Synthetic Communications: An International Journal for Rapid Communication of Synthetic Organic Chemistry
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/lsyc20

Simple and Efficient Procedure for the Friedel-Crafts Acylation of Aromatic Compounds with Carboxylic Acids in the Presence of P_2O_5/AL_2O_3 Under Heterogeneous Conditions

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Published online: 26 Jun 2009.

Synthetic Communications®, 39: 2702–2722, 2009

ISSN: 0039-7911 print/1532-2432 online
DOI: 10.1080/00397910802663436

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Simple and Efficient Procedure for the Friedel–Crafts Acylation of Aromatic Compounds with Carboxylic Acids in the Presence of P_2O_5/AL_2O_3 Under Heterogeneous Conditions

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Abstract: An efficient and chemoselective method for the Friedel–Crafts acylation of aromatic compounds using P_2O_5/Al_2O_3 and carboxylic acids. Both aromatic and aliphatic carboxylic acids reacted easily to afford the corresponding aromatic ketones in good yields.

Keywords: Carboxylic acids, Friedel–Crafts, P_2O_5/Al_2O_3

INTRODUCTION

Friedel–Crafts acylation is one of the most important methods to prepare aromatic ketones used in manufacturing fine and specialty chemicals as well as pharmaceuticals.[1] The disadvantages associated with the classical procedures include the use of toxic acid chlorides or acid anhydrates as

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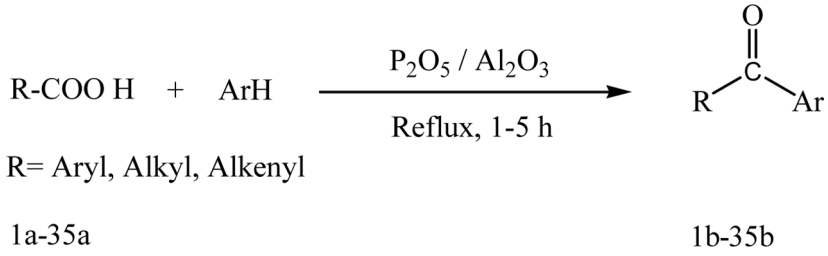
acylating agents and an excess amount of aluminum trichloride as a Lewis acid, which entails environment pollution and tedious workup. To minimize this problem, some catalytic Friedel–Crafts acylations have been developed recently.[2] Using carboxylic acids as acylating agents is a superior method with respect to the procedures utilizing acyl chlorides and anhydrides for the synthesis of aryl ketones. Carboxylic acids are stable, less toxic, and more available compounds, and their handling is much easier than that of their corresponding acyl chlorides and anhydrides. Zeolites,[3] heteropolyacids and their salts,[4] clay,[5] alumina/trifluoroacetic anhydride (TFAA),[6] $MeSO_3H$/graphite,[7] and Lewis acids[8] are reported to catalyze Friedel–Crafts acylation using carboxylic acids as acylating agents. However, the catalytic efficiency and/or applicable substrate range are very limited. For instance, a methodology of acylation of anisole with carboxylic acids over HZSM-5 zeolite, although environmentally safe, has limitations with regard to generality (no reaction with higher acids) and efficiency (reaction time of 48 h and concomitant O-acylation).[3c] Thus, a reliable general method for this useful reaction involving nonhazardous reagents is in demand.

RESULTS AND DISCUSSION

Recently, the use of catalysts and reagents on solid supports was developed because such reagents not only simplify purification processes but also help to prevent release of reaction residues into the environment. This has led to growth in the field of solid supported on alumina.[9] Although there are many reports of using phosphorus pentoxide as a reagent in organic reactions,[10] P_2O_5 is difficult to handle because of its moisture sensitivity at room temperature. P_2O_5 on alumina (P_2O_5/Al_2O_3) is easy to prepare and handle and also is a useful reagent that could be removed from the reaction mixture by simple filtration.[11] Herein, we report an efficient, convenient, and chemoselective procedure for the conversion of carboxylic acids to the corresponding aryl ketones in the presence of P_2O_5/Al_2O_3. These reactions are easily carried out under heterogeneous and reflux conditions (Scheme 1).

The acylation reactions were carried out by heating a stirring mixture of the corresponding carboxylic acids, P_2O_5/Al_2O_3, and aromatic compounds such as toluene, *p*-xylene, *m*-xylene, mesitylene, thiophene, bromobenzene, chlorobenzene, and nitrobenzene under reflux conditions. However, for the compounds such as anisole, 1,3-dimethoxybenzene, 2-methoxynaphtalene, naphthalene, anthracene, 2-methylthiophene, thioanisole, and biphenyl, the acylation reactions were carried out in 1,2-dichloroethane under reflux conditions. The products were isolated

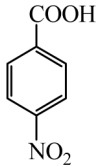
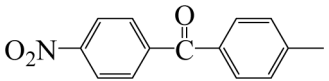
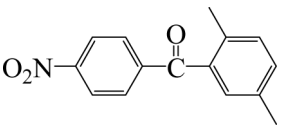
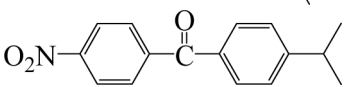
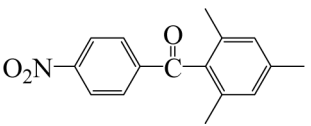
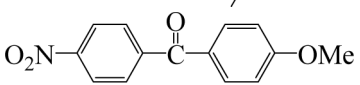
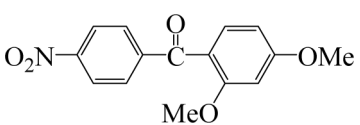


