niques were identical with those reported previously.[4] In a typical example, L(+)-butane-2-*d* was prepared by adding 8.0 g. (0.058 mole) D(+)-2-bromobutane to 1.0 g. (0.024 mole) lithium aluminum deuteride and 0.9 g. (0.10 mole) lithium deuteride in 50 ml. tetrahydrofuran at reflux temperature. The product was passed through two scrubbers containing 85% phosphoric acid, dried over sodium hydroxide pellets, and distilled: b.p. −2 to −1° (740 mm.) (lit.[17] $-1^1/_2$ to $^1/_2$°, for DL-butane-2-*d*); yield, 2.8 g., 82%. Additional physical constants are given in Table I.

RIVERSIDE, CALIF.

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(17) C. D. Wagner and D. P. Stevenson, *J. Am. Chem. Soc.*, **72**, 5785 (1950).

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, DUKE UNIVERSITY]

Certain Acylations of Ferrocene and Some Condensations Involving the α-Hydrogen of Acetylferrocene[1]

CHARLES R. HAUSER AND JACQUE K. LINDSAY

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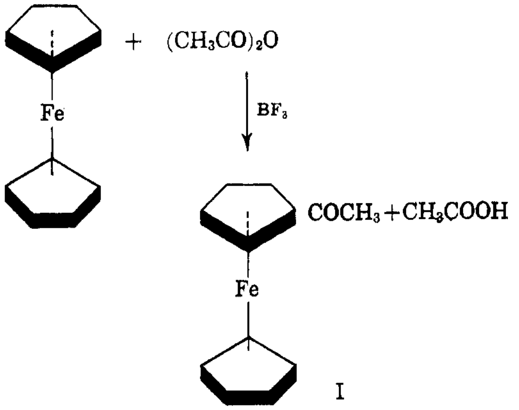
The boron fluoride method of acylation of ferrocene was developed, and some base-catalyzed aldol and Claisen type condensations involving the α-hydrogen of acetylferrocene were effected. The β-diketone from acetylferrocene and methyl benzoate was cyclized with hydrazine, and the β-keto ester from this ketone and ethyl carbonate was cyclized with phenylhydrazine. Attempts to effect boron fluoride catalyzed condensations involving the α-hydrogen of acetylferrocene were unsuccessful.

Earlier workers have shown that the Friedel-Crafts type of acetylation of ferrocene (dicyclopentadienyliron) to form acetylferrocene (I) may be effected with acetyl chloride by aluminum chloride,[2] and with acetic anhydride by hydrogen fluoride,[3] stannic chloride,[4] or boron fluoride.[2] The reaction may be illustrated with the last reagent (Equation 1).

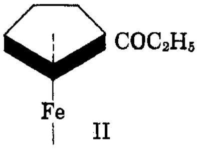


(1)

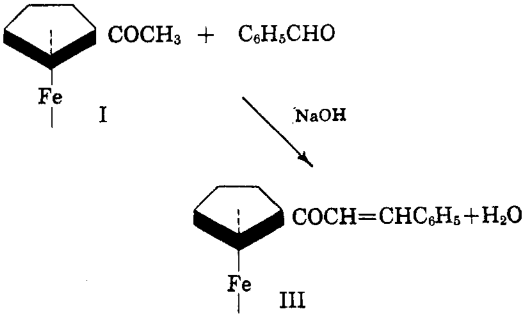
In the present investigation a study was made of the boron fluoride method of acylation of ferrocene,[5] and of some condensations involving the α-hydrogen of acetylferrocene (I).

The details of the earlier boron fluoride procedure for the acetylation of ferrocene have not been available.[2] Our procedure involved simply the saturation of a methylene chloride solution of ferrocene and acetic anhydride with the gaseous reagent at 0° (or the use of a boron fluoride-ethyl acetate complex), and the decomposition of the reaction mixture with aqueous sodium acetate. The yields of acetylferrocene (I) were 88–90%. This method appears preferable to those employing the other reagents listed above.

