Some Reactions of Chloroferrocene with Organolithium Compounds[1]

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The reaction of chloroferrocene with butyllithium in hexane–tetrahydrofuran to afford butylferrocene, biferrocenyl, and some minor reaction products is reported. The same reaction when carried out in the presence of lithium piperidide affords also 1-ferrocenylpiperidine. The mechanism of these reactions is discussed.

Although it is well known that many aromatic halogen compounds react with strong base to afford products that can only be explained by invoking a "benzyne" intermediate,[2] there have been no reported examples of reactions of this type observed in the metallocene series. While there appear to be no *a priori* reasons why halometallocenes in general and haloferrocenes in particular should not undergo reactions of this type, it would be expected that the electron-rich nature of the metallocene nucleus, coupled with the inherent difficulty of forming a formal triple bond in a five-membered ring would cause reactions of the elimination–addition type to proceed less readily than in classical aromatic systems.

Our initial attempts to carry out reactions of haloferrocenes which would proceed *via* a benzyne-type (ferrocyne) intermediate involved the reactions of chloroferrocene[3] with various strong bases. Among the conditions employed were sodium and potassium amide in liquid ammonia and potassium ethylamide in ethylamine both at reflux and at 35° in a sealed tube. From all these reactions the only isolable material was recovered chloroferrocene. When chloroferrocene was allowed to react with a stronger base, namely phenyllithium, once again the only product, in addition to biphenyl, was recovered starting material. However, when chloroferrocene was treated with an even stronger base, butyllithium,[4] in ether–tetrahydrofuran, there was obtained, in addition to 22.6% ferrocene and 8.6% recovered chloroferrocene, 18.1% *n*-butylferrocene[5] and 6.75% biferrocenyl.[6] Although this reaction could be explained by a metal–halogen interconversion[7] (eq. 1) to give lithioferrocene and butyl chloride, followed by

$$C_5H_5Fe-C_5H_4Cl + C_4H_9Li \longrightarrow C_5H_5Fe-C_5H_4Li + C_4H_9Cl \quad (1)$$

$$C_4H_9Cl + C_5H_5-Fe-C_5H_4Li \longrightarrow n\text{-butylferrocene} \quad (2)$$

$$C_5H_5-Fe-C_5H_4Li + C_5H_5-Fe-C_5H_4Cl \longrightarrow \text{biferrocenyl} \quad (3)$$

Wurtz–Fittig reactions (eq. 2 and 3) to give the observed product, it could equally well be pictured as proceeding *via* a ferrocyne intermediate (Chart I). From this reaction there were also obtained small quantities (less than 1%) of two other ferrocene derivatives. One of these is almost certainly a derivative of terferrocenyl, since the experimentally determined molecular weight (590) cannot be accommodated by less than three ferrocene units. The ultraviolet spectrum is virtually identical with that of biferrocenyl, as would be expected for a terferrocenyl, and the infrared spectrum indicates no absorption due to any functional groups other than the ferrocene nucleus.

The nuclear magnetic resonance spectrum of this compound[8] was rather similar to that of biferrocenyl,[6] showing multiplets at τ 5.73 and 5.89 with a singlet at 6.04. By analogy with biferrocenyl the peaks at τ 5.73 arise from the protons β to the bond between ferrocene nuclei, the τ 5.89 signal is caused by the α-protons, and the τ 6.04 singlet is assigned to the protons on an unsubstituted ferrocene ring. The ratio of protons on a substituted ferrocene ring to those on an unsubstituted ring for 1,1′-terferrocenyl is 1.60, while for 1,2- or 1,3-terferrocenyl it is 0.734. Since the relative ratios of these protons determined experimentally was 1.45 ± 0.15, it appeared that this compound was probably 1,1′-terferrocenyl. However, direct comparison with 1,1′-terferrocenyl[9] indicated that, although the compounds had virtually identical infrared and ultraviolet spectra, they decomposed at different temperatures, had different R_f values on thin layer chromatography, and gave different X-ray powder patterns.[10] Although the mass spectrum of this compound indicates that it is a chloroterferrocenyl, there are at present insufficient data to permit any further assignment of structure.[11]

The second minor product was obtained in insufficient quantity to permit any characterization other than examination of its infrared and ultraviolet spectra (see Experimental).

In an attempt to trap a possible ferrocyne intermediate, chloroferrocene was treated with butyllithium in the presence of lithium piperidide in either ether–hexane or tetrahydrofuran–hexane. From this reaction was isolated, in addition to 1% recovered chloroferrocene, 21% ferrocene, 15% butylferrocene, and 10% biferrocenyl, a 9% yield of 1-ferrocenylpiperidine. Although once again the products could be accounted for in terms of classical halogen–metal interconversion and Wurtz–Fittig reactions, these products could equally well be explained by the reaction of lithium piperidide with a ferrocyne intermediate, combined with the reactions shown in Chart I.