Scheme 1. Friedel–Crafts acylation of aromatic compounds.

by simple filtration of the reaction mixture and then by usual workup. Different structures of aromatic rings underwent acylation with a wide rang of carboxylic acids. These reaction conditions were successfully applied for the preparation of different aryl ketones from electron-rich and electron-poor aromatic compounds. The results of this study are presented in Table 1. The reactions are remarkably clean, convenient, and no chromatographic separation is necessary to get the spectra-pure compounds except in few cases (Table 1, entries 26, 28, 29). By using this reagent, acylation occurs at the para position with high selectivity. However, in cases where the para positions are blocked (Table 1, entries 2, 14), the acyl group is introduced ortho to the substituted groups on aromatic rings. This procedure is also good enough for the acylation of heterocyclic aromatic compounds such as thiophene and 2-methyltiophene (Table 1, entries 8, 17), as well as polycyclic aromatic hydrocarbons (Table 1, entries 7, 9, 25, 26), producing the corresponding acylated products in good yields. These reactions are rather fast even with the higher carboxylic acids. However, for deactivated aromatic rings such as bromobenzene and chlorobenzene (Table 1, entries 11, 22), the corresponding 4-acylated products were obtained in poor yields. Using nitrobenzene, no product was obtained (Table 1, entry 12). It is notable that the acylation reaction between 3-phenylpropionic acid and anisole in the presence of P_2O_5/Al_2O_3 produces the corresponding 4-acylated product in good yield (Table 1, entry 27). However, the reaction between 3-phenylpropionic acid and toluene or the reaction between 3-phenylpropionic acid and *m*-xylene produces 2,3-dihydro-3′H-[1,2′]biindenyliden-1′-one as a major product (Table 1, entries, 28, 29). These results show that at first intramolecular Friedel–Crafts acylation occurs and then the aldol condensation reaction is carried out consequently.

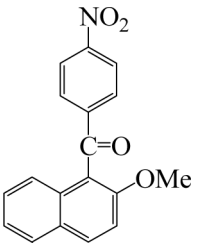
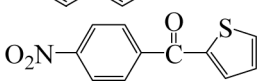
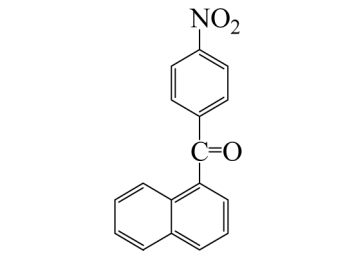
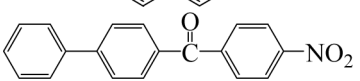
To evaluate the role of Al_2O_3, we studied the acylation of toluene with 4-nitrobenzoic acid in the absence of Al_2O_3. This reaction was carried out under reflux conditions for 5 h in the presence of P_2O_5 alone. The yield of (4-nitrophenyl) (*p*-tolyl)methanone was obtained in 42%.

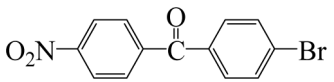
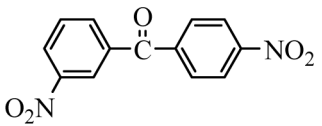
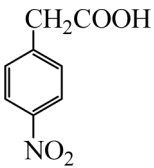
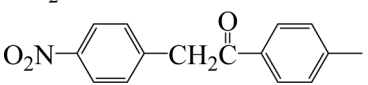
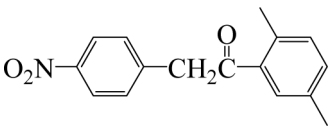
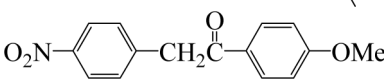
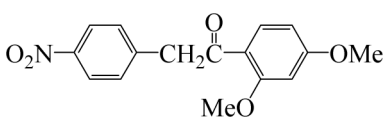
Table 1. Direct acylation of aromatic compounds with carboxylic acids in the presence of P_2O_5/Al_2O_3 under reflux conditions[a]

Entry	Carboxylic acid	Aromatic hydrocarbon	Product	Time (h)	Yield (%)
1		Toluene		5	63
2		p-Xylene		3	65
3		Cumene		3	50
4		Mesitylene		2	60
5[b]		Anisole		5	66
6[c]		1,3-Dimethoxybenzene		3	75

(*Continued*)

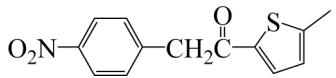
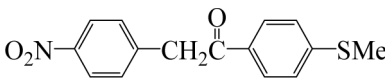
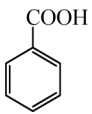
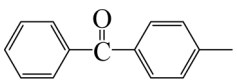
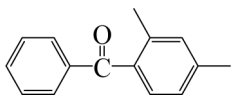
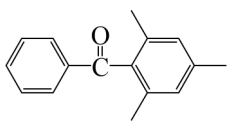
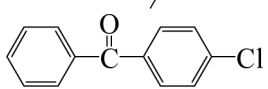
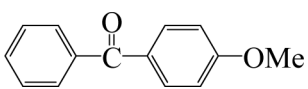
Table 1. Continued