Similarly ferrocene was propionylated with propionic anhydride to form propionylferrocene (II) which was isolated in good yield as its oxime.



Several condensations involving the α-hydrogen of acetylferrocene (I) were realized satisfactorily with bases. Thus, the aldol type of condensation (accompanied by dehydration) was effected with this ketone and benzaldehyde by means of dilute sodium hydroxide to form α,β-unsaturated ketone III in 70% yield (Equation 2).



(2)

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[1] Supported by the Office of Ordnance Research, U. S. Army.

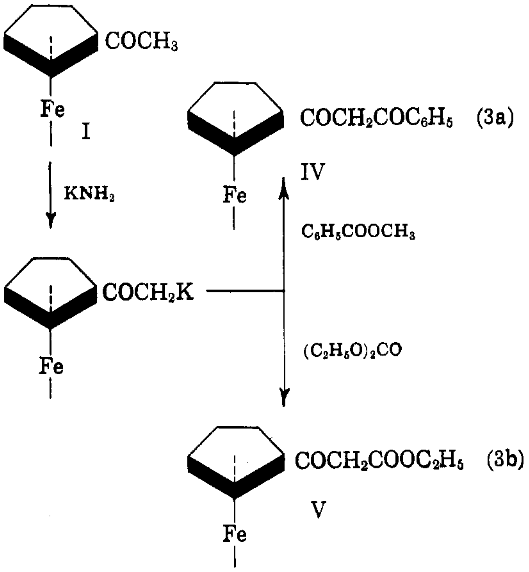
[2] See P. L. Pauson, *Quart. Revs.* (*London*), **9**, 392 (1955).

[3] V. Weinmayr, *J. Am. Chem. Soc.*, **77**, 3009 (1955).

[4] A. N. Nesmeyanov, E. G. Perevalova, R. V. Golovnya, and O. A. Nesmeyanova, *Doklady Akad. Nauk U.S.S.R.*, **97**, 459 (1954).

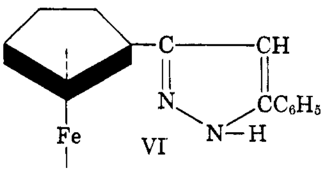
[5] We are indebted to Linde Air Products Co., Tonawanda, N. Y. (Dr. R. L. Pruett) for a generous sample of this compound.

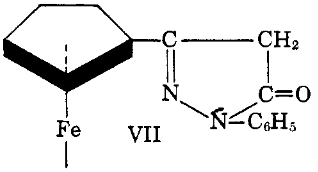
Two condensations of the Claisen type were effected by means of potassium amide in a mixture of liquid ammonia and ether. These reactions involved the benzoylation and carbethoxylation of acetylferrocene with methyl benzoate and ethyl carbonate to form β-diketone IV and β-keto ester V in yields of 63% and 65%, respectively (Equations 3a and 3b).



In order to achieve maximum yield based on acetylferrocene, one equivalent of this ketone was used to two equivalents each of the alkali amide and the ester.[6] The products were isolated by a modification of the usual procedure.[6] This involved filtering the ether suspensions of the potassium salts of the β-diketone and β-keto ester (after removing the liquid ammonia), and washing these salts with ether until free from unreacted starting materials. The free β-diketone and β-keto ester were then liberated by acidification. The benzoylation of acetylferrocene was also realized satisfactorily by means of sodium amide.

Cyclizations were effected between β-diketone IV and hydrazine and between β-keto ester V and phenylhydrazine to form pyrazole VI and pyrazolone VII in yields of 61% and 89%, respectively. β-Diketone IV was also converted in good yield to its copper chelate.