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[1] Presented at the 147th National Meeting of the American Chemical Society, Philadelphia, Pa., April 1964.

[2] (a) H. Heaney, *Chem. Rev.*, **62**, 81 (1962); (b) R. Huisgen in "Organometallic Chemistry," H. Zeiss, Ed., Reinhold Publishing Corp., New York, N. Y., 1960, pp. 36–88.

[3] A. N. Nesmeyanov, W. A. Ssasonowa, and V. N. Drosd, *Ber.*, **93**, 2717 (1960).

[4] D. E. Applequist and D. F. O'Brien [*J. Am. Chem. Soc.*, **85**, 743 (1963)] have discussed the relative basicity of organolithium compounds.

[5] K. Schloegel, A. Mohar, and M. Peterlik, *Monatsh.*, **92**, 921 (1961).

[6] S. I. Goldberg, D. W. Mayo, and J. A. Alford, *J. Org. Chem.*, **28**, 1708 (1963). We would like to thank Dr. Goldberg for the gift of a sample of biferrocenyl.

[7] H. E. Gilman and R. G. Jones, *Org. Reactions*, **6**, 339 (1951).

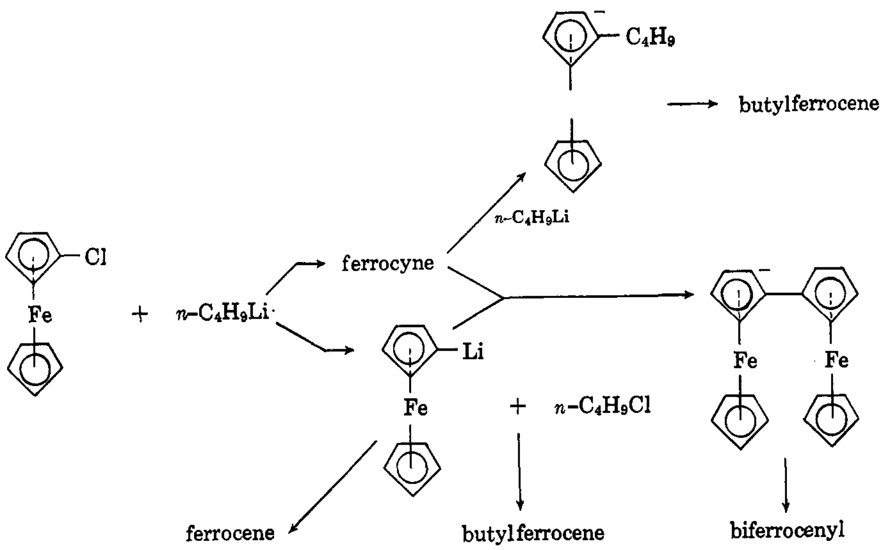
[8] We would like to thank Dr. Stanley I. Goldberg of the University of South Carolina for carrying out this measurement.

[9] K. L. Rinehart, D. G. Ries, and P. A. Kittle, Abstracts of Papers, 146th National Meeting of the American Chemical Society, Denver, Colo., Jan. 1964, p. 23C. We would like to thank Dr. Rinehart for a comparison sample of 1,1′-terferrocenyl.

[10] We would like to thank Dr. C. Q. Brown of Clemson University for carrying out the X-ray determination.

[11] K. L. Rinehart, private communication.

Chart I



If the products of these reactions were indeed arising *via* Wurtz–Fittig-type reactions, then it would be expected that reaction of chloroferrocene with either piperidyllithium or ferrocenyllithium should afford piperidylferrocene and biferrocenyl, respectively. However, when chloroferrocene was treated with these reagents no biferrocenyl or piperidylferrocene was obtained, excluding direct displacement reactions as a possible explanation for the formation of the products obtained when chloroferrocene is treated with butyllithium.[12] Although it is thus apparent that the formation of neither piperidylferrocene nor biferrocenyl could be explained by a direct displacement, the possibility remains that at least a portion of the *n*-butylferrocene was being produced by a preliminary halogen–metal interconversion, followed by the reaction of the butyl chloride produced with ferrocenyllithium. That this is indeed possible may be shown by the fact that ferrocenyllithium and *n*-butyl chloride afford a 45% yield of butylferrocene, based on 30% conversion of ferrocene to lithioferrocene. Although this experiment indicates that metal–halogen interconversion, followed by a Wurtz–Fittig reaction may account for at least some of the butylferrocene formed in the above reactions with butyllithium, it is not possible to give a quantitative estimation of the amount formed *via* each path on the basis of the above data.

