# Electrochemically promoted Friedel–Crafts acylation of aromatic compounds

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## Abstract

Friedel–Crafts acylation is carried out with several aromatic substrates in the presence of an electrochemically active aluminium anode to minimize the inorganic reagents. Only a catalytic amount of $AlCl_3$ (5 mol %) is required to enable the anodic polarization of the aluminium electrode to promote continuous acylation. This process typically gave products in good yields (70–96%).
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Friedel–Crafts acylation has been used for the acylation of aromatics since the turn of the last century.[1] Friedel–Crafts acylation of aromatic compounds is a common process resulting in C–C coupling and is one of the most fundamental and important reactions in synthetic, industrial and pharmaceutical applications.[2,3]

Friedel–Crafts acylation reactions represent one of the greatest challenges to 'green chemistry'. Traditional methods generally employ more than stoichiometric amounts of hazardous water soluble Lewis acids such as $AlCl_3$ or $BF_3$, which are destroyed during the workup leading to large volumes of waste.[4] The loss of inorganic reagents as waste products is undesirable and thus alternative reaction conditions are sought to minimize or eliminate the waste problem. In recent years, the search for suitable catalytic conditions to replace the need for excess inorganic reagents has resulted in numerous investigations focusing particularly on the use of novel Lewis acid such as $FeCl_3$,[5] $ZnCl_2$,[6] $BiCl_3$[7] and other metallic chlorides,[6] the application of triflates in ionic liquids[8] and heterogeneous processes employing zeolites.[9] There are three main difficulties that chemists meet during the conventional acylation of aromatics: preparation, storage and handling of anhydrous Lewis acids such as $AlCl_3$. A possible way to overcome these challenges is in situ generation of the Lewis acid catalyst using a sacrificial aluminium anode. Using this novel electrochemically promoted method, only a relatively small amount of $AlCl_3$ (5 mol %) is sufficient to catalyze various acylation reactions at room temperature. In general, aluminium electrodes are commonly used as anodes to avoid the oxidation of organic compounds during reactions and here it is used as a mild source of Lewis acid to promote the Friedel–Crafts acylation.

In recent years, electroorganic synthesis has become increasingly attractive as an environmentally friendly process. Through the anodic dissolution of aluminium,[10] zinc,[11] magnesium,[12] etc., in situ generation of catalysts has been observed, which can be used in organic reactions. The anodic dissolution of aluminium in an appropriate medium is a versatile method for the electrochemical introduction of active Al(III) species as a catalyst and using this technique, the acylation of alkenes[13] and ferrocene[14] as well as alkylation[15] and electrocarboxylation has been reported.[16] Gambino et al. have demonstrated the acylation of aromatics in the presence of an aluminium anode with $AlCl_3$ as the electrolyte.[17]

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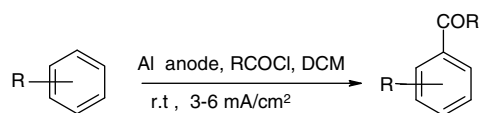
Scheme 1. Electrochemical acylation of benzene.

In this Letter, we describe the electrochemically promoted acylation of a number of aromatic compounds using an Al anode and tetrabutylammonium bromide ($Bu_4NBr$) as electrolyte along with a catalytic amount (5 mol %) of $AlCl_3$ (Scheme 1).

All experiments were carried out galvanostatically (constant current electrolysis) in a simple undivided cell under a nitrogen atmosphere. An aluminium anode and stainless steel cathode were used in all the reactions and the current density was maintained at 3–6 $mA/cm^2$.

The Friedel–Crafts acylation was carried out by electrolyzing a solution of tetrabutylammonium bromide in DCM, containing 5 mol % of $AlCl_3$, 1.2 equiv of acetyl chloride and alkylarenes at room temperature. After passing 1 F/mol charge, the corresponding acylated product was obtained in 70–96% yield (Table 1).[18] In the case of toluene, anisole and ethylbenzene, 0.7–0.8 F/mol of charge was sufficient to obtain the best yields. On passing additional charge, side product formation was observed. It is believed that the catalytic amount of $AlCl_3$ induces anodic polarization and corrosion of the aluminium electrode, which leads to more facile formation of the ionic aluminium species at the anode resulting in better yields of acylated products.

