. Org. Chem.* **1998**, *63*, 2342–2347. (b) Procopiou, P. A.; Baugh, S. P. D.; Flack, S. S.; Inglis, G. G. A. *Chem. Commun.* **1996**, 2625–2626.
9. (a) Orita, A.; Tanahashi, C.; Kakuda, A.; Otera, J. *Angew. Chem., Int. Ed. Engl.* **2000**, *39*, 2877–2879. (b) Orita, A.; Tanahashi, C.; Kakuda, A.; Otera, J. *J. Org. Chem.* **2001**, *66*, 8926–8934. (c) Carrigan, M. D.; Freiberg, D. A.; Smith, R. C.; Zerth, H. M.; Mohan, R. S. *Synthesis* **2001**, 2091–2093. (d) Mohammadpoor-Baltrok, I.; Aliyan, H.; Khosropour, A. R. *Tetrahedron* **2001**, *57*, 5851–5854.
10. (a) Saravanan, P.; Singh, V. K. *Tetrahedron Lett.* **1999**, *40*, 2611–2614. (b) Chandra, K. L.; Saravanan, P.; Singh, R. K.; Singh, V. K. *Tetrahedron* **2002**, *58*, 1369–1374.
11. Chauhan, K. K.; Frost, C. G.; Love, I.; Waite, D. *Synlett* **1999**, 1743–1744.
12. Chandrasekhar, S.; Ramachander, T.; Takhi, M. *Tetrahedron Lett.* **1998**, *39*, 3263–3266.
13. Ballini, R.; Bosica, G.; Carloni, S.; Ciaralli, L.; Maggi, R.; Sartori, G. *Tetrahedron Lett.* **1998**, *39*, 6049–6052.
14. Li, A.-X.; Li, T.-S.; Ding, T.-H. *Chem. Commun* **1997**, 1389–1390.
15. Kumareswaran, R.; Pachamuthu, K.; Vankar, Y. D. *Synlett* **2000**, 1652–1654.
16. Kumar, P.; Pandey, R. K.; Bodas, M. S.; Dongare, M. K. *Synlett* **2001**, 206–209.
17. Chakraborti, A. K.; Gulhane, R. *Tetrahedron Lett.* **2003**, *44*, 3521–3525.
18. Olah, G. A.; Prakash, G. K. S. *Superacids*; Wiley: New York, 1985.
19. Jarowicki, K.; Kocienski, P. *Contemp. Org. Synth.* **1997**, 454.
20. Weinstein, S.; Smith, S.; Darwish, D. *J. Am. Chem. Soc.* **1959**, *81*, 5511–5512.
21. Pocker, Y.; Buchholz, R. F. *J. Am. Chem. Soc.* **1970**, *92*, 2075–2084.
22. Springer, G.; Elam, C.; Edwards, A.; Bowe, C.; Boyles, D.; Bartmess, J.; Chandler, M.; West, K.; Williams, J.; Green, J.; Pagni, R. M.; Kabalka, G. W. *J. Org. Chem.* **1999**, *64*, 2202–2210.
23. Nakae, Y.; Kusaki, I.; Sato, T. *Synlett* **2001**, 1584–1586.
24. Huheey, J. E. *Inorganic Chemistry: Principles of Structure and Reactivity*; 3rd ed. Harper & Row: Singapore, 1983.
25. Lessene, G.; Tripoli, R.; Cazeau, P.; Biran, C.; Bordeau, M. *Tetrehedron Lett.* **1999**, *40*, 4037–4040.
26. Ireland, R. E.; Mueller, R. H.; Willard, A. K. *J. Am. Chem. Soc.* **1976**, *98*, 2868–2877.
27. After the present study was completed a related work appeared in the literature wherein $Mg(ClO_4)_2$, preserved as a stock solution in Ac_2O, has been used as catalyst; Bartoli, G.; Bosco, M.; Dalpozzo, R.; Marcantoni, E.; Massaccesi, M.; Rinaldi, S.; Sambri, L. *Synlett* **2003**, 39–42.
