Activation of Bismuth(III) derivatives in ionic liquids: novel and recyclable catalytic systems for Friedel-Crafts acylation of aromatic compounds

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Experimental section

General Methods.

All reactions were carried out using standard Schlenk techniques under argon. Toluene, benzene and ether were carefully dried and distilled from Na/benzophenone prior to use. All other standard chemicals were purchased from ACROS Chimica or Aldrich Chemical Co. and used without further purification. Reactions were monitored by gas chromatography (GC-MS) (GC system: HP 6890 series, Mass selective detector HP 5973) using a capillary column DB-5MS. Column chromatography purifications were performed on silica gel Si 60 (40-63 µm, 230-400 mesh,Merck). Melting points were determined on an electrothermal IA9300 digital melting point instrument. NMR spectra were recorded on a Bruker ARX 200 (^{1}H: 200.13 MHz, ^{13}C: 50.32 MHz) or AC 300 P (^{1}H: 300.13 MHz), ^{1}H chemical shifts (δ) are given in ppm relative to TMS as internal standard, *J* values in Hz; ^{13}C chemical shifts are given relative to the central signal of $CDCl_3$ at 77.0 ppm. IR spectra were obtained on a Bio-Rad FTS 175C FT-IR spectrophotometer. High resolution mass spectra measurements were performed at the Centre Regional de Mesures Physiques de l'Ouest (C.R.M.P.O, University of Rennes 1) using a Varian MAT 311 with BE geometry (reversed NIER-JOHNSON) and EI athod or Micromass ZABSpec TOF with EBE OA TOF geometry with LSIMS Ionization (Liquid Secondary Ion Mass Spectrometry) at 8 kV with Cs^+ gun in *m*-nitrobenzyl alcohol (mNBA).

Benzoylation of 0.2 mol of toluene:

A round-bottomed flask was charged with Bi_2O_3 (0.465g, 1mmol) and [emim][NTf_2] (0.782g, 2mmol). After drying under high vacuum for 1 h at 40°C with stirring and flushing several times with argon, toluene (4.28ml, 40mmol) was introduced. The mixture was heated at 150°C and benzoyl chloride (2.21ml, 20mmol) was added. Upon completion of the reaction, the pure methylbenzophenones were isolated by bulb to bulb distillation (oven temperature 90-100°C, 0.1 torr).

Typical procedure for the benzoylation of aromatic derivatives (table 3):

A 25 ml flask equipped with a condenser and a stirring bar was charged with catalyst (0.05mmol of bismuth oxide or 0.1 mmol of bismuth triflate), [emim][NTf_2] (0.039g, 0.1mmol), aromatic (2mmol) and benzoyl chloride (0.11ml, 1mmol). The flask was heated in a thermostated oil bath at 150°C for the time indicated in table 3). After cooling, GC/MS analysis of crude product indicated the total transformation of benzoyl chloride. Ether (30 ml) was added to the crude mixture under stirring. After decantation, the ether phase was cannulated out of the flask and the remaining ionic liquid phase was subjected to another extraction with ether (30 ml). The combined ether phases were concentrated under reduced pressure. The product was purified by flash chromatography (silica gel; eluent: heptane/ethylacetate = 8.5/1.5). The ionic phase was put under high vacuum for one hour and then ready for another run.

Preparation of bismuth triflate in ionic liquids :

To a suspension of Bi_2O_3 (0.46g, 1mmol) in [emim][NTf_2] (0.782g, 2mmol) was added trifluoromethane sulfonic acid (0.53ml, 6mmol) at room temperature. The mixture was stirred at 70°C for 4h and then maintained at 50°C under reduced pressure for 12h leading to a solution of $Bi(OTf)_3$ which can be directly used for a reaction.

1/4 mixture of 2 and 4-Methylbenzophenones:[1]

^{1}H NMR (200 MHz, $CDCl_3$): δ 2.38 (s, 0.5H, 2-Me), 2.46 (s ,2.5H, 4-Me), 7.56-7.68 (m, 8H). RMN ^{13}C (50 MHz, $CDCl_3$): δ 20.45, 21.8, 125.68, 128.94, 128.97, 130.1, 130.5, 132.4, 135.0, 138.1, 143.4, 196.6. HRMS (EI) m/z calcd. For $C_{14}H_{12}O$ $(M+H^+)$: 196.0888 Found : 196.0782. IR (neat): υ (C=O) 1710 cm^{-1}.