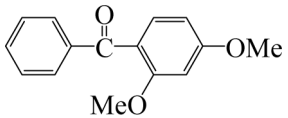
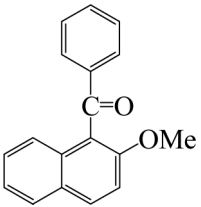
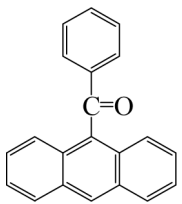
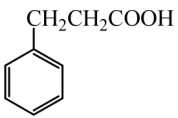
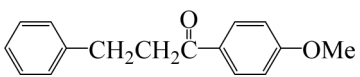
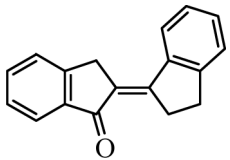
Entry	Carboxylic acid	Aromatic hydrocarbon	Product	Time (h)	Yield (%)
7[d]		2-Methoxynaphthalene		2	82
8		Thiophene		3	50
9[d]		Naphthalene		2	87
10[d]		Biphenyl		3	83

11		Bromobenzene		3	35
12		Nitrobenzene		3	0
13		Toluene		3	78
14		p-Xylene		3	63
15[b]		Anisole		5	88
16[c]		1,3-Dimethoxybenzene		3	82

(*Continued*)

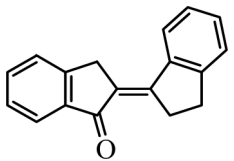
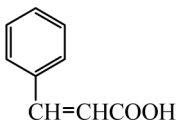
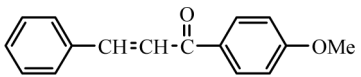
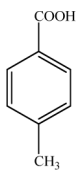
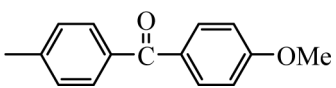
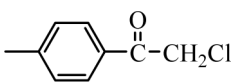
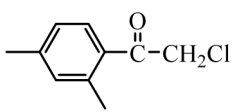
Table 1. Continued

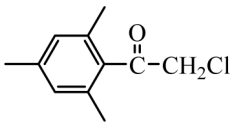
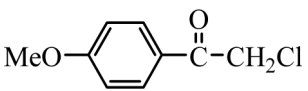
Entry	Carboxylic acid	Aromatic hydrocarbon	Product	Time (h)	Yield (%)
17[b]		2-Methyl thiophene		3	52
18[c]		Thioanisole		5	58
19		Toluene		5	70
20		m-Xylene		3	78
21		Mesitylene		3	82
22		Chlorobenzene		5	26
23[b]		Anisole		5	65

24[c]		1,3-Dimethoxybenzene		3	78
25[d]		2-Methoxynaphthalene		3	70
26[d]		Anthracene		3	56
27[b]		Anisole		3	80
28		Toluene		3	15

(*Continued*)

Table 1. Continued

Entry	Carboxylic acid	Aromatic hydrocarbon	Product	Time (h)	Yield (%)
29		m-Xylene		3	22
30[b]		Anisole		3	85
31[b]		Anisole		5	70
32	CL-CH_2COOH	Toluene		2	65
33		m-Xylene		2	70

34	Mesitylene		1	72
35[b]	Anisole		3	62

[a]The yields refer to isolated pure products and were characterized from their spectra (IR, ^{1}H NMR, ^{13}C NMR, MS, and CHNS) and comparison to authentic samples.

[b]The molar ratio of aromatic compound/carboxylic acid is 5/1.5, and the reaction was carried out in 5 mL of 1,2-dichloroethane under reflux conditions.

[c]The molar ratio of aromatic compound/carboxylic acid is 3/1.5, and the reaction was carried out in 5 mL of 1,2-dichloroethane under reflux conditions.

[d]The molar ratio of aromatic compound/carboxylic acid is 1/1.5, and the reaction was carried out in 5 mL of 1,2-dichloroethane under reflux conditions.

However, by using the combination of P_2O_5/Al_2O_3, the yield of (4-nitrophenyl) (*p*-tolyl)methanone was greater (21%) than that with P_2O_5 alone under the same conditions (Table 1, entry 1). The effect of Al_2O_3 may be due to good dispersion of P_2O_5 on the surface of alumina, leading to significant improvements in its reactivity. Al_2O_3 as a support may also minimize cross contamination between inorganic and organic components.[12]

EXPERIMENTAL

General

All reagents were purchased from Merck and Aldrich and used without further purification. All yields refer to isolated products after purification. Products were characterized by comparison with authentic samples and by spectroscopic data [Fourier transform–infrared (FTIR, ^{1}H NMR, ^{13}C NMR, mass spectra (MS), CHNS, and melting point]. ^{1}H NMR spectra were recorded at FT 300 MHz. The spectra were measured in $CDCl_3$ unless otherwise stated, relative to tetramethylsilane (TMS) (0.00 ppm). P_2O_5/Al_2O_3 (w/w 50%) was prepared according to previous works.[11a]

