

Ferrocene Derivatives. Part II. Arylation.*

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It is shown that aryl groups may be introduced into ferrocene by reaction with diazonium salts or with nitrosoacetanilide.

FERROCENE can be obtained by the reaction of *cyclopentadienylmagnesium bromide* (or of the alkali-metal derivatives of *cyclopentadiene*) with ferric chloride (Kealy and Pauson, *Nature*, 1951, **168**, 1039). In Part I* of this series, this method was extended to the preparation of di-, tetra-, and hexa-phenylferrocene from the corresponding phenyl-substituted *cyclopentadienes*. It was also shown that a small yield of monophenylferrocene can be obtained by using a mixture of *cyclopentadiene* and phenyl*cyclopentadiene*. The inaccessibility of phenyl*cyclopentadiene*, however, made this route impracticable on a larger scale. We now describe a reaction which makes mono- and di-phenylferrocene readily accessible and can be extended to other arylferrocenes.

Although ferrocene undergoes smooth Friedel-Crafts acylation (Woodward, Rosenblum, and Whiting, *J. Amer. Chem. Soc.*, 1952, **74**, 3458), other typical aromatic substitution reactions have been limited by the ease of oxidation of ferrocene to metalation with *n*-butyl-lithium (Benkeser, Goggin, and Schroll, *ibid.*, 1954, **76**, 4025). We have found that ferrocene is readily arylated on treatment with diazonium salts.† Adding benzenediazonium sulphate solution to approx. 1 mol. of ferrocene in glacial acetic acid causes steady evolution of gas during several hours at 0°. On chromatography of the product some ferrocene is always recovered. Allowing for this, a 65% yield of phenylferrocene (approx. 40% conversion) is obtained together with 9% of diphenylferrocene. A similar reaction occurred in acetone. By the use of other diazonium salts, *p*-methoxy-, *o*-methyl-, and *m*-chlorophenylferrocene were readily isolated in 35–45% yields. We have also applied the reaction with success to diazotised *p*-hydroxyaniline, anthranilic acid, and sulphanic acid.

The only limitation of the reaction is again due to the ease of oxidation of ferrocene and was encountered with 2 : 4-dinitroaniline: a considerable proportion of the ferrocene was converted into ferricinium salt, and the diazonium salt reduced to *m*-dinitrobenzene.

* Part I, *J. Amer. Chem. Soc.*, 1954, **76**, 2187.

† [Added 12.12.54.] An example of this reaction has recently been reported (Nesmeyanov, Perevalova, Golovnya, and Nesmeyanova, *Doklady Akad. Nauk S.S.S.R.*, 1954, **97**, 459), and ferricinium salts have been shown to undergo similar reactions (Weinmayr, *J. Amer. Chem. Soc.*, in the press).

Only in one experiment were we able to isolate a few dark purple crystals believed to consist of 2 : 4-dinitrophenylferrocene, but the amount was insufficient for complete characterization.

Intermediate behaviour was shown by *o*- and *p*-nitrobenzenediazonium salts. The expected nitrophenylferrocenes were readily isolated, but the yields were rather low and a strong smell of nitrobenzene together with the presence of much ferricinium salt indicated oxidation-reduction.

Disubstitution products are undoubtedly always formed in small yield, but we have isolated these only in a few representative cases. It is, however, clear from these that the second substituent enters preferentially the unsubstituted ring to yield the 1 : 1'-diarylferrocene. In the case of di-(*p*-methoxyphenyl)ferrocene a second isomer is readily isolated from the chromatogram although in much smaller yield. That this has one unsubstituted *cyclopentadiene* ring is indicated by the presence of characteristic bands in the infra-red spectrum (cf. Part I, *loc. cit.*), but it is unknown whether the second aryl group has entered at position 2 or 3 or into the first aryl group.

The diphenylferrocene fraction appeared chromatographically homogeneous and the recrystallized product was identical with the product described in Part I (*loc. cit.*). However, the material from the chromatogram was low-melting and the mother liquors from the recrystallizations gave a viscous oil, the infra-red spectrum of which showed bands characteristic of ferrocene derivatives with one unsubstituted ring.

To obtain larger amounts of diphenylferrocene, benzenediazonium sulphate was allowed to react with phenylferrocene, a 52% yield (26% conversion) being obtained together with a small amount of a triphenylferrocene of unknown orientation.