Although acetylferrocene underwent base-catalyzed aldol and Claisen condensations (Equations 2, 3a, and 3b) this ketone failed to undergo similar boron fluoride catalyzed reactions. Thus, acetylferrocene was recovered unchanged after treatment with benzaldehyde or acetic anhydride in the presence of boron fluoride. It has previously been shown that acetophenone may be condensed with benzaldehyde[7] and acetic anhydride[8] by means of this reagent (Equations 4 and 5).

$$C_6H_5COCH_3 + C_6H_5CHO \xrightarrow{BF_3} C_6H_5COCH{=}CHC_6H_5 + H_2O \quad (4)$$

$$C_6H_5COCH_3 + (CH_3CO)_2O \xrightarrow{BF_3} C_6H_5COCH_2COCH_3 + CH_3COOH \quad (5)$$

The failure of such condensations with acetylferrocene is rather surprising since, similar to acetophenone, this ketone was found to be converted by boron fluoride to a coordination complex although this complex appeared to be less reactive than that from acetophenone (see Experimental). It has been assumed[8] that the acetylation of acetophenone with acetic anhydride to form the β-diketone (Equation 5) involves the intermediate formations of an enol-type coordination complex from the ketone and a carbonium ion from the anhydride. Apparently the enol-type complex is not formed with acetylferrocene and boron fluoride or, if it is, it is not sufficiently reactive to condense with the carbonium ion from the anhydride. The influence of the iron in acetylferrocene is not clear but ferrocene, which has no ketone group, was shown not to form a complex with boron fluoride.

It is rather surprising also that the Friedel-Crafts type of acetylation involving the unsubstituted cyclophentadienyl ring of acetylferrocene did not occur on treatment with acetic anhydride and boron fluoride. Such a diacetylation of ferrocene to form diacetylferrocene has been observed with excess acetyl chloride and aluminum chloride.[9] Incidentally, in contrast to boron fluoride, aluminum chloride appears incapable of effecting the acylation of ketones at the α-hydrogen to form β-diketones.[10]

It should be mentioned that the oxime of acetylferrocene failed to undergo the Beckmann rearrangement with polyphosphoric acid or with boron fluoride in acetic acid. These reagents were

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[6] See (a) C. R. Hauser, F. W. Swamer, and J. T. Adams, *Org. Reactions*, **VIII**, 114 (1954); (b) R. Levine and C. R. Hauser, *J. Am. Chem. Soc.*, **66**, 1768 (1944).

[7] D. S. Breslow and C. R. Hauser, *J. Am. Chem. Soc.*, **62**, 2385 (1940).

[8] See Ref. 6a, pages 98–105.

[9] R. B. Woodward, M. Rosenblum, and M. C. Whiting, *J. Am. Chem. Soc.*, **74**, 3458 (1952).

[10] See H. G. Walker, J. J. Sanderson, and C. R. Hauser, *J. Am. Chem. Soc.*, **75**, 4109 (1953).

shown recently[11,12] to be especially effective for the rearrangement of ordinary ketoximes. Arimoto and Haven[13] reported the failure of the rearrangement of the oxime of acetylferrocene under the usual Beckmann conditions.

EXPERIMENTAL[14]

Acetylation of ferrocene to form ketone I. Procedure A. A stirred solution of 93.0 g. (0.5 mole) of ferrocene and 102 g. (1.0 mole) of acetic anhydride in 800 ml. of methylene chloride, cooled in an ice bath, was saturated with gaseous boron fluoride (copious evolution of white fumes). The amber-colored solution soon became deep purple. After stirring for 0.5 hr. the reaction mixture was allowed to come to room temperature during 4 hr. Excess aqueous sodium acetate solution was then added with stirring and cooling, and the two layers were separated. The methylene chloride layer (with which was combined a methylene chloride extract of the aqueous layer) was washed with water, followed by saturated sodium bicarbonate solution, and dried over magnesium sulfate. After filtering, the solvent was removed, and the residue recrystallized from hexane to give 102 g. (90%) of orange needles of acetylferrocene (I), m.p. 85–86°, reported[3] m.p. 85–86°.