An alternative explanation, which might well be used to explain all the above reactions, is that the observed products are the result of free-radical coupling reactions. This possibility was excluded when it was found that ferrocenyllithium, after being subjected to the conditions of the reactions with butyllithium, gave ferrocene as the only isolable product upon quenching with water. It would be expected that if these conditions were conducive to free-radical reactions, some biferrocenyl should have been formed in this experiment.[13]

It was also found, in agreement with the observations of Eastham and Gibson,[14] that when the reaction of chloroferrocene and butyllithium was carried out in hexane, no butylferrocene could be detected, and only a trace (0.7%) of biferrocenyl was formed. This is what would be expected in terms of the high degree of association of organolithium compounds in the absence of an ether.

Although all the above data tend to indicate that the reaction of chloroferrocene with butyllithium in tetrahydrofuran–hexane proceeds *via* a ferrocyne intermediate, in order to obtain additional evidence an effort was made to obtain a 2-substituted ferrocenecarboxylic acid by carbonation of the lithiated ferrocenes produced in these reactions. When the products of the reaction in tetrahydrofuran were carbonated, an intractable mixture of acids was obtained; however, when the reaction was carried out using ether as a cosolvent at either reflux or room temperature, a 31% yield of an acid, $C_{11}H_9ClFeO_2$, was obtained. The infrared spectrum of this product showed strong absorption at 9 and 10 μ, indicative of an unsubstituted cyclopentadiene ring.[15] Thus, the acid must be either 2- or 3-chloroferrocenecarboxylic acid. By analogy with the known position of lithiation of halobenzenes,[7] this compound should be the 2-chloro compound and this was confirmed by the n.m.r. spectrum.[8] This acid shows three one-proton multiplets at τ 5.32, 5.57, and 6.19 and a five-proton singlet at 5.95. In the n.m.r. spectrum of chloroferrocene the α-protons appear as a multiplet at τ 5.65 while those β to the chlorine appear at 6.05.[16] The α- and β-protons in ferrocenecarboxylic acid resonate at τ 5.11 and 5.51, respectively. Since the β-proton in 3-chloroferrocenecarboxylic acid is also α to the carboxyl group it would be expected to be relatively deshielded and appear somewhat downfield from the protons on the unsubstituted ring.

The neutral fractions from the above reactions gave 5% recovery of chloroferrocene and 3% yield of ferrocene when the reaction was carried out at reflux and 21% recovery of chloroferrocene and 2% of ferrocene at room temperature. In neither case could any butyl-

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(12) R. Huisgen, W. Mack, and L. Moebius [*Tetrahedron*, **9**, 29 (1960)] have found that piperidyllithium converts fluoro- and chlorobenzene to benzyne many times faster than does the much stronger base phenyllithium, and have suggested a lithium–hydrogen exchange *via* a four-membered cyclic transition state (see ref. 1b, p. 59). It would seem probable that the electron-rich nature of the ferrocene nucleus is responsible for the failure of chloroferrocene to react in this manner.

(13) (a) M. S. Kharasch, D. W. Lewis, and W. B. Reynolds, *J. Am. Chem. Soc.*, **65**, 598 (1943); (b) I. J. Spilners and J. P. Pellegrini, Abstracts of Papers, 148th National Meeting of the American Chemical Society, Chicago Ill., Sept. 1964, p. 55.

(14) J. F. Eastham and G. W. Gibson, *J. Am. Chem. Soc.*, **85**, 2171 (1963).

(15) M. Rosenblum and R. B. Woodward, *ibid.*, **80**, 5443 (1958).

(16) S. I. Goldberg, private communication.

ferrocene be detected. When the reaction under these conditions was quenched with water it was found that biferrocenyl had been formed in 11% yield, but again, no butylferrocene could be detected. No biferrocenyl could be detected in those cases where the reaction was quenched by pouring onto Dry Ice; however, this experiment is inconclusive since biferrocenyl might well be lithiated after it was formed.

Since the typical elimination–addition reaction path outlined in Chart I demands that biferrocenyl and butylferrocene be formed simultaneously from ferrocyne, the formation of biferrocenyl alone must proceed by a different path. Since ferrocenyllithium and chloroferrocene themselves do not afford biferrocenyl, it seems apparent that excess butyllithium must be necessary for coupling and that the biferrocenyl must arise from a termolecular coupling reaction involving butyllithium, chloroferrocene, and ferrocenyllithium.[14] A similar mechanism may also be invoked to explain the formation of piperidylferrocene, and indeed would account for all the products obtained from this reaction as well. Although this explanation adequately accounts for the major products of the reaction of chloroferrocene with butyllithium, the possibility that at least a portion of these products are formed *via* a ferrocyne intermediate cannot be excluded. In particular, the lithiation of chloroferrocene α to the halogen, and the formation of butylferrocene from chloroferrocene, butyllithium, and lithium piperidide seem to indicate that the ferrocyne intermediate may well be playing a role in these reactions.