4-Methoxybenzophenones:[2]

^{1}H NMR (200 MHz, $CDCl_3$): δ 3.79 (s, OCH3, 3H), 6.90-7.98 (m, 2H), 7.15-7.25 (m, 2H), 7.43-7.52 (m, 5H). ^{13}C NMR (50 MHz, $CDCl_3$) : δ 55.89, 114.01, 128.62, 130.09, 130.52, 132.28, 132.97,138.68, 165.98, 195.09. HRMS (EI) m/z calcd.For $C_{14}H_{12}O_2$ (M+ H^+) : 212.0837 Found : 212.0768. IR (neat): υ(C=O) 1670 cm^{-1}.

2,4,6-Trimethylbenzophenone:[3]

^{1}H NMR (200 MHz, $CDCl_3$): δ 2.02 (s, 6H), 2.35 (s, 3H), 6.85 (s, 2H), 7.42-7.51 (m, 2H), 7.59-7.68 (m, 2H), 7.83-7.91 (m, 2H). ^{13}C NMR (50 MHz, $CDCl_3$) : δ 21.01, 24.45, 128.92, 129.17, 129.72, 133.43, 134.52, 137.28, 138.68, 199.19. HRMS (EI) m/z calcd. For $C_{16}H_{16}O$ (M+ H^+) : 224.1201 Found : 224.1210. IR (neat): υ (C=O) 1672 cm^{-1}.

1- and 2-benzoylnaphthalenes:[4]

^{1}H NMR (200 MHz, $CDCl_3$) : δ 7.25-8.06 (m**,** 10H), 8.49-8.61 (m, 2H), ^{13}C NMR (50 MHz,$CDCl_3$) :124.81, 126.15, 126.24, 126.94, 127.74, 128.26, 128.83, 128.92, 129.88, 130.57, 130.87, 131.42, 131.75, 132.36, 132.88, 133.72, 197.20, 198.46. HRMS (EI) m/z calcd. For $C_{17}H_{12}O$ (M+ H^+) : 232.08882 Found : 232.08682. IR (neat): υ (C=O) 1651, 1658cm^{-1}.

8/92 mixture of 2-and 4-Benzoyl-1-methylnaphthalenes:[5]

^{1}H NMR (200 MHz, $CDCl_3$) : δ 2.45 (s, 0.25H, 2-benzoyl), 2.78 (s, 2.75H, 4-benzoyl), 7.21-7.75 (m, 6H), 7.82-8.24 (m, 4H), 8.40-8.49 (m, 1H). ^{13}C NMR (50 MHz, $CDCl_3$) : 20.25, 20.38, 124.99, 125.66, 126.00, 126.86, 126.88, 127.44, 128.61, 128.91, 129.06, 129.42, 129.52, 130.16, 130.85, 131.67, 133.37, 133.53, 135.12, 138.81, 139.16, 198.24, 200.54. HRMS (EI) m/z For $C_{18}H_{14}O$ (M+ H^+) : 246.10447, Found : 246.10229. IR (neat): υ(C=O) 1651, 1659cm^{-1}.

1/3 mixture of 1- and 4-benzoyl-2-6-dimethylnaphthalenes :[5]

^{1}H NMR (200 MHz, $CDCl_3$) : δ 2.37 (s, 2H, 4-benzoyl), 2.49 (s, 1H, 1-benzoyl), 2.55 (s, 1H), 2.62 (s, 2H), 7.29-8.09 (m, 10H). ^{13}C NMR (50 MHz, $CDCl_3$) : 20.11, 21.85, 21.96, 22.41, 124.96, 125.23, 127.68, 128.19, 128.96, 129.08, 129.29, 129.37, 129.48, 130.18, 13.30, 130.58, 130.88, 132.46, 133.44, 133.53, 133.68, 134.30, 135.54, 138.11, 138.96, 198.87, 200.70. HRMS (EI) m/z calcd. For $C_{19}H_{16}O$ (M+ H^+): 260.12012, Found : 260.12013. IR (neat): υ (C=O) 1663cm^{-1}.