Procedure B. A mixture of 264.3 g. (3.0 mole) of ethyl acetate and 100 ml. of ethylene chloride was saturated with boron fluoride at 0°,[15] and the resulting complex then added with stirring and cooling to a solution of 186 g. (1.0 mole) of ferrocene and 204 g. (2.0 mole) of acetic anhydride in 800 ml. of ethylene chloride. After 1 hr. in the ice bath and 3 hr. at room temperature, the reaction mixture was worked up as described above. The residue was recrystallized from hexane to give 201 g. (88%) of acetylferrocene (I) (orange needles), m.p. 84–86°.

Propionylation of ferrocene to form ketone II. This reaction was carried out essentially as described above for the acetylation (Procedure B) using propionic anhydride on a 0.1 mole scale. Propionylferrocene (II) was obtained as a viscous liquid (23 g.) a sample of which was converted to its oxime (amber plates), m.p. 140–142°.

Anal. Calcd. for $C_{13}H_{15}ONFe$: C, 60.72; H, 5.88; N, 5.45; Fe, 21.72. Found: C, 60.67; H, 5.78; N, 5.40; Fe, 21.52.

Condensation of acetylferrocene (I) *with benzaldehyde to form α,β-unsaturated ketone III.* To a stirred solution of 2.18 g. (0.055 mole) of sodium hydroxide in 20 ml. of water and 10 ml. of 95% ethanol, cooled to 15°, was added a solution of 9.8 g. (0.043 mole) of acetylferrocene (I) and 4.6 g. (0.043 mole) of purified benzaldehyde in 20 ml. of 95% ethanol. After stirring for 2 hr. at room temperatures, the thick, pink-colored reaction mixture was chilled and filtered. The solid was washed thoroughly with water, and recrystallized from 95% ethanol to give 9.4 g. (70%) of violet needles of α,β-unsaturated ketone III, m.p. 139–140°. A second recrystallization raised the melting point to 141–142°.

Anal. Calcd. for $C_{19}H_{16}OFe$: C, 72.17; H, 5.10; Fe, 17.66. Found: C, 72.28; H, 5.20; Fe, 17.60.

Condensation of acetylferrocene (I) *with methyl benzoate to form β-diketone IV.* To a stirred solution of 0.4 mole of potassium amide[16] in 500 ml. of liquid ammonia was added 45.6 g. (0.2 mole) of solid acetylferrocene over a 30-min. period to produce a yellow-green suspension. After stirring for 15 min. longer, a solution of 54.5 g. (0.4 mole) of redistilled methyl benzoate in 100 ml. of dry ether was added dropwise and the stirring continued for 1 hr. The ammonia was then allowed to evaporate as dry ether was added, and the resulting ether suspension stirred and refluxed for 10 min. After cooling slightly the thick, tan-colored paste was collected on a funnel, and washed rapidly with dry ether avoiding contact with moisture. The pale yellow solid was added to 500 ml. of water and 70 ml. of 6*N* hydrochloric acid and, after stirring thoroughly, the mixture was extracted with three portions of ether. The combined ethereal extract was washed with water, followed by saturated sodium bicarbonate solution, and dried over magnesium sulfate. After filtering and removing the solvent, the residue was recrystallized from *n*-heptane to give 41.5 g. (63%) of β-diketone IV (purple crystals) m.p. 106–107°.

Anal. Calcd. for $C_{19}H_{16}O_2Fe$: C, 68.70; H, 4.86; Fe, 16.81. Found: C, 68.51; H, 5.05; Fe, 16.61.

A sample of β-diketone IV in methyl alcohol was treated with aqueous copper acetate solution[17] to form the copper chelate which, after recrystallization from 10:1 benzene-petroleum ether, was obtained as purple plates, m.p. 234–235° dec. This chelate was reconverted to the β-diketone by shaking an ether suspension of it overnight with 20% phosphoric acid in a mechanical shaker.

Cyclization of β-diketone IV with hydrazine to form pyrazole VI. To a solution of 1 g. of β-diketone IV in 200 ml. of absolute ethanol was added a solution of 5 g. of 95% hydrazine in 10 ml. of absolute ethanol. The resulting solution was heated on the steam bath for 1 hr. (color changed from deep red to orange) and then allowed to cool slowly. Orange needles crystallized out and were recrystallized from absolute ethanol to give 0.6 g. (61%) of pyrazole VI, m.p. 267–269°.

