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Trifluoromethanesulphonic Acid as a Catalyst in the Acylation of Phosphaferrocenes

R. M. G. ROBERTS and A. S. WELLS

Department of Chemistry, University of Essex, Wivenhoe Park, Colchester CO4 3SQ, Essex, U.K.

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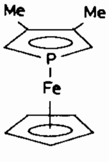
Abstract

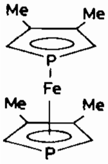
The use of trifluoromethanesulphonic acid (Triflic' acid) as an acid catalyst in Friedel–Crafts acylations results in much improved yields of the derivatives of 3,4-dimethylphosphaferrocene (I) whereas Lewis acid catalysts result in extensive decomposition. The method also provides a rapid route to the acylated derivatives of 3,3′4,4′-tetramethyldiphosphaferrocene (II) and ferrocenes.

Introduction

Ferrocene shows many classical electrophilic aromatic substitution reactions. This aromatic chemistry is paralleled by the phosphorus analogues I and II.



I 3,4-dimethylphosphaferrocene



II 3,3′4,4′-tetramethyldiphosphaferrocene

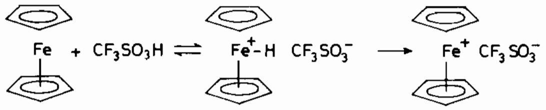
Mathey *et al.* have shown that both I [1] and II [2] undergo Friedel–Crafts substitution often in good yield for the diphosphaferrocene derivative **II**. However, acylation of **I** results in low yields [1]- undoubtedly due to oxidation by the aluminium trichloride catalyst.

In order to study the acyl derivatives of phosphaferrocenes, a high yield synthesis of these compounds seemed desirable. Triflic acid (CF_3SO_3H) is a very strong acid and has the advantage of being non-oxidizing. This acid has been shown to be a rapid and efficient catalyst giving much improved yields of the 2-acetyl and 2-benzoyl derivatives of **I**.

Discussion

Mixed triflic anhydrides have been reported to be very powerful acylating agents due to the high nucleofugacity of the triflate anion [3–5]. Benzene can be acylated by such mixed anhydrides without a catalyst [3, 4] and arenes acylated by acid chlorides and a catalytic amount of triflic acid [3, 4].

Since metallocenes in general are very reactive towards electrophilic aromatic substitution and triflic acid is non-oxidising and non-sulphonating, this seemed an ideal method for acylating metallocenes which are sensitive to Lewis acids. Some initial work on ferrocene indicated that the method was viable, although several drawbacks were encountered, the chief being oxidation to ferrocenium triflate due to ferrocene acting as a base and competing with the acyl substrate for the triflic acid. Oxidation occurs via disproportionation of the protonated ferrocene [6] (eqn. 1).



(1)

The removal of the substrate via protonation was not considered a major drawback as the amount of ferricinium produced was small and good yields of acyl derivatives obtained. 3,3′4,4′-Tetramethyldiphosphaferrocene (II) was found to be stable in neat triflic acid*. 3,4-Dimethyl phosphaferrocene was fairly unstable, however, the low concentration of triflic acid present was not considered to present a problem.

One factor which was apparent for the reaction with ferrocene was that the amount of triflic acid needed for good yields was stoichiometric rather

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*A. Wells and R. M. G. Roberts, unpublished results.

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TABLE I. Yields of Acylated Products

Product	Yield	Published method	Reference
2-acetyl-3,4-dimethylphosphaferrocene	65	17% (CH_3COCl $AlCl_3$, 2 h R.T.)	1
2-benzoyl-3,4-dimethylphosphaferrocene	62		
2-acetyl-3,3′4,4′-tetramethyldiphosphaferrocene	78	74% (CH_3COCl, $AlCl_3$, 3 h ~50 °C)	2
2-benzoyl-3,3′4,4′-tetramethyldiphosphaferrocene	71	42% (C_6H_5COCl, $AlCl_3$, 3 h 50 °C)	2

than catalytic (as in the case when arenes are reacted with acid chlorides [3, 4]).

The preferred procedure was to mix triflic acid with excess acid anhydride and then add ferrocene. Upon the addition of ferrocene, reaction mixtures turned instantly deep purple, indicative of protonated ferrocenyl ketones [7]. Thus the triflic acid freed after the reaction protonated the keto function of the product rather than being recycled. This is in keeping with the known high basicity of ferrocenyl ketones [7]. Such effects do not occur for the much weaker aryl ketone bases. Although CF_3SO_3H does not act as a true catalyst, it may be recovered as barium triflate after hydrolysis [3, 4].