General Procedure for Acylation of Aromatic Compounds Using Carboxylic Acids and P_2O_5/Al_2O_3 in Reflux of Aromatic Rings

P_2O_5/Al_2O_3 (w/w 50%, 0.6 g) was added to a mixture of a carboxylic acid (1.5 mmol) and an aromatic compound (5 mL). The reaction mixture was stirred under reflux conditions for the appropriate reaction times (Table 1). After completion of the reaction (monitored by thin-layer chromatography, TLC), the mixture was diluted with Et_2O and filtered. The organic layer was washed with 10% $NaHCO_3$ solution and then dried over anhydrous Na_2SO_4. The solvent was evaporated under reduced pressure to give the corresponding pure aryl ketone.

Typical Procedure for Acylation of Toluene Using 4-Nitrophenylacetic Acid and P_2O_5/Al_2O_3

P_2O_5/Al_2O_3 (w/w 50%, 0.6 g) was added to a mixture of 4-nitrophenylacetic acid (1.5 mmol, 0.27 g) and toluene (5 mL), and the reaction mixture was stirred under reflux conditions for 3 h. After cooling, the mixture was diluted with Et_2O (15 mL) and filtered. The organic layer

was washed with 10% $NaHCO_3$ solution and then dried over anhydrous Na_2SO_4. The solvent was evaporated under reduced pressure to give 1-((*p*-tolyl)-2-(4-nitrophenyl)ethanone in 78% yield.

Typical Procedure for Acylation of 1,3-Dimethoxybenzene Using 4-Nitrobenzoic Acid and P_2O_5/Al_2O_3 in 1,2-Dichloroethane Under Reflux Conditions

P_2O_5/Al_2O_3 (w/w 50%, 0.6 g) was added to a mixture of 4-nitrobenzoic acid (1.5 mmol, 0.25 g), 1,3-dimethoxybenzene (3 mmol, 0.4 mL), and 1,2-dichloroethane (5 mL), and the reaction mixture was stirred under reflux conditions for 3 h. After cooling, the mixture was diluted with CH_2Cl_2 (15 mL) and filtered. The organic layer was washed with 10% $NaHCO_3$ solution and then dried over anhydrous Na_2SO_4. The solvent was evaporated under reduced pressure. The crude product was washed with cold n-hexane to give (2,4-dimethoxyphenyl)(4-nitrophenyl)-methanone in 75% yield.

^{1}H NMR and IR Spectral Data for Some Products

Compound **1b**

Mp 118–120°C; ^{1}H NMR (300 MHz, $CDCl_3$, TMS) $\delta = 8.6$ (2H, d, $J = 9.1$ Hz), 8.2 (2H, d, $J = 9.1$ Hz), 8 (2H, d, $J = 8.6$ Hz), 7.55 (2H, d, $J = 8.6$ Hz), 2.55 (3H, s). IR (KBr) cm^{-1}: 3080, 1645, 1595, 1525, 1340, 1305, 1260, 910, 840, 825, 730, 700. Anal. calcd. for $C_{14}H_{11}NO_3$: C, 69.7; H, 4.56; N, 5.81%. Found: C, 69.78; H, 4.61; N, 5.77%.

Compound **3b**

Mp 96–98°C; ^{1}H NMR (300 MHz, $CDCl_3$, TMS) $\delta = 8.33$ (2H, d, $J = 8.89$ Hz), 7.92 (2H, d, $J = 8.89$ Hz), 7.64 (2H, d, $J = 8.35$ Hz), 7.37 (2H, d, $J = 8.35$ Hz), 3 (1H, septed, $J = 7.3$ Hz), 1.3 (6H, d, $J = 7.3$ Hz). IR (KBr) cm^{-1}: 3060, 2973, 1660, 1600, 1515, 1340, 1265, 925, 850, 700. Anal. calcd. for $C_{16}H_{15}NO_3$: C, 71.37; H, 5.57; N, 5.2%. Found: C, 71.25; H, 5.68; N, 5.31%.

Compound **4b**

Mp 122–124°C; ^{1}H NMR (300 MHz, $CDCl_3$, TMS) $\delta = 8.3$ (2H, d, $J = 8.92$ Hz), 7.96 (2H, d, $J = 8.92$ Hz), 6.92 (2H, s), 2.38 (3H, s), 2.1

(6H, s). IR (KBr) cm^{-1}: 3050, 2875, 1670, 1600, 1520, 1440, 1345, 1260, 910, 870, 845, 720. Anal. calcd. for $C_{16}H_{15}NO_3$: C, 71.37; H, 5.57; N, 5.2%. Found: C, 71.26; H, 5.68; N, 5.28%.

Compound **5b**

Mp 122–123°C; ^1H NMR (300 MHz, $CDCl_3$, TMS) $\delta = 8.35$ (2H, d, $J = 9.12$ Hz), 7.9 (2H, d, $J = 9.12$ Hz), 7.83 (2H, d, $J = 9.2$ Hz), 7 (2H, d, $J = 9.2$ Hz), 3.92 (3H, s). IR (KBr) cm^{-1}: 3080, 2960, 1630, 1590, 1510, 1350, 1320, 1260, 1170, 1010, 935, 845. Anal. calcd. for $C_{14}H_{11}NO_4$: C, 65.37; H, 4.28; N, 5.44%. Found: C, 65.48; H, 4.37; N, 5.36%.