The above reactions are similar to the reactions of iodoferrocene with butyllithium reported by Schecter[17]; however, the product distribution is somewhat different. Schecter apparently obtained no butylferrocene, but did obtain some metal–halogen interconversion as evidenced by the formation of ferrocenecarboxylic acid upon carbonation of the crude reaction mixture. The biferrocenyl obtained by these workers probably arises from the termolecular reaction of iodoferrocene, lithioferrocene, and butyllithium.[14] Under our reaction conditions iodoferrocene afforded ferrocene as the only isolable product in 8% yield, the balance of the material apparently undergoing gross decomposition.

Experimental[18]

Reaction of Chloroferrocene with Sodamide.—To about 30 ml. of liquid ammonia was added with stirring, 0.025 g. of clean metallic sodium and a crystal of ferric nitrate. After the blue color was discharged, another 0.025 g. of sodium (total 0.05 g., 0.002 g.-atom) was added. To the colorless mixture, 0.22 g. (0.001 mole) of chloroferrocene[3] was added and the solution was stirred at reflux overnight. The ammonia was allowed to evaporate, the yellow residue was taken up in ether and extracted with 10% hydrochloric acid, and the blue aqueous solution was made basic with 10% sodium hydroxide. This afforded an orange precipitate which could neither be filtered nor extracted with organic solvents. Removal of solvent from the organic solution gave 0.17 g. (77%) of recovered chloroferrocene, m.p. 59–60°.

Similar conditions were employed using 0.6 g. (0.015 g.-atom) of potassium metal in about 40 ml. of ammonia with 0.22 g. of chloroferrocene. Once again, no basic material could be obtained.

Reaction of Chloroferrocene with Potassium Ethylamide.—About 25 ml. of ethylamine was condensed, and to this was added three small pieces of clean metallic potassium. After 1 hr. a crystal of ferric nitrate was added and after 1 additional hr. the metal finally dissolved. To this solution 0.22 g. (0.001 mole) of chloroferrocene was added and the solution was heated at reflux for 7 hr., after which the solvent was allowed to boil off. The residue was taken up in 20 ml. of ether and the yellow ethereal solution was extracted with three 5-ml. portions of 1% hydrochloric acid. The light blue aqueous solution was made basic with dilute sodium hydroxide solution and the resulting pale yellow solution was extracted with ether. The pale yellow ethereal solution was dried over magnesium sulfate and filtered, and the solvent was removed leaving 3–5 mg. of ferrocene.[19]

Removal of the solvent, after drying, from the ethereal solution gave 0.16 g. (73%) of recovered chloroferrocene.

The above reaction was repeated on the same scale but at 35° for 48 hr. in a Parr bottle. Similar work-up of the reaction mixture gave a trace of an unidentified neutral yellow oil and a trace of a nonferrocenyl basic material.

Reaction of Chloroferrocene with Phenyllithium.—To a solution of 0.88 g. (0.004 mole) of chloroferrocene in 40 ml. (0.020 mole) of phenyllithium in ether was added 0.5 ml. (0.005 mole) of piperidine and 10 ml. of tetrahydrofuran. The solution was heated at reflux for 4 hr. under nitrogen and then poured over cracked ice. The aqueous layer was drawn off and extracted with ether. The orange organic solution was extracted with 10% hydrochloric acid, washed well with water, dried over anhydrous magnesium sulfate, and filtered, and the solvent was removed. The residue was chromatographed on Merck acid-washed alumina to give a mixture of chloroferrocene and biphenyl.

Reaction of Chloroferrocene with Butyllithium. A.—To 0.22 g. (0.001 mole) of chloroferrocene in 5 ml. of tetrahydrofuran, was added 20 ml. (0.032 mole) of *n*-butyllithium in hexane (Foote Mineral Co.) and the solution was refluxed for 7 hr. under nitrogen. The reaction was terminated by pouring the mixture over cracked ice and the aqueous layer was drawn off and extracted with ether. The extracts were combined with the original organic layer, dried over anhydrous magnesium sulfate, and filtered, the solvent was removed, and the residue was chromatographed on Merck reagent grade alumina. The quantity and per cent of the theoretical yield of ferrocene, chloroferrocene, and butylferrocene were determined from the vapor phase chromatogram of the first fraction which was eluted with petroleum ether (b.p. 30–60°). Further elution with benzene–hexane gave biferrocenyl. The results of this reaction are summarized in Table I. When this reaction was repeated using 4.41 g. of chloroferrocene there was obtained a small quantity (0.02 g.) of a substance which was eluted from an alumina column with 2:3 benzene–hexane. This compound formed orange crystals, m.p. 207–212° dec. from benzene–hexane, and is probably a chloroterferrocenyl.