Since simple ketones of the diphospha- and monophospha-ferrocene system show basicities comparable to ferrocenyl ketones* triflic acid was also used in a stoichiometric ratio. Ferrocenyl ketones are readily disubstituted as is 3,3′4,4′-tetramethyldiphosphaferrocene using $AlCl_3$. However the CF_3SO_3H method gave no traces of disubstituted products. Protonation of the mono ketone clearly strongly deactivates the molecule to further electrophilic attack.

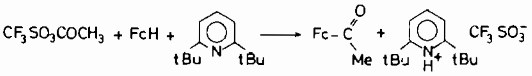
Using stoichiometric amounts of triflic acid, the method proved a rapid and clean route to the acetyl and benzoyl derivatives of **I** and **II**.

Results

The results given in Table I were obtained using excess acid anhydrides and a stoichiometric amount of triflic acid. The data were obtained for a reaction time of one hour at room temperature after the addition of the metallocene, although in some cases nothing appears to be gained from prolonging the reaction after the addition of the metallocene. Where available, previously published yields and conditions have also been given. Ferrocene could be acetylated and benzoylated in ~80 and 55% yields respectively by similar methods. The reaction appeared to be very fast, and a time dependence study was undertaken for ferrocene and acetic anhydride/triflic acid. The acid was first added to the anhydride then ferrocene in dichloromethane. After the addition of the ferrocene there was no difference in yield between quenching the reaction mixture immediately or allowing it to stand at room temperature for 1 h. Neither did the time allowed for reaction between the triflic acid and the anhydride appear to influence yields.

A series of experiments, in which triflic acid (1 equivalent) was added to a measured excess of acetic anhydride and ferrocene (1 equivalent), gave the following yields of acetylferrocene *t* = 1 min, 84%; *t* = 10 min, 82%; *t* = 60 min, 78%*. These results indicated that both the reaction between ferrocene and the acetylating medium and between triflic acid and the anhydride were fast. The formation of the mixed anhydride or protonated acetic anhydride is therefore very rapid.

In order to distinguish between the possible acetylating species, the reaction was modified by adding the sterically hindered base 2,6-di-t-butyl pyridine. Such bases are not N-acylated by triflic anhydrides [8] for steric reasons. Thus if the active species is a mixed triflic anhydride the base should be protonated by freed triflic acid after acetylation has taken place (eqn. 2). A protonated anhydride would be deprotonated by the pyridine base and hence no acetylation would occur. The addition of 2,6-di-t-butyl pyridine immediately after the triflic acid and before the addition of ferrocene resulted in no acetyl ferrocene being produced. Even allowing one hour triflic acid/anhydride reaction time before the addition of the base, there was no acetylation. This result strongly suggests that the acetylating agent is a protonated anhydride rather than a mixed triflic/anhydride, which differs from the behaviour when arenes are acylated with acid chlorides and triflic acid [4].



(2)

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*R. M. G. Roberts and A. S. Wells, unpublished results, (1983).

*This compares with a 71% yield from the original method of synthesis using Ac_2O/H_3PO_4 at 100 °C for 10 min (Ref. 12).

Acid chlorides could be used in place of anhydrides. The addition of triflic acid (1 equivalent) to excess acetyl chloride and benzoyl chloride immediately followed by ferrocene (1 equivalent in dichloromethane), on quenching gave acetylferrocene (65%) and benzoylferrocene (48%). The rapid reactions here imply that the acetylating agent is a protonated acid chloride as triflic acid/acid chloride does not appear to be a good route to triflic anhydrides [3, 4]. The use of acetic acid as an acetyl source proved ineffective. Despite being a very reactive system, all attempts to acetylate acetylferrocene failed, the mono acetyl compound being recovered in >80% yield, even after prolonged reaction times. The basic keto oxygen probably just deprotonates the protonated anhydride.

Conclusion

Whilst the use of triflic acid as a catalyst does not markedly improve the yields of acylferrocenes (*vide supra*), the method gave a great improvement in the yield of 2-acetyl-3,4-dimethylphosphaferrocene and proved a useful route to the 2-benzoyl derivative. The good yields obtained here confirm Mathey's observation that the low yield of phosphaferrocene derivatives when acetylated by standard Friedel–Crafts procedures, is due to decomposition rather than a lack of reactivtiy [9]. This method also gave a worthwhile improvement in the yield of 2-benzoyl-3,3′4,4′-tetramethyldiphosphaferrocene. The reaction appeared to proceed very rapidly, and the reaction time of one hour may well be lowered (see 'Results').