Compound **6b**

Mp 119–121°C; ^1H NMR (300 MHz, $CDCl_3$, TMS) $\delta = 8.27$ (2H, d, $J = 8.8$ Hz), 7.86 (2H, d, $J = 8.8$ Hz), 7.55 (1H, d, $J = 8.7$ Hz), 6.62 (1H, dd, $J_1 = 8.7$ Hz, $J_2 = 1.74$ Hz), 6.5 (1H, d, $J = 1.74$ Hz), 3.9 (3H, s), 3.65 (3H, s). ^{13}C NMR (75 MHz, $CDCl_3$, TMS) $\delta = 196$, 165, 160.3, 147.7, 145, 133.3, 130.2, 123.5, 120.3, 105.4, 98.8, 55.8, 55.5. IR (KBr) cm^{-1}: 3075, 2930, 1640, 1600, 1515, 1465, 1345, 1275, 1200, 1155, 1120, 945, 850, 815, 730. Anal. calcd. for $C_{15}H_{13}NO_5$: C, 62.71; H, 4.53; N, 4.88%. Found: C, 62.61; H, 4.63; N, 4.81%.

Compound **7b**

Mp 172–174°C; ^1H NMR (300 MHz, $CDCl_3$, TMS) $\delta = 8.25$ (2H, d, $J = 8.82$ Hz), 7.98 (3H, m), 7.74 (1H, d, $J = 7.35$ Hz), 7.52 (1H, d, $J = 9.1$ Hz), 7.4 (2H, m), 7.32 (1H, d, $J = 9.1$ Hz), 3.8 (3H, s). ^{13}C NMR (75 MHz, $CDCl_3$, TMS) $\delta = 196.6$, 155.5, 151.2, 143.3, 133.2, 132.3, 131, 129.6, 129.2, 128.7, 125.2, 124.6, 124.2, 122, 113.5, 57.2. EIMS m/z (%): 307 (M^+, 56), 290 (16), 276 (13), 260 (12), 185 (100), 142 (25), 127 (21), 120 (27), 114 (26), 106 (15), 92 (14), 76 (14), 43 (34). IR (KBr) cm^{-1}: 3040, 2920 1675, 1600, 1530, 1340, 1235, 1080, 890, 840, 800. Anal. calcd. for $C_{18}H_{13}NO_4$: C, 70.03; H, 4.23; N, 5.56%. Found: C, 70.16; H, 4.21; N, 4.51%.

Compound **8b**

Mp 173–174°C; ^1H NMR (500 MHz, $CDCl_3$, TMS) $\delta = 8.39$ (2H, d, $J = 8.62$ Hz), 8.22 (1H, d, $J = 4.16$ Hz), 8.06 (2H, d, $J = 8.62$ Hz), 7.75

(1H, d, $J = 2.85$ Hz), 7.33 (1H, t, $J = 3.95$ Hz). EIMS m/z (%): 233 (M^+, 27), 187 (2), 150 (5), 111 (100), 83 (10), 76 (12), 50 (9), 44 (4). IR (KBr) cm^{-1}: 3062, 1630, 1600, 1510, 1410, 1355, 1300, 1050, 875, 840, 725. Anal. calcd. for $C_{11}H_7NSO_3$: C, 56.65; H, 3; N, 6; S, 13.73%. Found: C, 56.71; H, 3.1; N, 5.95; S, 13.8%.

Compound **9b**

Mp 89–91°C; mp 89–91°C; ^1H NMR (300 MHz, $CDCl_3$, TMS) $\delta = 8.32$ (2H, d, $J = 8.66$ Hz), 8.05–7.91 (5H, m), 7.62–7.51 (4H, m). EIMS m/z (%): 277 (M^+, 80), 230 (12), 202 (15), 155 (100), 127 (93), 101 (28), 76 (15), 43 (8). IR (KBr) cm^{-1}: 3060, 1675, 1600, 1520, 1340, 1270, 1240, 910, 850, 790, 720. Anal. calcd. for $C_{17}H_{11}NO_3$: C, 73.6; H, 3.97; N, 5.05%. Found: C, 73.51; H, 3.88; N, 4.96%.

Compound **10b**

Mp 163–165°C; ^1H NMR (300 MHz, $CDCl_3$, TMS) $\delta = 8.37$ (2H, d, $J = 9.1$ Hz), 7.97 (2H, d, $J = 9.1$ Hz), 7.88 (2H, d, $J = 8.65$ Hz), 7.74 (2H, d, $J = 8.65$ Hz), 7.66 (2H, d, $J = 8.4$ Hz) 7.5 (3H, m). EIMS m/z (%): 303 (M^+, 70), 181 (100), 153 (30), 152 (53), 76 (15). IR (KBr) cm^{-1}: 3060, 1650, 1600, 1515, 1355, 1280, 935, 845, 755, 730, 700. Anal. calcd. for $C_{19}H_{13}NO_3$: C, 75.24; H, 4.29; N, 4.62%. Found: C, 75.34; H, 4.22; N, 4.51%.