TABLE I
RESULTS OF THE REACTION OF CHLOROFERROCENE WITH *n*-BUTYLLITHIUM

Components of the reaction mixtures	% yield
Ferrocene	22
Chloroferrocene	9
n-Butylferrocene	18
Biferrocenyl	7

Anal.[20] Calcd. for $C_{30}H_{25}ClFe_3$: C, 61.22; H, 4.28; mol. wt., 588. Found: C, 63.31, 62.74, 63.50; H, 4.23, 5.42, 4.89; mol. wt., 590.

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(17) H. J. Schecter and J. F. Helling, *J. Org. Chem.*, **26**, 1034 (1961).

(18) Al melting points were taken on a Fisher-Johns melting point block unless otherwise stated, and are uncorrected. Infrared spectra were taken on a Perkin-Elmer Model 137 spectrophotometer either as liquid films on sodium chloride plates or as potassium bromide disks. Vapor phase chromatograms were carried out at a column temperature of 200° on a Perkin-Elmer Model 154D vapor fractometer with a 0.25 in. × 2 m. column of silicone grease on diatomaceous earth (Perkin-Elmer column O_X). Microanalysis were formed by Galbraith Laboratories, Knoxville, Tenn. All reactions employing organolithium compounds were carried out under nitrogen.

(19) All the chloroferrocene used in this work was contaminated with 8 to 10% ferrocene. In our hands this mixture resists separation by all the usual methods.

(20) We have not been able to obtain reproducible analyses for this material.

The infrared spectrum was very similar to that of biferrocenyl and 1,1′-terferrocenyl. The direct comparison of the properties of this compound with those of 1,1′-terferrocenyl[9] is summarized in Table II. The ultraviolet spectrum of this compound has λ_{max} (ethanol) 265 mμ (sh) (log ϵ 4.23) and 301 mμ (log ϵ 4.17) while 1,1′-terferrocenyl shows λ_{max} 264 (sh) and 301 mμ with extinction coefficients similar to those of our material.

TABLE II

	Chloroterferrocenyl (?)	1,1′-Terferrocenyl
M.p., °C.	207–212 dec.	215–234 dec.
M.m.p., °C.	180–206 dec.	
R_f (alumina G, benzene)	0.801	0.785
R_f (alumina G, benzene–hexane, 1:1)	0.717	0.709

A trace (0.005 g.) of another compound, which formed orange crystals from benzene–hexane, m.p. 221–224° dec., was obtained from the 3:2 benzene–hexane fraction of the chromatogram; however, there was insufficient material for analysis. The infrared spectrum showed bands at 2.90, 3.20, 3.41, and 6.16 μ, and absorption in the 9–10-μ region typical of ferrocenes with one unsubstituted ring.[15] The ultraviolet spectrum has λ_{max} 268 (sh) and 307 mμ; however, the compound was too insoluble in normal solvents to permit the determination of extinction coefficients. There was insufficient material for analysis.

B.—To a solution consisting of 0.109 g. (4.94×10^{-4} mole) of chloroferrocene which was contaminated with 11.0 mg. (0.592×10^{-4} mole) of ferrocene, in 2.40 ml. of anhydrous ether and 2.40 ml. of anhydrous hexane prepared in an oven-dried flask was added 4.00 ml. of 1.45 *N* butyllithium in hexane (5.80×10^{-3} mole). The reaction mixture was heated at reflux for 7 hr. in a nitrogen atmosphere, and the contents were poured over crushed ice.

After warming to room temperature, the aqueous and the organic layers were separated and the aqueous portion was extracted with ether. The combined ethereal extracts were washed with water, 2% aqueous hydrochloric acid, and dried over magnesium sulfate. The solvent was removed at reduced pressure and room temperature.

Chromatography of the crude product on Merck acid-washed alumina gave two distinct orange bands. The first, which was eluted with hexane, consisted of 74% ferrocene (59.2 mg., 53% yield) and 23% chloroferrocene (20.6 mg., 19% recovery); analysis was by gas chromatography. The second band, eluted with benzene, gave 0.01 g. of biferrocenyl, identical in all respects with that obtained in part A.

Reaction of Chloroferrocene with *n*-Butyllithium in the Presence of Piperidine. A.—To a solution of 1.76 g. (0.008 mole) of chloroferrocene in 20 ml. of purified tetrahydrofuran was added 78 ml. (0.101 mole) of *n*-butyllithium in hexane, followed by 2.0 ml. (0.020 mole) of piperidine. The solution was heated at reflux 7 hr. under nitrogen. After the additions were complete the solution turned dark brown and a finely divided solid suspension (lithium chloride) appeared.