With 3,4-dimethylphosphaferrocene no Cp ring substitution was found, as in the case with the acid chloride/aluminium trichloride method [1]. The selectivity of the triflic acid method was checked using 1,1′-dimethyl ferrocene and gave identical isomeric distribution of the 1,2 and 1,3 products in 77% yield, as obtained by the acid chloride/aluminium trichloride method [10, 11]. Hence the electrophile does not appear to be reactive enough for a route to the hetero substituted acyl phosphaferrocenes. The lack of reactivity of the cyclopentadienyl ring is due to electron withdrawal by the phosphorus atom [9] rather than activation of the phosphacyclopentadienyl ring by the 3 methyl substituents, since the unsubstituted phosphaferrocene substitutes only on the phosphacyclopentadienyl ring [1].

Overall the method provides a useful alternative to Lewis acid catalysis in the Friedel–Crafts substitution of metallocenes and may prove a more successful route for derivatives which are susceptible to oxidation by Lewis acids. In this case the mechanism is probably via a protonated anhydride/acid chloride, we can see no reason why isolated triflates should not prove to be equally efficient; however, in the case of mixed alkyl triflic anhydrides, isolation is impaired by decomposition [3].

Experimental

All preparations were performed under dry N_2 or Ar. All manipulation involving phosphaferrocenes were carried out under N_2 to avoid atmospheric oxidation.

Trifluoromethanesulphonic acid was purchased from 3M Chemicals and used without further purification. Dichloromethane was dried over anhydrous calcium chloride prior to use.

Column chromatography was performed on active acidic alumina (BGI) freshly deactivated with 5% H_2O (wt/wt).

The identity of products was confirmed by comparison of ^1H NMR and IR spectra to authentic samples. Derivatives of 3,3′4,4′-tetramethyl diphosphaferrocene were synthesised as in ref. 2.

Ferrocene derivatives were purchased from Aldrich Chemical Co.

Spectral results for the derivatives of 3,4-dimethylphosphaferrocene have been reported in full.

^1H NMR spectra were run on a Varian EM 360 spectrometer in $CDCl_3$, δ are given in ppm relative to external TMS*. ^{31}P NMR were recorded on a Bruker WP80 spectrometer in $CDCl_3$ relative to 85% H_3PO_4 + ve downfield shift. The ^1H NMR spectrum of 2-acetyl-3,4-dimethylphosphaferrocene agrees with that given in ref. 11. Molecular weights are from M^+ in mass spectrum at 70 eV.

Microanalysis of 2-benzoyl-3,4-dimethylphosphaferrocene was performed by the Analytical Department, Manchester University.

For preparation of 3,4-dimethylphosphaferrocene and 3,3′4,4′-tetramethyldiphosphaferrocene, see refs. 1 and 2, respectively.

2-Acetyl-3,4-dimethyl Phosphaferrocene

Triflic acid (0.39 ml, 4.3 mmol) was added to excess acetic anhydride (~25 ml) and strirred under N_2 for 0.5 h. 3,4-Dimethylphosphaferrocene (1.0 g, 4.3 mmol) dissolved in CH_2Cl_2 (~5 cm^3) was added dropwise and the resulting purple solution stirred at room temperature for 1 h. The reaction mixture was quenched with excess water and anhydrous Na_2CO_3 added in small portions to hydrolyse the excess acetic anhydride. Upon completion of the hydrolysis, the product was extracted into CH_2Cl_2 (~100 ml) and the organic phase washed with water (2 × 100 ml). After drying over anhydrous sodium sulphate, the volume of the organic phase was reduced *in vacuo* and the residue chromatographed with diethyl ether as the eluent. A trace of unreacted 3,4-dimethyl-

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*s = singlet, d = doublet, m = multiplet.

phosphaferrocene was eluted first followed by the 2 acetyl derivative.