Anal. Calcd. for $C_{19}H_{16}N_2Fe$: C, 69.53; H, 4.91; N, 8.54; Fe, 17.02. Found: C, 69.86; H, 5.18; N, 8.32; Fe, 16.70.

Condensation of acetylferrocene (I) *with ethyl carbonate to form β-keto ester V.* To a stirred solution of 0.4 mole of potassium amide in 500 ml. of liquid ammonia was added 45.6 g. (0.2 mole) of acetylferrocene (I) followed, after 10 min., by a solution of 47.2 g. (0.4 mole) of redistilled ethyl carbonate in 100 ml. of dry ether (added dropwise). The liquid ammonia was removed as more dry ether was added and the resulting ether suspension refluxed 30 min. The solid was collected on a funnel, washed well with dry ether, dissolved in water, and acidified with cold acetic acid. The oil was taken up in ether washed with saturated sodium bicarbonate solution, dried over magnesium sulfate, filtered, and the solvent removed. The oily residue slowly crystallized to give 39.1 g. (65%) of orange needles of β-keto ester V, m.p. 55–57°. Recrystallization from 9:1 hexane-benzene raised the melting point to 57.5–58.5°.

Anal. Calcd. for $C_{15}H_{16}O_3Fe$: C, 60.02; H, 5.37; Fe, 18.61. Found: C, 60.16; H, 5.57; Fe, 18.78.

Cyclization of β-keto ester V with phenylhydrazine to form pyrazolone VII. To a solution of 2 g. of β-keto ester V in 10 ml. of 95% ethanol was added a solution of 2 g. of phenylhydrazine in 10 ml. of 50% aqueous acetic acid. The mixture was heated to reflux and allowed to cool to room temperature. The solid was collected on a funnel, washed with water, and recrystallized from 95% ethanol to give 2.0 g. (89%) of pyrazolone VII (orange needles), m.p. 186–188° dec.

Anal. Calcd. for $C_{19}H_{16}N_2OFe$: C, 66.30; H, 4.69; N, 8.14; Fe, 16.23. Found: C, 66.35; H, 4.50; N, 8.14; Fe, 15.97.

Attempts to effect condensations of acetylferrocene (I) *by means of boron fluoride.* A solution of acetylferrocene and acetic anhydride in methylene chloride was saturated with boron fluoride at 0°. The amber-colored solution soon became deep purple. After 3 hr. at room temperature the

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[11] E. C. Horning and V. L. Stromberg, *J. Am. Chem. Soc.*, **74**, 2680 (1952).

[12] C. R. Hauser and D. S. Hoffenberg, *J. Org. Chem.*, **20**, 1482 (1955).

[13] F. S. Arimoto and A. C. Haven, Jr., *J. Am. Chem. Soc.*, **77**, 6295 (1955).

[14] Melting points and boiling points are uncorrected. Analyses are by Galbraith Laboratories, Knoxville, Tenn.

[15] See Ref. 6a, p. 131.

[16] See R. S. Yost and C. R. Hauser, *J. Am. Chem. Soc.*, **69**, 2325 (1947).

[17] See ref. 6a, p. 122.

reaction mixture was decomposed with sodium acetate solution. Acetylferrocene was recovered.

A solution of acetylferrocene and benzaldehyde in methylene chloride was similarly treated with boron fluoride (deep purple solution) followed by sodium acetate. The ketone was recovered.

When a methylene chloride solution containing only acetylferrocene was saturated with boron fluoride a deep purple colored solution was again obtained. Evaporation of the solvent in a vacuum desiccator left purple crystals which appeared to be stable on standing in the desiccator for one week. These crystals were hygroscopic but did not fume in air. They reacted readily with water to regenerate acetylferrocene (orange needles), the purple color being destroyed.