Compound **11b**

Mp 124–126°C; ^1H NMR (300 MHz, $CDCl_3$, TMS) $\delta = 8.38$ (2H, d, $J = 8.71$ Hz), 7.95 (2H, d, $J = 8.71$ Hz), 7.72 (4H, s). EIMS m/z (%): 307 ($M^+ + 2$, 40), 305 (M^+, 40), 277 (8), 275 (8), 185 (100), 183 (100), 157 (35), 155 (35), 150 (36), 120 (37), 76 (56). IR (KBr) cm^{-1}: 3070, 1660, 1600, 1580, 1510, 1340, 1275, 1060, 990, 930, 845, 720. Anal. calcd. for $C_{13}H_8BrNO_3$: C, 51.14; H, 2.62; N, 4.59%. Found: C, 51.03; H, 2.71; N, 4.51%.

Compound **13b**

Mp 110–112°C; ^1H NMR (300 MHz, $CDCl_3$, TMS) $\delta = 8.17$ (2H, d, $J = 8.4$ Hz), 7.88 (2H, d, $J = 8.1$ Hz), 7.4 (2H, d, $J = 8.4$ Hz), 7.27 (2H, d, $J = 8.1$ Hz), 4.38 (2H, s), 2.4 (3H, s). ^{13}C NMR (75 MHz, $CDCl_3$,

TMS) δ = 195.5, 145, 143, 136, 134, 131, 130, 129, 124.5, 45.5, 20.5. IR (KBr) cm^{-1}: 3020, 2875, 1680, 1595, 1510, 1345, 1320, 1290, 995, 845, 800, 725. Anal. calcd. for $C_{15}H_{13}NO_3$: C, 70.58; H, 5.1; N, 5.49%. Found: C, 70.49; H, 5.18; N, 5.41%.

Compound **14b**

Mp 86–88°C; ^{1}H NMR (300 MHz, $CDCl_3$, TMS) δ = 8.2 (2H, d, J = 8.5 Hz), 7.55 (1H, s), 7.4 (2H, d, J = 8.5 Hz), 7.22 (1H, d, J = 8.05 Hz), 7.15 (1H, d, J = 8.05 Hz), 4.37 (2H, s), 2.42 (3H, s), 2.39 (3H, s). IR (KBr) cm^{-1}: 3065, 2890, 1680, 1600, 1510, 1340, 1170, 985, 960, 820, 720. Anal. calcd. for $C_{16}H_{15}NO_3$: C, 71.37; H, 5.57; N, 5.2%. Found: C, 71.3; H, 5.5; N, 5.28%.

Compound **15b**

Mp 114–116°C; ^{1}H NMR (300 MHz, $CDCl_3$, TMS) δ = 8.3 (2H, d, J = 8.65 Hz), 8.1 (2H, d, J = 8.7 Hz), 7.55 (2H, d, J = 8.65 Hz), 7.06 (2H, d, J = 8.7 Hz), 4.43 (2H, s), 4 (3H, s). ^{13}C NMR (75 MHz, $CDCl_3$, TMS) δ = 195, 165, 143.2, 131.5, 131.1, 130, 124.4, 115, 110.6, 56, 46. IR (KBr) cm^{-1}: 3055, 2930, 1680, 1600, 1510, 1450, 1350, 1340, 1270, 1175, 990, 825, 730. Anal. calcd. for $C_{15}H_{13}NO_4$: C, 66.4; H, 4.79; N, 5.16%. Found: C, 66.38; H, 4.85; N, 5.09%.

Compound **16b**

Mp 119–121°C; ^{1}H NMR (300 MHz, $CDCl_3$, TMS) δ = 8.18 (2H, d, J = 8.7 Hz), 7.85 (1H, d, J = 8.65 Hz), 7.38 (2H, d, J = 8.7 Hz), 6.55 (1H, dd, J_1 = 8.65 Hz, J_2 = 2.48 Hz), 6.48 (1H, d, J = 2.48 Hz), 4.4 (2H, s), 3.92 (3H, s), 3.88 (3H, s). IR (KBr) cm^{-1}: 3045, 2920, 1660, 1600, 1515, 1355, 1310, 1270, 1140, 990, 830, 735. Anal. calcd. for $C_{16}H_{15}NO_5$: C, 63.78; H, 4.98; N, 4.65%. Found: C, 63.71; H, 5.08; N, 4.72%.

Compound **17b**

Mp 104–106°C; ^{1}H NMR (300 MHz, $CDCl_3$, TMS) δ = 8.2 (2H, d, J = 8.9 Hz), 7.63 (1H, d, J = 3.83 Hz), 7.47 (2H, d, J = 8.9 Hz), 6.85 (1H, d, J = 3.85 Hz), 4.28 (2H, s), 2.57 (3H, s). IR (KBr) cm^{-1}: 3050, 1650, 1600, 1515, 1445, 1340, 1230, 930, 810, 730. Anal. calcd. for

$C_{13}H_{11}NSO_3$: C, 59.77; H, 4.21; N, 5.36; S, 12.26%. Found: C, 59.68; H, 4.26; N, 5.42; S, 12.19%.