The arylation of ferrocene here described is reminiscent of the free-radical arylations studied chiefly by Gomberg and Hey and their collaborators, but our conditions differ sufficiently from those of a normal Gomberg reaction to raise doubts whether aryl radicals are involved in this case. To obtain further evidence the reaction conditions were varied. When ferrocene reacted in *cyclohexane* with the benzenediazonium chloride-zinc chloride complex or with *N*-nitrosoacetanilide, mono- and di-phenylferrocene were obtained in yields and proportions similar to those obtained in acetic acid. On the other hand ferrocene was not attacked by phenylazotriphenylmethane in warm *cyclohexane* or by phenyl radicals generated from a mixture of phenylmagnesium bromide and bromobenzene by cobaltous chloride or (cf. Part I) by benzoyl peroxide. It is considered probable that ferrocene and the diazonium salt form an intermediate complex which rearranges to give the observed products either directly, or *via* a ferricinium salt as suggested by the experiment in which acetone was used as solvent (see p. 369). A more detailed study is in progress.

EXPERIMENTAL

Light petroleum used had b. p. 40—60°.

General Method.—A solution of the appropriate diazonium chloride or sulphate was prepared in the conventional manner in as small a volume of water as convenient. This solution was rapidly dropped into a stirred solution of ferrocene (3 g.) in glacial acetic acid (100 ml.) at room temperature, under nitrogen. At the end of the reaction (which may conveniently be ascertained by testing a small sample of the mixture with alkaline β -naphthol) or next morning, water was added, followed by sufficient titanous sulphate solution to reduce any ferricinium salt present. The whole was then extracted with ether, washed with water and sodium carbonate solution, dried (Na_2SO_4), and evaporated. The residue was chromatographed on activated alumina, except in the case of the carboxylic and sulphonic acids.

Yields are based on unrecovered ferrocene.

Mono- and Di-phenylferrocene.—(a) Benzenediazonium sulphate prepared from aniline (1.5 ml.) was used. Light petroleum (b. p. 40—60°) was employed throughout the chromatographic separation. In a typical run 41% of ferrocene was recovered and, after allowance for this, the yields of mono- and di-phenylferrocene were 66% and 9% respectively. Both products after crystallization from light petroleum had m. p.s identical with and undepressed by those of the products described in Part I (*loc. cit.*). In larger-scale experiments ferrocene was removed from the products by steam-distillation before the chromatographic separation.

(b) With acetone in place of acetic acid, ferrocene yielded an immediate greenish-blue precipitate (presumably a ferricinium salt) on addition of aqueous benzenediazonium sulphate. Brisk evolution of nitrogen soon commenced and next morning the precipitate had completely redissolved. The clear brown solution yielded unchanged ferrocene (37%) and phenylferrocene (36%) together with small amounts of higher substitution products.

(c) The benzenediazonium chloride-zinc chloride double salt (Hodgson and Marsden, *J.*, 1940, 208) (3.7 g.), sodium acetate (0.6 g.), and glacial acetic acid (0.62 g.) were added to a stirred solution of ferrocene (3 g.) in cyclohexane (100 ml.) under nitrogen. After being kept overnight, the mixture was worked up as before, yielding phenylferrocene (33%) and diphenylferrocene (9%), after recovery of ferrocene (32%).

(d) *N*-Nitrosoacetanilide (2.64 g.) was rapidly added to the stirred solution of ferrocene (3 g.) in cyclohexane (100 ml.). The mixture was warmed to 50° to initiate the reaction and then kept at room temperature overnight. Working up as before gave ferrocene (54%) and mono- (46%) and di-phenylferrocene (8%).

Attempted Reaction of Ferrocene with Phenylazotriphenylmethane.—Phenylazotriphenylmethane (3.6 g.) was added to a solution of ferrocene (2 g.) in cyclohexane. The mixture was heated at 50–60° for 2 hr. and then at the boiling point until nitrogen evolution ceased. On evaporation and chromatography ferrocene was recovered almost quantitatively.

Further Phenylation of Phenylferrocene.—Phenylferrocene (5 g.) in acetic acid (150 ml.) was allowed to react with the diazonium sulphate prepared from aniline (2.13 g.). Light petroleum was employed for chromatography and separated unchanged phenylferrocene (49%) from diphenylferrocene (52%) and triphenylferrocene (10%), which crystallized from light petroleum as an orange powder, m. p. 116–118° (Found: C, 80.6; H, 5.7. $C_{28}H_{22}Fe$ requires C, 81.2; H, 5.4%).

o-Tolylferrocene.—The diazonium chloride prepared from *o*-toluidine (1.72 g.) was used. A mixture of light petroleum and cyclohexane effected chromatographic separation of the product from unchanged ferrocene (31%) and a small amount of ditolylferrocene (not isolated pure). *o*-Tolylferrocene (43%) crystallized from alcohol in orange leaflets, m. p. 51–52° (Found: C, 73.6; H, 6.0. $C_{17}H_{16}Fe$ requires C, 73.9; H, 5.8%).