Under these electrochemical conditions, the Friedel–Crafts acylation consists of two steps involving an electrochemical reaction followed by a chemical reaction. The anodic production of Al(III) is an electrochemical process. The aluminium(III) species is chemically reactive towards halogenated molecules, and its reaction with acetyl halide affords the product.

In an appropriate supporting electrolyte medium (tetrabutylammonium bromide) and in the presence of $AlCl_3$, the aluminium metal surface is activated and anodically more polarized (vide infra),[17] hence the dissolution of aluminium is more facile.
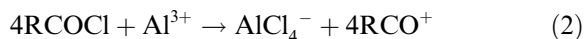
Activated aromatics such as toluene, anisole and para-*t*-butyltoluene gave high acylation yields (Table 1, entries 2, 3 and 9) and the ring deactivated molecule chlorobenzene gave a very low yield (Table 1, entry 10). Highly deactivated nitrobenzene did not give any product (Table 1, entry 11). When the reaction was carried out in the presence of $AlCl_3$ without passing any current, the yield of acylated product obtained from toluene was only 11%. The above-mentioned reaction was carried out electrochemically without adding $AlCl_3$ and the yield of the product was 28%. Therefore, the electrochemical step is essential in promoting the acylation reaction leading to the desired products in high yield with minimum of waste products. A simplified

Table 1
Electrochemical Friedel–Crafts acylation of various aromatic compounds

| Entry | Reactant | Product | Charge passed (F/mol) | Yield[a] (%) |
|---|---|---|---|---|
| 1 |  |  | 1 | 70 |
| 2 |  |  | 0.7 <br> 1.0 | 95 <br> 93 |
| 3 |  |  | 0.7 <br> 1.0 | 75 <br> 70 |
| 4 |  |  | 0.8 <br> 1.0 | 81 <br> 78 |
| 5 |  |  | 1 | 75 |
| 6 |  |  | 1 | 95 |
| 7 |  |  | 1 | 74 |
| 8 |  |  | 1 | 90 |
| 9 |  |  | 1 | 96 |
| 10 |  |  | 1 | 5 |
| 11 |  | — | 1 | No product was formed |

[a] Isolated yield.

mechanism can be proposed for this electrochemical process (Eqs. 1–3):

$$Al \rightarrow Al^{3+} + 3e^- \qquad (1)$$

$$4RCOCl + Al^{3+} \rightarrow AlCl_4^- + 4RCO^+ \qquad (2)$$

$$RCO^+ + Ar–H \rightarrow ArCOR + H^+ \qquad (3)$$

One equivalent of electrochemically generated aluminium ions can combine with 4 equiv of acyl halide to produce reactive acylium ions and $AlCl_4^-$, which catalyzes the reaction and hence a minimum amount of current is required. The theoretical loss of aluminium, from the anode is 0.050 g/F charge transferred but the observed weight loss was 0.120 g and therefore the mechanism is probably even more complex than proposed.

Nitrogen gas was passed into the reaction mixture throughout the experiment to remove HCl, which is evolved during the course of the reaction. If HCl is not promptly removed, it reacts with the product and leads to the formation of side products such as diphenylethane (Eqs. 4 and 5):

$$C_6H_5COCH_3 + 2e^- + 2H^+ \rightarrow C_6H_5CH(OH)CH_3 \qquad (4)$$

$$C_6H_6 + C_6H_5CH(OH)CH_3 \rightarrow (C_6H_5)_2CHCH_3 + H_2O \qquad (5)$$
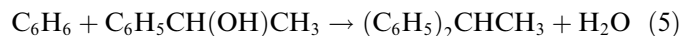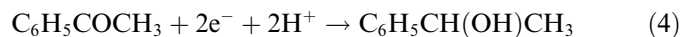
The water formed during the side alkylation process will further deactivate an equivalent amount of catalyst leading to a reduced yield of the Friedel–Crafts acylated product.

In summary, the electrochemically promoted Friedel–Crafts acylation of aromatic compounds by in situ generation of $Al^{3+}$ from an aluminium anode in the presence of tetrabutylammonium bromide as electrolyte gives acylated products in good yields (70–95%). This reaction is carried out at room temperature with a catalytic amount of $AlCl_3$ instead of a stoichiometric amount applying a minimum amount of current. There are considerable advantages in this electrochemically promoted reaction compared to conventional Friedel–Crafts conditions.