The reaction was terminated by pouring the mixture over cracked ice, the aqueous layer was drawn off and extracted with ether until the extracts were colorless, and the extracts were combined with the original organic phase. The ethereal solution was extracted with four 15-ml. portions of 10% hydrochloric acid, washed well with water, dried over anhydrous magnesium sulfate, and filtered, and the solvent was removed. The residual mixture of neutral material was chromatographed on Merck reagent alumina. Elution with petroleum ether gave 0.625 g. of a mixture of ferrocene, chloroferrocene, and butylferrocene in a ratio of 16.8 to 1 to 12, by gas chromatography. Elution with 1:1 benzene–hexane gave first 0.10 g. of a mixture of biferrocenyl and the compound, m.p. 203–210 dec., obtained above, and then 0.155 g. of biferrocenyl.

The dark brown aqueous extract was made alkaline with 10% sodium hydroxide and extracted twice with ether. The ethereal extracts were combined, dried over anhydrous magnesium sulfate, and filtered, the solvent was removed, and the dark brown residue was chromatographed on Merck alumina. Elution with 1:1 hexane–benzene gave 0.20 g. (9.3%) of piperidylferrocene, m.p. 97–100°. Recrystallization from hexane gave the analytical sample, m.p. 103–104°.

Anal. Calcd. for $C_{15}H_{19}FeN$: C, 66.93; H, 7.12; N, 5.20; mol. wt., 269. Found: C, 66.71; H, 7.12; N, 4.97; mol. wt., 273.

B.—To 0.88 g. (0.004 mole) of chloroferrocene was added 10 ml. of dry ether, 14 ml. of butyllithium solution (0.020 mole), and 1.0 ml. (0.010 mole) of piperidine. The solution was heated at reflux for 7 hr. and poured into an ice–water mixture, the layers were separated, and, after extraction with ether, the aqueous solution was discarded. The combined organic solution was extracted with 10% aqueous hydrochloric acid and the product was isolated as described above. Chromatography of the basic material on Merck reagent alumina gave 0.080 g. (7%) of piperidylferrocene, m.p. and m.m.p. 90–99°.

Chromatography of the neutral material on reagent alumina and gas chromatography of the hexane fraction gave 36% ferrocene (0.122 g., 16.8% yield), 49% chloroferrocene (0.166 g., 18.9% recovery), and 15% butylferrocene (0.052 g., 5.4% yield).

Elution with 1:1 hexane–benzene gave 0.135 g. (9%) of biferrocenyl.

Reaction of Chloroferrocene with Piperidyllithium.—To a solution of 6 ml. (0.060 mole) of piperidine in 10 ml. of tetrahydrofuran was added 31 ml. (0.040 mole) of *n*-butyllithium in hexane at such a rate that an even reflux was maintained. The solution was stirred for 15 min. after the addition was completed and cooled to room temperature; 0.88 g. (0.004 mole) of chloroferrocene and 3 ml. of petroleum ether were added, bringing the total volume to 50 ml. The solution was heated at reflux under nitrogen for 7 hr. during which time it slowly turned brown. A Gilman test with Mischler's ketone after 2.5 hr. was negative.

The reaction was terminated by pouring the reaction mixture over cracked ice, and the products were isolated as described above for the reaction of chloroferrocene with *n*-butyllithium in the presence of piperidine. There was obtained 0.063 g. (8.5%) of ferrocene and 0.458 g. (52%) of chloroferrocene.

Reaction of Lithioferrocene with *n*-Butyllithium.—Monolithioferrocene was prepared from 0.372 g. (0.0020 mole) of ferrocene and 3 ml. of *n*-butyllithium solution in 10 ml. of anhydrous ether.[21] After stirring at room temperature for 6 hr., 19 ml. (0.025 mole) of *n*-butyllithium solution, 8 ml. of ether, and 10 ml. of tetrahydrofuran were added. After refluxing for 7 hr., the reaction mixture was poured over cracked ice and the aqueous layer was separated and extracted with ether, the extracts being combined with the organic layer. The organic solution was washed with water, dried over magnesium sulfate, and filtered, and the solvent was removed. The residue was chromatographed on Merck alumina to give 0.270 g. (73%) of ferrocene as the only isolable product. Gas chromatography of the crude product indicated that it was homogeneous.