m-Chlorophenyl- and Di-*m*-chlorophenyl-ferrocene.—The diazonium chloride was prepared from *m*-chloroaniline (2.1 g.). Light petroleum was used for chromatography. The first band consisted of unchanged ferrocene (30%). The second band yielded *m*-chlorophenylferrocene (34%) crystallizing from light petroleum in orange leaflets, m. p. 77–78° (Found: C, 64.7; H, 4.6. $C_{16}H_{13}ClFe$ requires C, 64.8; H, 4.5%). The final band afforded 1:1'-di-*m*-chlorophenylferrocene (0.4%), obtained as a microcrystalline powder, m. p. 183–184° from cyclohexane (Found: C, 64.9; H, 4.0. $C_{22}H_{16}Cl_2Fe$ requires C, 64.9; H, 4.0%).

p-Methoxyphenyl- and Di-*p*-methoxyphenyl-ferrocene.—The diazonium chloride was prepared from *p*-anisidine (2 g.). A mixture of cyclohexane and benzene was employed for chromatography, yielding ferrocene (54%) followed by *p*-methoxyphenylferrocene (35%), crystallizing from cyclohexane as orange-yellow leaflets, m. p. 112–114° (Found: C, 70.25; H, 5.6. $C_{17}H_{16}OFe$ requires C, 69.9; H, 5.5%). 1:1'-Di-*p*-methoxyphenylferrocene (7%), crystallizing from the same solvent as orange leaflets, m. p. 167–168° (Found: C, 72.4; H, 5.4. $C_{24}H_{22}O_2Fe$ requires C, 72.4; H, 5.6%), was isolated from the last (fourth) band of the chromatogram. An isomer (0.7%) forming dark orange crystals from cyclohexane, m. p. 112–114° (depressed to 90° on admixture with the monosubstitution product) was isolated from the intermediate (third) fraction (Found: C, 72.4; H, 5.7%).

p-Hydroxyphenylferrocene.—The diazonium chloride was prepared from *p*-aminophenol (4.7 g.). The product was strongly adsorbed on alumina and, after removal of unchanged ferrocene (20%) by benzene, was extracted by boiling the adsorbent with alcohol. *p*-Hydroxyphenylferrocene (14%) crystallized from absolute alcohol in orange-yellow leaflets, m. p. 163–164° (Found: C, 68.9; H, 5.3%. $C_{16}H_{14}OFe$ requires C, 69.1; H, 5.1%).

o-Carboxyphenylferrocene.—The diazonium chloride was prepared from anthranilic acid (2.2 g.). The ethereal solution of the products was extracted with 2*N*-sodium hydroxide. The neutral fraction gave ferrocene (66%). Acidification of the alkaline solution precipitated *o*-carboxyphenylferrocene (7%) which crystallized from light petroleum in orange needles, m. p. 128–129° (Found: C, 66.7; H, 4.7. $C_{17}H_{14}O_2Fe$ requires C, 66.7; H, 4.6%).

Barium p-Ferrocenylbenzenesulphonate.—The diazonium chloride prepared from sulphanilic acid (3.36 g.) was added to the ferrocene solution. After 12 hr. the mixture was diluted with water, titanous chloride added, and the precipitated ferrocene filtered off. Addition of aqueous barium chloride solution to the filtrate precipitated barium *p*-ferrocenylbenzenesulphonate as an

orange-brown powder. It was recrystallized from water (Found: C, 41.0; H, 4.1; S, 7.15. $C_{32}H_{26}O_6S_2BaFe_2 \cdot 6H_2O$ requires C, 40.7; H, 4.05; S, 6.8%. $C_{32}H_{26}O_6S_2BaFe_2 \cdot 5H_2O$ requires C, 41.5; H, 3.9; S, 6.9%).

o-Nitrophenylferrocene.—The diazonium chloride was prepared from *o*-nitraniline (4.46 g.). Chromatography with a mixture of cyclohexane and benzene separated unchanged ferrocene (23%) from *o*-nitrophenylferrocene (5%), which crystallized from light petroleum in purple plates, m. p. 112–114° (Found: C, 61.8, 63.1; H, 4.2, 4.7; N, 4.3. $C_{16}H_{13}O_2NFe$ requires C, 62.6; H, 4.3; N, 4.6%).

p-Nitrophenylferrocene.—The diazonium chloride was prepared from *p*-nitroaniline (4.46 g.). The chromatogram was developed with benzene–ether, separating unchanged ferrocene (20%) from *p*-nitrophenylferrocene (18%) which formed deep purple rhombs (from absolute alcohol), m. p. 169–170° (Found: C, 62.2; H, 4.35; N, 4.9%).

Reaction of Ferrocene with Diazotized 2:4-Dinitroaniline.—An acetic acid solution of the diazonium sulphate from 2:4-dinitroaniline (3 g.) was used. Chromatography of the products with benzene yielded ferrocene (40%) followed on the column by *m*-dinitrobenzene. The latter was always contaminated by a trace of purple material, but in only one experiment out of three could a few dark purple crystals be separated from the mother-liquors after crystallization of this fraction.

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