28. Casaschi, A.; Desimoni, G.; Faita, G.; Invernizzi, A. G.; Lanati, S.; Righetti, P. P. *J. Am. Chem. Soc.* **1993**, *115*, 8002–8007.
29. Reaction with 4-hydroxybenzaldehyde resulted in a mixture of 4-acetoxybenzaldehyde, 4-hydroxybenzaldehyde-1,1-diacetate, and 4-acetoxybenzaldehyde-1,1-diacetate.
30. Harrowven, D. C.; Dainty, R. F. *Tetrahedron Lett.* **1996**, *37*, 7659–7660.
31. Garrett, R. L. In *Designing Safer Chemicals*; *American Chemical Society Synposium Series 640*; Garrett, R. L., De Vito, S. C., Eds. 1996; Chapter 1.
32. Schumacher, J. C. *Perchlorates—Their Properties, Manufacture and Uses*; *ACS Monograph Series*; Reinhold: New York, 1960.
33. Long, J. *Chemical Health and Safety* **2002**, *9*, 12–18.
34. Grieco, P. A.; Nunes, J. J.; Gaul, M. D. *J. Am. Chem. Soc.* **1990**, *112*, 4595–4596.
35. http://www.jtbacker.com/msds/englishhtml/a6648.htm.
36. Material Safety Data Sheet, No. 4240-2141; Bacharach Inc.: Pittsburgh, PA, USA.
37. (a) Pouchart, C. J.; Jacqlynn, B.; I ed. *The Aldrich Libraray of ^{13}C and ^{1}H FT NMR Spectra*; Aldrich Chemical: Milwauke, 1993; Vol. I. (b) Pouchart, C. J.; Jacqlynn, B.; I ed. *The Aldrich Libraray of ^{13}C and ^{1}H FT NMR Spectra*; Aldrich Chemical: Milwauke, 1993; Vol. II.
38. Parish, R. C.; Stock, L. M. *J. Org. Chem.* **1965**, *30*, 927–929.
39. Furniss, B. S.; Hannaford, A. J.; Smith, P. W. G.; Tatchell, A. R. *Vogel's Textbook of Practical Organic Chemistry*; 5th ed. Longman: Singapore, 1989.
40. Prashad, M.; Jigajinni, V. B. *Indian J. Chem* **1980**, *19B*, 822–823.
41. Lowrance, W. W., Jr. *Tetrahedron Lett.* **1971**, 3453–3454.
42. Cirovic, M. M. *Properties of Organic Compounds*; CRC, 1996; POC-personal edn, version 5.1.
43. Kahns, A. H.; Bundgaard, H. *Int. J. Pharm.* **1991**, *76*, 99–112.
44. Alves, K. B.; Bastos, M. P.; Amaral, L. *J. Org. Chem.* **1978**, *43*, 4032–4038.
45. Ridd, J. H.; Travellick, S.; Sandall, J. P. B. *J. Chem. Soc. Perkin Trans. 2* **1992**, 1535–1540.
46. Pincock, J. A.; Wedge, P. J. *J. Org. Chem.* **1994**, *59*, 5587–5595.
47. Ward, J. L.; Beale, M. H. *J. Chem. Soc., Perkin Trans. 1* **2002**, 710–712.
48. Kann, N.; Rein, T.; Akermark, B.; Helquist, P. *J. Org. Chem.* **1990**, *55*, 5312–5323.
49. Karimi, B.; Serdj, H. *Synlett* **2001**, 519–520.
50. Brown, L.; Koreeda, M. *J. Org. Chem.* **1984**, *49*, 3875–3880.
51. Corre, M. L.; Hercooet, A.; Stanc, Y. L.; Baron, H. L. *Tetrahedron* **1985**, *41*, 5313–5320.
52. Maude, A. B.; Williams, A. *J. Chem. Soc. Perkin Trans. 2* **1997**, 179–183.