## Acknowledgements

## References and notes

1. (a) Olah, G. A. *Friedel–Crafts Chemistry*; Wiley: New York, 1973; (b) *Friedel–Crafts and Related Reactions*; Gore, P. H., Olah, G. A., Eds.; Wiley-Interscience: New York, 1964; Vol. III.
2. Franck, G.; Stadelhofer, J. W. *Industrial Aromatic Chemistry*; Springer: Berlin, 1988.
3. Sheldon, R. A. *Chem. Ind.* **1992**, *7*, 903; Harvey, G.; Mader, G. *Collect. Czech. Chem. Commun.* **1992**, *57*, 862.
4. Furniss, B. S.; Hannaford, A. J.; Smith, P. W. G.; Tatchell, A. R. *Vogels Text Book of Practical Organic Chemistry*, 5th ed.; Longman: Singapore, 1989; Kirk-Othmer, *Encyclopedia of Chemical Technology*, 5th ed.; 1997; Vol. 24, p 38.
5. Göndös, Gy.; Kapocsi, I. *J. Phys. Chem. Solids* **1996**, *57*, 855.
6. Pivsa-Art, S.; Okuro, K.; Miura, M.; Murata, S.; Nomura, M. *J. Chem. Soc., Perkin Trans. 1* **1994**, 1703.
7. Repichet, S.; Roux, C. L.; Roquesb, N.; Dubac, J. *Tetrahedron Lett.* **2003**, *44*, 2037.
8. Ross, J.; Xiao, J. *Green Chem.* **2002**, *4*, 129.
9. Kantam, M. L.; Ranganath, K. V.; Sateesh, M.; Balaji, K. S.; Choudary, B. M. *J. Mol. Catal. A: Chem.* **2005**, *225*, 15.
10. Canizares, P.; Carmona, M.; Lobato, J.; Martinez, F.; Rodrigo, M. A. *Ind. Eng. Chem. Res.* **2005**, *44*, 4178.
11. Louati, A.; Vataj, R.; Gabelica, V.; Lejeunec, M.; Mattc, D. *Tetrahedron Lett.* **2005**, *46*, 7499.
12. Yee, R.; Mallory, J.; Parrish, J. D.; Carroll, G. L.; Little, R. D. *J. Electroanal. Chem.* **2006**, *593*, 69.
13. Vukicevic, R. D.; Joksovic, L.; Konstantinovic, S.; Markovic, Z.; Mihailovic, M. L. *Bull. Chem. Soc. Jpn.* **1998**, *71*, 899.
14. Vukicevic, R. D.; Ratkovic, Z. R.; Vukicevic, M. D.; Konstantinovic, S. K. *Tetrahedron Lett.* **1998**, *39*, 5837.
15. Silvestri, G.; Gambino, S.; Filardo, G. *Electrochim. Acta* **1987**, *32*, 965.
16. Ahmed Isse, A.; Scialdone, O.; Galia, A.; Gennaro, A. *J. Electroanal. Chem.* **2005**, *585*, 220.
17. Gambino, S.; Filardo, G.; Silvestri, G. *J. Mol. Catal.* **1989**, *56*, 296.
18. *Representative procedure for electrochemical acylation:* Tetrabutylammonium bromide was crystallized from ethyl acetate and was dried under vacuum. The aluminium electrode was prepared by means of the following standard procedure: Polished with emery paper, degreased with acetone, etched with an aqueous solution of HCl (5%) + HF (2%), rinsed with distilled water and methanol and finally dried with warm air. This activation treatment was performed immediately before use. Stainless steel was used as the cathode. A solution of toluene (10 mmol) in 20 ml of dichloromethane was added to an undivided cell containing 1 g of electrolyte (tetrabutylammonium bromide), acetyl chloride (12 mmol) and 0.065 g of $AlCl_3$ (5 mol %). An aluminium anode (12.5 cm$^2$) and stainless steel cathode (10 cm$^2$) were placed in the solution and 50 mA of current was passed for 3 h at room temperature (30–35 °C). Nitrogen gas was purged throughout the reaction to remove HCl vapour.
   After completion of the reaction, the reaction mixture was poured into 50 ml of cold water and 5 ml of concd HCl was added with constant stirring. The product was extracted with diethyl ether (3 × 25 ml) and the ethereal layer was washed with water and dried over anhydrous sodium sulfate. The organic solvent was removed under reduced pressure and the product was identified by HPLC, IR and NMR spectroscopy.