After evaporation, the product was recrystallised from petroleum ether (b.p. 60–80 °C) to give 2-acetyl-3,4-dimethylphosphaferrocene. 0.77 g (65% yield). Melting point 58 °C, Literature 61 °C [1]. ν(C=O) = 1680 cm^{-1} (nujol). Molecular weight: 274 (m/e). ^{1}H NMR: δ(Cp) 4.30(s) 5H; $\delta(H_\alpha)$ 4.16(d), ^{1}H, (^{2}J(P–H) 38 Hz); $\delta(\mathrm{Me}-\overset{\mathrm{O}}{\overset{\|}{\mathrm{C}}}-)$ 2.35(d), ^{4}J(P–H) 3 Hz, $\delta(\beta$Me) 2.26(s) 3H, 2.46 ppm(s), 3H. ^{31}P NMR: δ = –55.00 ppm.

2-Acetyl-3,3′4,4′-tetramethyldiphosphaferrocene

By a similar procedure 3,3′4,4′-tetramethyldiphosphaferrocene was acetylated as above. Dichloromethane/hexane (20/80 v/v) was used as the column eluant. The 2-acetyl derivative was produced in 78% yield. Melting point 70 °C, Literature 71 °C [2].

2-Benzoyl-3,4′-dimethylphosphaferrocene

Benzoic anhydride (0.98 g, 4.3 mmol) was dissolved in dry CH_2Cl_2 (~20 ml). Triflic acid (0.2 ml, 2.2 mmol) was added and the solution stirred under N_2 for 1 h. 3,4-Dimethylphosphaferrocene (0.5 g, 2.2 mmol) in CH_2Cl_2 (~5 ml) was added dropwise then stirred for 1 h at room temperature. The resulting work up was identical to that used for the acetyl derivative except that benzene was used as the column eluant.

The product was recrystallised from petroleum ether (b.p. 30–40 °C) at –15 °C to give red orange rods of 2-benzoyl-3,4-dimethylphosphaferrocene 0.45 g (62%). Melting point 71 °C. *Anal.* Found: C, 63.7; H, 5.0*. Calc. for $C_{18}H_{17}FeOP$: C, 64.3; H, 5.1%. Molecular weight: 336 (m/e). ν(C=O) 1645 cm^{-1} (Nujol). ^{1}H NMR: δ(Cp) 4.27(s), 5H; $\delta(H_\alpha)$ 4.13(d), 1H, ^{2}J(P–H) = 38 Hz; δ(phenyl) (H_o 7.90(m) 2H, $H_{m,p}$ 7.50(m) 3H). $\delta(\beta$Me) 2.20(s) 3H, 2.38 ppm(s) 3H. $\delta(^{31}$P) = –52.66 ppm.

2-Benzoyl-3,3′4,4′-tetramethyldiphosphaferrocene

3,3′4,4′-Tetramethyldiphosphaferrocene was benzoylated as above to give this compound in 71% yield. Melting point 68 °C, (Literature [2] 71 °C). Acetylferrocene and benzoylferrocene could be prepared using identical procedures to those given above.

References

1 F. Mathey, *J. Organomet. Chem., 139,* 77 (1977);

2 G. De Lauzon, B. Deschamps, J. Fischer, F. Mathey and A. Mitschler, *J. Am. Chem. Soc., 102,* 994 (1980).

3 F. Effenberger and G. Epple, *Angew. Chem., Int. Ed. Engl., 11,* 299 (1972).

4 F. Effenberger and G. Epple, *Angew. Chem., Int. Ed. Engl., 11,* 299 (1972).

5 R. M. G. Roberts and A. R. Sadri, *Tetrahedron, 39,* 137 (1983).

6 M. S. Foster and J. L. Beauchamp, *J. Am. Chem. Soc., 97,* 4814 (1975).

7 G. Neshvad, R. M. G. Roberts and J. Silver, *J. Organomet. Chem., 236,* 349 (1982).

8 T. Forbus, Jr. and J. C. Martin, *J. Org. Chem., 44* (2), 313 (1979).

9 F. Mathey, J. Fischer and J. H. Nelson, *Struct. Bonding (Berlin), 55,* 154 (1983).

10 M. Rosenblum, 'Chemistry of the Iron Group Metallocenes, Part 1', 1965, p. 72, Wiley-Interscience, New York.

11 G. K. Knox, I. G. Morrison, P. L. Pauson, M. A. Sandhu and W. E. Watts, *J. Chem. Soc. (C),* 1853 (1967).

12 P. J. Graham, R. V. Lindsey, G. W. Parshall, M. L. Peterson and G. M. Whitman, *J. Am. Chem. Soc., 79,* 3416 (1957).

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*Samples slowly oxidize on exposure to air.