Compound **18b**

Mp 183–185°C; ^{1}H NMR (300 MHz, $CDCl_3$, TMS) $\delta = 8.16$ (2H, d, $J = 8.96$ Hz), 7.96 (2H, d, $J = 8.6$ Hz), 7.52 (2H, d, $J = 8.9$ Hz), 7.32 (2H, d, $J = 8.6$ Hz), 4.5 (2H, s), 2.53 (3H, s). IR (KBr) cm^{-1}: 3055, 2910, 1675, 1590, 1515, 1340, 1225, 1175, 1080, 980, 800, 700. Anal. calcd. for $C_{15}H_{13}NSO_3$: C, 62.71; H, 4.53; N, 4.87; S, 11.15%. Found: C, 62.64; H, 4.61; N, 4.96; S, 11.21%.

Compound **19b**

Mp 51–53°C; ^{1}H NMR (300 MHz, $CDCl_3$, TMS) $\delta = 8.1$–7.8 (7H, m), 7.45 (2H, d, $J = 8.25$ Hz), 2.45 (3H, s). IR (KBr) cm^{-1}: 3030, 2920, 1660, 1600, 1580, 1460, 1330, 1280, 925, 780, 710.

Compound **20b**

Thick oil; ^{1}H NMR (300 MHz, $CDCl_3$, TMS) $\delta = 7.8$ (2H, m), 7.55 (1H, m), 7.45 (2H, m), 7.23 (1H, dd, $J_1 = 6.8$ Hz, $J_2 = 3.07$ Hz), 7.1 (1H, s), 7.03 (1H, d, $J = 6.8$ Hz), 2.38 (3H, s), 2.27 (3H, s). IR (KBr) cm^{-1}: 3060, 2916, 1660, 1610, 1595, 1445, 1375, 1265, 1160, 940, 885, 825, 700.

Compound **21b**

Mp 34–35°C; ^{1}H NMR (300 MHz, $CDCl_3$, TMS) $\delta = 7.8$ (2H, d, $J = 8.57$), 7.56 (1H, t, $J = 7.8$ Hz), 7.43 (2H, t, $J = 7.8$ Hz), 6.9 (2H, s), 2.33 (3H, s), 2.08 (6 H, s). ^{13}C NMR (75 MHz, $CDCl_3$, TMS) $\delta = 201$, 138.6, 137.5, 137, 134.3, 133.75, 129.6, 128.9, 128.3, 21.4, 19.4. IR (KBr) cm^{-1}: 3045, 2895, 1670, 1610, 1595, 1580, 1450, 1375, 1310, 1265, 1170, 920, 850, 700.

Compound **24b**

Mp 85–87°C; ^{1}H NMR (300 MHz, $CDCl_3$, TMS) $\delta = 7.78$ (2H, d, $J = 8.2$), 7.53 (1H, t, $J = 7$ Hz), 7.4 (2H, t, $J = 7$ Hz), 6.55 (1H, dd, $J_1 = 8.2$ Hz, $J_2 = 2.1$ Hz), 6.5 (1H, d, $J = 2.1$ Hz), 3.88 (3H, s), 3.7 (3 H,

s). IR (KBr) cm^{-1}: 3020, 2920, 1640, 1600, 1440, 1370, 1285, 1100, 1020, 935, 830, 810, 690. Anal. calcd. for $C_{15}H_{14}O_3$: C, 74.38; H, 5.78%. Found: C, 74.29; H, 5.82%.

Compound **25b**

Mp 125–127°C; ^1H NMR (300 MHz, $CDCl_3$, TMS) $\delta = 8$–7.85 (4 H, m), 7.6–7.35 (7H, m), 3.85 (3H, s). EIMS m/z (%): 262 (M^+, 62), 245 (16), 185 (100), 142 (15), 105 (15), 77 (30). IR (KBr) cm^{-1}: 3060, 2916, 2830, 1660, 1590, 1500, 1450, 1250, 1070, 880, 780, 690. Anal. calcd. for $C_{18}H_{14}O_2$: C, 82.44; H, 5.34%. Found: C, 82.38; H, 5.45%.

Compound **27b**

Mp 96–98°C; ^1H NMR (300 MHz, $CDCl_3$, TMS) $\delta = 7.95$ (2H, d, $J = 8.87$ Hz), 7.37–7.2 (5 H, m), 6.92 (2H, d, $J = 8.87$ Hz), 3.86 (3H, s), 3.25 (2H, t, $J = 8.05$ Hz), 3.05 (2H, t, $J = 8.05$ Hz). ^{13}C NMR (75 MHz, $CDCl_3$, TMS) $\delta = 198$, 163.2, 141.5, 130.5, 130.2, 128.5, 126.3, 113.7, 55.5, 40.5, 30.5. IR (KBr) cm^{-1}: 3040, 2915, 1670, 1600, 1570, 1500, 1450, 1420, 1255, 1170, 1020, 980, 840, 780, 745, 700. Anal. calcd. for $C_{16}H_{16}O_2$: C, 80; H, 6.66%. Found: C, 79.94; H, 6.78%.