Reaction of Lithioferrocene with *n*-Butyl Chloride.—Lithioferrocene was prepared from 0.93 g. (0.005 mole) of ferrocene in 10 ml. of anhydrous ether and 10 ml. (0.016 mole) of *n*-butyllithium solution.[20] At the end of this time a 2.0-ml. aliquot was withdrawn and carbonated according to the standard procedure, indicating that 30% conversion to lithioferrocene had been effected.

After withdrawal of the 2-ml. aliquot, 5 ml. of tetrahydrofuran and 1.85 g. (2.1 ml., 0.020 mole) of *n*-butyl chloride were injected into the reaction mixture and the solution was heated at reflux for 7 hr. The reaction was terminated by pouring the reaction mixture over cracked ice. The aqueous layer was drawn off and extracted with ether, the extracts being combined with the organic solution. After washing the organic phase with water it was dried over anhydrous magnesium sulfate and filtered, and the solvent was removed. The residue was chromatographed on Merck reagent alumina to give 0.662 g. of a 3 to 1 mixture (by gas chromatography) of ferrocene and butylferrocene. A trace, 0.02 g., of low-melting yellow solid was also obtained.

Reaction of Ferrocenyllithium with Chloroferrocene.—To a solution of ferrocenyllithium[21] from 0.744 g. (0.004 mole) of ferrocene and 3.0 ml. (0.0048 mole) of butyllithium in 30 ml. of ether was added 0.882 g. (0.004 mole) of chloroferrocene dissolved in 10 ml. of dry tetrahydrofuran and 7 ml. of ether. The solution was heated at reflux for 7 hr. and poured into ice water and the products were isolated as described above to give 1.390 g. of a mixture containing 62% ferrocene and 38% chloroferrocene. Thin layer chromatography on alumina G of the traces of ma-

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[21] S. I. Goldberg, L. H. Keith, and T. S. Prokopov, *J. Org. Chem.*, **28**, 850 (1963).

terial eluted from the chromatogram with more polar solvents showed no biferrocenyl or other recognizable compounds.

Reaction of Iodoferrocene with *n*-Butyllithium.—To 0.31 g. (0.001 mole) of iodoferrocene[17] in 8 ml. of anhydrous tetrahydrofuran was added 32 ml. (0.051 mole) of *n*-butyllithium in hexane. The solution was heated at reflux for 7 hr. under nitrogen, cooled, and poured onto ice. The aqueous layer was drawn off and extracted with ether until the extracts were colorless. The ethereal extracts were combined, dried, concentrated to about 10 ml., and chromatographed on Merck acid-washed alumina. Elution with hexane gave 0.015 g. (8.2%) of ferrocene, and further elution with hexane–benzene and benzene–ether mixtures gave only oils. Vapor phase chromatography and thin layer chromatography on alumina G both failed to detect any butylferrocene or biferrocenyl.

2-Chloroferrocenecarboxylic Acid. A.—To 1.76 g. (0.008 mole) of chloroferrocene was added 10 ml. of butyllithium solution (0.014 mole), 10 ml. of ether, and 10 ml. of hexane. The solution was stirred at room temperature for 7 hr. and then poured into a Dry Ice–ether slush. Water was added and the aqueous layer was drawn off. The ethereal solution was extracted with 5% sodium bicarbonate and dried and the solvent was removed at reduced pressure to give a mixture of 7% ferrocene (0.028 g., 1.9% yield) and 93% chloroferrocene (0.362 g., 20.6% recovery); analysis was by gas chromatography.

The aqueous layer was acidified and extracted with ether. After drying, removal of the solvent *in vacuo* gave 1.66 g. of a yellow solid which decomposed rapidly in air when impure. Recrystallization from hexane gave 0.060 g. of material, m.p. 170–172° (evacuated capillary).

Anal. Calcd. for $C_{11}H_9ClFeO_2$: C, 49.95; H, 3.43; Cl, 13.40. Found: C, 49.81; H, 3.46; Cl, 13.51.

B.—When the reaction was carried out at reflux using 1.76 g. of chloroferrocene there was obtained, in addition to 3% ferrocene and 5% chloroferrocene, 0.71 g. (crude) of the chloro acid, identical in all respects with that prepared in part A, above.

Studies on Resin Acids. II.[1] Synthesis of Some Tricyclic Steroid Analogs

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1-Ketonordehydroabietane (II) has been converted to a variety of tricyclic steroid analogs. Condensation of II with ethyl formate and base, followed by oxidation gave the seco diacid IV. Cyclization of the diester of this acid gave *cis*-1a-methyl-3-oxo-7-isopropyl-1,1a,2,3a,4,5-hexahydronaphthalene (V) which was converted to the ethynylcarbinol VI with the lithium acetylide–ethylenediamine complex. This acetylenic alcohol was rearranged to a Δ^{16}-20-keto steroid analog (VII) and also converted to a 17-hydroxy-20-keto steroid analog (X). The stereochemistry of these compounds is discussed.