When a solution of acetophenone in methylene chloride was similarly saturated with boron fluoride at 0° and the resulting yellow solution evaporated, a yellow solid was obtained which fumed in air.[6a] The solid reacted readily with water to regenerate acetophenone.

Under similar conditions, a solution of ferrocene in methylene chloride failed to absorb boron fluoride. No color change was noted and ferrocene was recovered.

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[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY OF PURDUE UNIVERSITY]

A Quantitative Treatment for Electrophilic Reactions of Aromatic Derivatives[1-3]

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Received December 4, 1956

Electrophilic reactions do not obey the usual Hammett treatment, presumably because of resonance interactions of the *para-* substituents with the electron deficient center of the transition states. The utility of the σ^+ constants, recently developed for aromatic substitution, was examined. Excellent agreement between the calculated and observed rates was observed for the nineteen electrophilic reactions for which quantitative rate data are available. A statistical analysis of the results indicates that the measure of agreement is as good as that realized by the usual Hammett treatment in reactions where it has been considered applicable. These σ^+ values should have considerable utility in correlating both the nuclear and the side-chain electrophilic reactions of aromatic systems.

The Hammett Equation 1 has provided a quantitative approach to the correlation of a large number of side-chain reactions of aromatic derivatives.[4,5]

$$\log k/k^\circ = \rho\sigma \qquad (1)$$

However, this treatment has not been satisfactory for electrophilic aromatic substitutions or for side-chain reactions involving resonance interactions between an electron-deficient center and the substituents.[6]

An attempt was made to develop a set of substituent constants suitable for electrophilic reactions, but the data available were too few to provide a satisfactory test of the idea.[6] The prevailing view has been that the resonance contributions by the substituent will vary quite markedly from reaction to reaction, so that the electronic contribution of the substituent could not be reproduced by a constant, as required by the Hammett treatment.[7]

This view is quite reasonable. However, our success in correlating rate and orientation data in electrophilic aromatic substitution by means of σ^+ constants developed from the solvolysis of phenyldimethylcarbinyl chlorides[8] led us to explore their possible utility in other types of electrophilic reactions.

Solvolysis reactions. The σ^+ constants were developed from the rate data for the solvolysis of the substituted phenyldimethylcarbinyl chlorides.[8] This solvolysis is believed to proceed to the incipient formation of the phenyldimethylcarbonium ion in the transition state. A rigorous test of the utility of the σ^+ constants should be provided by an examination of their ability to correlate rate data in solvolytic reactions where the carbonium ions will be both more and less stable than the phenyldimethyl derivative.

Fortunately, there exist in the literature data on the solvolysis of substituted triphenylcarbinyl chlorides, benzhydryl chlorides and benzyl tosyl-

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[1] Directive Effects in Aromatic Substitution. XV.

[2] Supported by the Petroleum Research Fund of the AMERICAN CHEMICAL SOCIETY.

[3] Based upon a thesis submitted by Y. Okamoto in 1956 in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

[4] L. P. Hammett, *Physical Organic Chemistry,* McGraw-Hill Book Co., Inc., New York, 1940, chap. VII.

[5] H. H. Jaffé, *Chem. Revs.,* **53,** 191 (1953).

[6] D. E. Pearson, J. F. Baxter, and J. C. Martin, *J. Org. Chem.,* **17,** 1511 (1952).

[7] P. B. D. de la Mare, *J. Chem. Soc.,* 4450 (1954).

[8] H. C. Brown and Y. Okamoto, *J. Am. Chem. Soc.,* **79,** 1913 (1957). A number of resonance enhanced substituent constants based on the conversion of di- and triarylcarbinols into carbonium ions and on the ionization of triarylmethyl chlorides have recently been proposed by N. C. Deno and A. Schriesheim, *J. Am. Chem. Soc.,* **77,** 3051 (1955) and N. N. Lichtin and H. P. Leftin, *J. Phys. Chem.,* **60,** 164 (1956), respectively. For the limited number of cases where these constants can be compared with the σ^+ values based on the solvolysis data of the present study, the agreement is quite good.