1-ethyl-3-methylimidazolium tetrachlorobismutate [emim][$BiCl_4$]:

Crystallisation in CH_2Cl_2 afforded small yellow needles: mp 112°C (88%); ^1H NMR (200 MHz,CD_3CN): δ 1,51 (t, J=7, 3Hz, 3H) ; 3.91(s, 3H) ; 4,26 (q, J=7.3Hz, 2H) ; 7,38-7.46 (m, 2H) ; 8.59 (s, 1H). ^{13}C NMR (75 MHz, CD_3CN): δ 14.80 ; 36.05 ; 44.86; 121.98 ; 123.66 ; 135.84. HRMS (FAB) calcd. For $C_{12}H_{22}N_4Cl_4Bi$, $[2C^+, BiCl_4^-]^+$: 571.04025, Found: 571.0395. Anal. Calcd for $C_6H_{11}N_2Cl_4Bi$: C, 15.60; H, 2.40; Cl, 30.70; N, 6.06; Bi, 45.24; Found: C, 15.52; H, 2.40; Cl, 29.44; N, 6, 09; Bi, 42.74.

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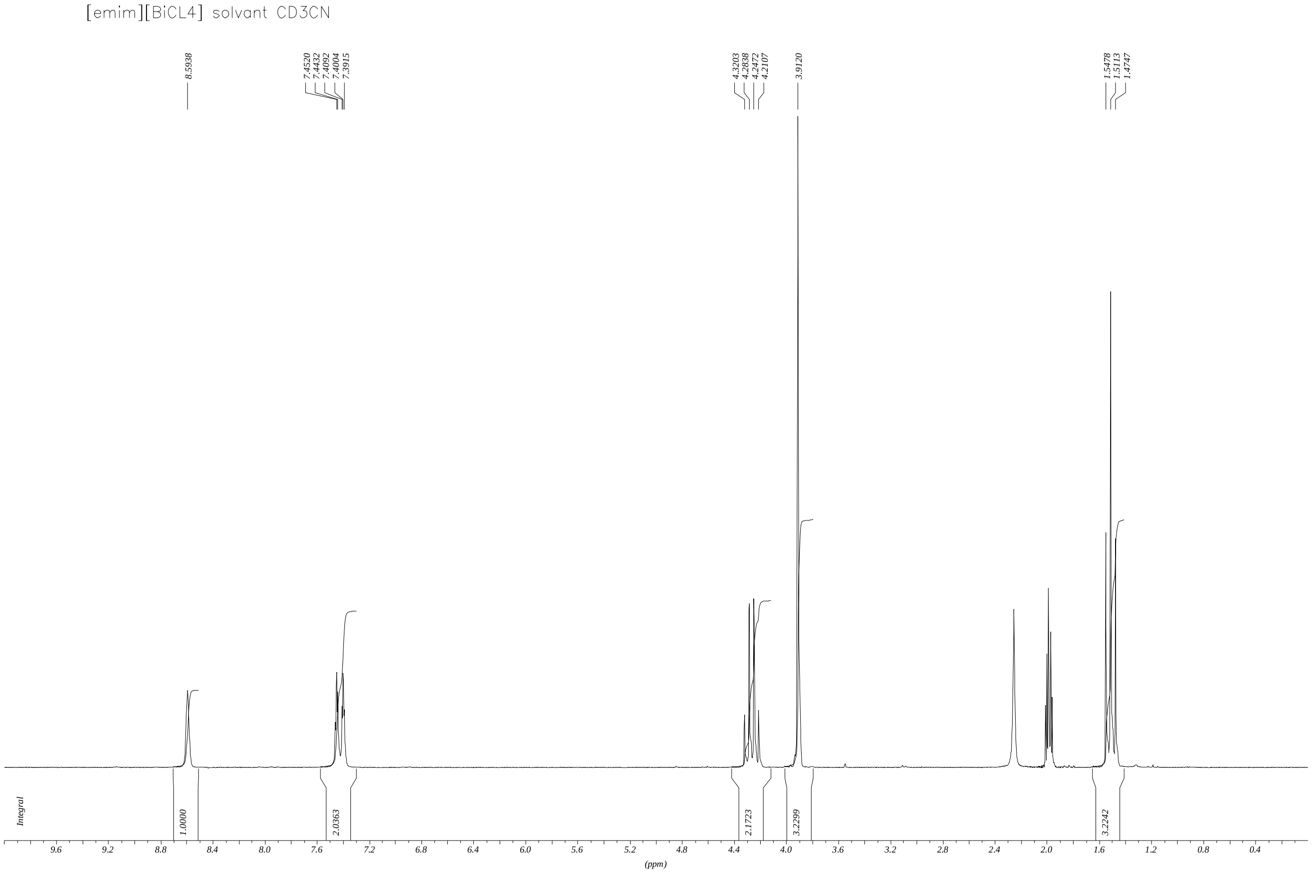
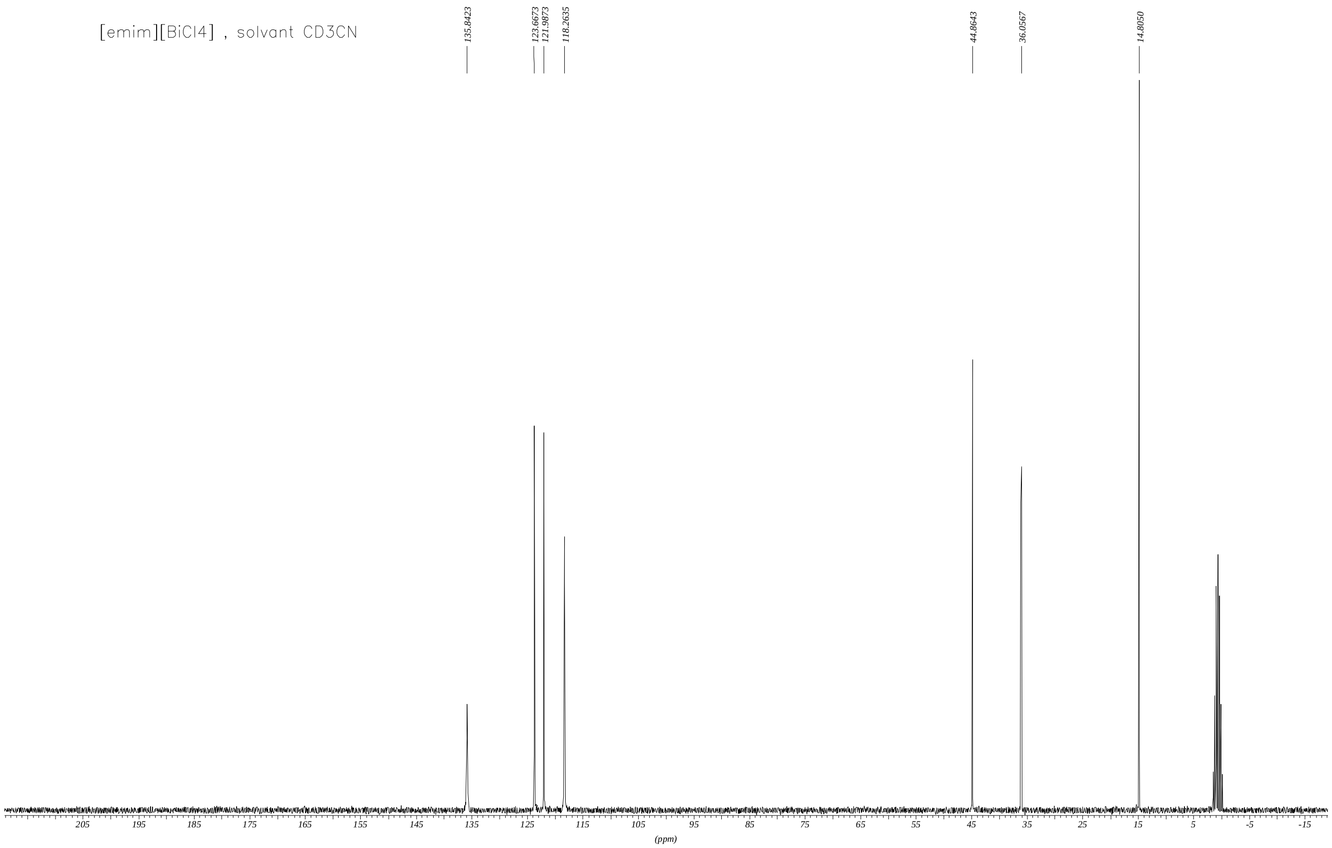


^{1}H NMR, 200MHz, CD_3CN (H_2O signal at $\delta = 2.26$ppm)



^{13}C NMR,75MHz,CD_3CN