Although various tricyclic steroid analogs have been prepared in the past, these compounds have all been made by relatively laborious totally synthetic routes.[3] The resin acids and, more specifically, dehydroabietic acid (I) appear to present an attractive source of a tricyclic steroid nucleus, with the A-ring of the resin acid becoming the D-ring of the des-A steroid.[4]

The starting material chosen for these synthetic efforts was 1-ketonordehydroabietane (II), which has been prepared in several steps from dehydroabietic acid.[1,5] Although the over-all yield by the modified version of this sequence is 39%,[1] the procedure is laborious and a new two-step synthesis has been devised. Reaction of dehydroabietic acid with lead tetraacetate affords $\Delta^{1\text{-}exo}$-dehydroabietene, the olefin corresponding to II, in 80% yield.[6] Ozonization of the olefin and reduction of the ozonide with zinc dust affords the ketone in 65% yield[1]; however, the crude product from this procedure shows strong infrared absorption at 2.92 in addition to the carbonyl band at 5.86 μ.[7] Consequently, the ozonide was decomposed with potassium iodide and the liberated iodine was then reduced with thiosulfate giving the ketone in 90% yield (72% for two steps).[8]

Condensation of the ketone with ethyl formate and base to the formyl derivative III followed by oxidation to the seco diacid IV proceeded smoothly. By analogy with II[1] and the cyclopentanone obtained on cyclization of IV (*vide infra*), it is assumed the diacid has the *cis* stereochemistry indicated (see Scheme I).

The dimethyl ester of this diacid was cyclized to *cis*-1a-methyl-3-oxo-7-isopropyl-1,1a,2,3a,4,5-hexahydrocyclopenta[*a*]naphthalene (V), using the method of Johnson.[9] The rotatory dispersion curve[10] of this ketone shows a strongly positive Cotton effect, and by analogy with A-nor-3-ketocholanic acid[11] has a *cis* ring fusion. Attempted direct cyclization of the acid IV with acetic anhydride[12] failed and afforded a compound which, although apparently a ketone, was not the desired material and is still of unknown structure.

The cyclopentanaphthalene V was envisioned as being the precursor of a series of compounds possessing a pregnane side chain and may itself be considered to be an equilenin analog. Reaction of the ketone with

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[1] Part I: J. W. Huffman and R. F. Stockel, *J. Org. Chem.*, **28**, 506 (1963).

[2] Abstracted from the thesis presented by P. G. Arapakos in partial fulfillment of the requirements for the Ph.D. degree.

[3] (a) L. J. Chinn, H. L. Dryden, and R. R. Burtner, *J. Org. Chem.*, **26**, 3910 (1961), and references cited therein; (b) N. A. Nelson, J. C. Wollensak, R. L. Foltz, J. B. Hester, J. I. Brauman, R. B. Garland, and G. H. Rasmusson, *J. Am. Chem. Soc.*, **82**, 2569 (1960).

[4] It should be noted that this approach suffers principally from the facts that this gives a steroid analog of unnatural configuration with the methyl group and hydrogen at the CD bridgeheads interchanged.

[5] (a) H. H. Zeiss and W. B. Martin, *J. Am. Chem. Soc.*, **75**, 5935 (1953); (b) A. Brossi, H. Gutman, and O. Jeger, *Helv. Chim. Acta*, **33**, 1730 (1950); (c) R. P. Jacobsen, *J. Am. Chem. Soc.*, **75**, 4709 (1953).

[6] N. A. Ayer, C. E. McDonald, and J. B. Stothers [*Can. J. Chem.*, **41**, 1113 (1963)] have carried out a similar reaction on a levopimaric acid derivative

[7] The presence of the band at 2.92 μ is apparently caused by partial reduction of the ketone by the zinc employed to reduce the ozonide.

[8] We would like to thank Dr. C. B. S. Rao of these laboratories for his assistance with the ozonizations.

[9] (a) W. S. Johnson, B. Bannister, and R. Pappo, *J. Am. Chem. Soc.*, **78**, 6331 (1956); (b) W. S. Johnson, R. Pappo, and W. F. Johns, *ibid.*, **78**, 6339 (1956).

[10] We would like to thank Professor Werner Herz of Florida State University for carrying out this determination.

[11] C. Djerassi, "Optical Rotatory Dispersion," McGraw-Hill Book Co., Inc., New York, N. Y., 1960, p. 97.

[12] (a) T. Rull and G. Ourisson, *Bull. soc. chim. France*, 1573 (1958); (b) J. F. Biellmann and G. Ourisson, *ibid.*, 341 (1962).