Compound **28b**

Mp 144–146°C; ^1H NMR (500 MHz, $CDCl_3$, TMS) $\delta = 7.9$ (1H, d, $J = 8$ Hz), 7.72 (1H, d, $J = 7.44$ Hz), 7.67 (2H, s), 7.51–7.04 (4 H, m), 4.1 (2H, s), 3.44 (2H, d, $J = 5.64$ Hz), 3.11 (2H, t, $J = 5.63$). IR (KBr) cm^{-1}: 3040, 2875, 1675, 1625, 1600, 1580, 1470, 1325, 1280, 980, 740. Anal. calcd. for $C_{18}H_{14}O$: C, 87.8; H, 5.69%. Found: C, 87.88; H, 5.75%.

Compound **30b**

Mp 100–102°C; ^1H NMR (300 MHz, $CDCl_3$, TMS) $\delta = 8.04$ (2H, d, $J = 8.68$ Hz), 7.8 (1H, d, $J = 15.1$ Hz), 7.62 (2H, m), 7.55 (1H, d, $J = 15.1$ Hz), 7.4 (3H, m), 6.97 (2H, d, $J = 8.68$ Hz), 3.88 (3H, s). EIMS m/z (%): 238 (M^+, 100), 237 (72), 223 (22), 135 (92), 131 (22), 107 (18), 103 (36), 92 (30), 77 (77). IR (KBr) cm^{-1}: 3045, 2875, 1650, 1600, 1575, 1440, 1420, 1260, 1230, 1180, 1015, 980, 830, 765, 700. Anal. calcd. for $C_{16}H_{14}O_2$: C, 80.67; H, 5.88%. Found: C, 80.54; H, 6%.

Compound **31b**

Mp 83–85°C; ^{1}H NMR (300 MHz, $CDCl_3$, TMS) $\delta = 7.8$ (2H, d, $J = 9$ Hz), 7.67 (2H, d, $J = 8.4$ Hz), 7.25 (2H, d, $J = 8.4$ Hz), 6.95 (2H, d, $J = 9$ Hz), 3.85 (3H, s), 2.4 (3H, s). ^{13}C NMR (75 MHz, $CDCl_3$, TMS) $\delta = 193.9$, 161.4, 141.4, 133.9, 131, 128.9, 128.5, 127.5, 112, 53.9, 20. IR (KBr) cm^{-1}: 3055, 2960, 1665, 1590, 1495, 1405, 1345, 1250, 1160, 1020, 940, 825. Anal. calcd. for $C_{15}H_{14}O_2$: C, 79.64; H, 6.19%. Found: C, 79.55; H, 6.15%.

Compound **33b**

Mp 62–63°C; ^{1}H NMR (300 MHz, $CDCl_3$, TMS) $\delta = 7.55$ (1H, d, $J = 7.5$ Hz), 7.08(2H, s), 4.6 (2H, s), 2.56 (3H, s), 2.38 (3H, s). IR (KBr) cm^{-1}: 3050, 2935, 1685, 1610, 1565, 1440, 1390, 1290, 1135, 990, 815, 790, 735. Anal. calcd. for $C_{10}H_{13}ClO$: C, 65.75; H, 6.02%. Found: C, 65.64; H, 6.13%.

Compound **34b**

Mp 68–70°C; ^{1}H NMR (300 MHz, $CDCl_3$, TMS) $\delta = 6.88$ (2H, s), 4.4 (2H, s), 2.3 (3H, s), 2.22 (6 H, s). EIMS m/z (%): 198 ($M^+ + 2$, 3), 196 (M^+, 8), 160 (5), 147 (100), 119 (50), 91 (27), 77 (17), 43 (27). IR (KBr) cm^{-1}: 2890, 1715, 1615, 1390, 1210, 1150, 980, 860, 765, 715. Anal. calcd. for $C_{11}H_{13}ClO$: C, 67.17; H, 6.61%. Found: C, 67.08; H, 6.66%.

Compound **35b**

Mp 100–102°C; ^{1}H NMR (500 MHz, $CDCl_3$, TMS) $\delta = 7.97$ (2H, d, $J = 8.53$ Hz), 7 (2H, d, $J = 8.53$ Hz), 5.1 (2H, s), 3.88 (3H, s). IR (KBr) cm^{-1}: 3045, 2875, 1640, 1600, 1500, 1450, 1310, 1250, 1160, 1140, 1020, 925, 850, 750. Anal. calcd. for $C_9H_9ClO_2$: C, 58.22; H, 4.85%. Found: C, 58.31; H, 4.91%.

CONCLUSION

P_2O_5/Al_2O_3 is an inexpensive, easily available, noncorrosive, and environmentally benign compound. In this work, we have reported a simple and efficient procedure for the preparation of aryl ketones in good yields and short reaction times. The notable advantages of this methodology

are direct use of a wide variety of carboxylic acids, operational simplicity, generality, high regioselectivity, availability of reactants, and easy workup as a result of the heterogeneous conditions. Further investigation on new applications of P_2O_5/Al_2O_3 is ongoing in our laboratories.

ACKNOWLEDGMENTS

We gratefully acknowledge the funding support received for this project from the Isfahan University of Technology (IUT), IR Iran (A. R. H.) and Grant GM 33138 (A. E. R.) from the National Institutes of Health, USA. Further financial support from Center of Excellency in Sensor and Green Chemistry Research (IUT) is gratefully acknowledged.

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