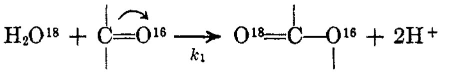
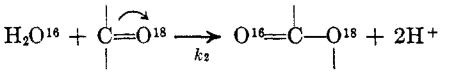
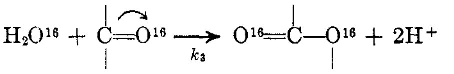
The theoretical value of the ratio, $C_6H_5CO^*O/C_6H_5COO$, in product of inverted configuration (*threo* fraction from I) is based on the following equations.



$$H_2O^{18} + C{=}O^{16} \xrightarrow[k_1]{} O^{18}{=}C{-}O^{16} + 2H^+ \qquad (7)$$



$$H_2O^{16} + C{=}O^{18} \xrightarrow[k_2]{} O^{16}{=}C{-}O^{18} + 2H^+ \qquad (8)$$



$$H_2O^{16} + C{=}O^{16} \xrightarrow[k_3]{} O^{16}{=}C{-}O^{16} + 2H^+ \qquad (9)$$

The relative amounts of the three benzoyloxy species formed in the reactions will be in the same proportion as the relative rates of the reactions. In calculating the relative rates, the relative concentrations of total isotopic species of water and of carbonyl oxygen in the hydroxyamide are constant[20] and may be disregarded. If it is assumed that there is no isotope effect, *i.e.*, that the specific reaction rates, k_1, k_2, and k_3, are equal, each relative rate, v, or abundance of benzoyloxy species, may be represented as equal to the product of isotopic abundances. For eq 7, $v_1 = (0.017 \pm 0.001) \times 0.998 = 0.017 \pm 0.001$, $^{18}O{=}CO^{16}$; for eq 8, $v_2 = (0.983 \pm 0.001) \times 0.002 = 0.002$, $^{16}O{=}CO^{18}$; for eq 9, $v_3 = (0.983 \pm 0.0001) \times 0.998 = 0.981 \pm 0.001$, $^{16}O{=}CO^{16}$.

In mass spectrometry, $^{18}O{=}C{-}O^{16}$ and $^{16}O{=}C{-}O^{18}$ are equivalent; hence, the theoretical value, 0.019 ± 0.001, of the ratio, $C_6H_5CO^*O/C_6H_5COO$, is based on the sum of the abundances of the two species.

The theoretical value ($0.006 = 0.019 \times 0.12 + 0.004 \times 0.88$) for the ratio of benzoyloxy species in the *erythro*-rich fraction from I is derived from that calculated for inverted substance, the value 0.004 characteristic of normal benzoic acid and expected in substance formed *via* the R mechanism, and the polarimetrically determined composition of the fraction.

Acknowledgments.—The author is grateful for a critical review of the manuscript provided by the late G. Forrest Woods, Professor of Chemistry, University of Maryland. For microanalyses, he acknowledges his indebtedness to Dr. W. C. Alford and his associates, Microanalytical Laboratory, National Institutes of Health. For helpful discussions on mass spectrometry, he wishes to thank Mr. E. E. Hughes, Analytical Chemistry Division, National Bureau of Standards, who also performed the analyses.

---

[20] In view of the low value of the ratio of hydroxyamide to water (1:230), one can ignore the effect of change in the original abundance of O^{18} in the aqueous system owing to the formation of water of normal isotopic composition in the displacement of the hydroxyl group at C-1.

Preparation and Reactions of Ferrocenyl(trichloromethyl)carbinol and of Metal Derivatives of Ferrocene

WILKINS REEVE AND EDWARD F. GROUP, JR.[1]

Chemistry Department, University of Maryland, College Park, Maryland 20740

Received March 11, 1966

The syntheses of some new derivatives of ferrocene employing condensation and metalation reactions are described. Ferrocenyl(trichloromethyl)carbinol has been prepared by four methods: from ferrocene by a Friedel–Crafts reaction with chloral, from chloromercuriferrocene and chloral with aluminum chloride, from ferrocenylmagnesium bromide and chloral, and from ferrocenecarboxaldehyde and chloroform. The ferrocenylmagnesium bromide was prepared from lithioferrocene and magnesium bromide. The carbinol was converted into α-methoxyferroceneacetic acid by treatment with potassium hydroxide in methanol. The methoxy acid was also prepared in one step from ferrocenecarboxaldehyde, bromoform, and methanolic potassium hydroxide. Lithioferrocene reacts normally with ethylene oxide, propylene oxide, and styrene oxide, but not with chloral, and a halogen–metal interchange reaction occurs with 3,3,3-trichloro-1,2-epoxypropane.

It has been shown that ferrocenecarboxaldehyde enters into many condensation reactions typical of aromatic aldehydes.[2,3] In the present work, a new condensation reaction was studied, namely the one-step conversion of an aromatic aldehyde to an α-methoxyarylacetic acid by treatment with bromoform and methanolic potassium hydroxide.[4] From ferrocenecarboxaldehyde (I) the α-methoxyferroceneacetic acid (II) was formed in 73% yield. Almost all α-methoxyphenylacetic acids are strong plant-growth regulators, but the α-methoxyferroceneacetic acid was found to be inactive when tested on bean plants;[5] strongly indicating that plants metabolize the ferrocenyl group more readily than the phenyl group.

Ferrocenecarboxaldehyde was found to react with chloroform, using potassium *t*-butoxide in *t*-butyl alcohol as the base, to form ferrocenyl(trichloromethyl)carbinol (III), the intermediate in the one-step synthesis of α-methoxyferroceneacetic acid (II). On treatment with methanolic potassium hydroxide, III gave the α-methoxyferroceneacetic acid (II) in 57% yield.

The reaction of ferrocene with a twofold excess of chloral in the presence of aluminum chloride was investigated as an alternative route to the trichloromethylcarbinol (III). Methylene chloride was used as the solvent. The best yield obtained was 21% of theory. Two per cent of the disubstitution product, 1,1′-di(2,2,2-trichloro-1-hydroxyethyl)ferrocene, was obtained and 60% of the starting ferrocene was recovered. In this reaction, the solvent and the amount of aluminum chloride employed are critical; with carbon disulfide as the solvent, only traces of products could be isolated. With methylene chloride as the solvent, too little aluminum chloride results in no reaction, and more than the optimum amount (0.25 mole/mole of chloral) resulted in the formation of an olefin as the major product in 15% yield. The olefin is tentatively assigned the formula (2,2-dichlorovinyl)ferrocene (IV). The mechanism by which this is formed probably involves the intermediate formation of (1,2,2,2-tetrachloroethyl)ferrocene and the subse-

---

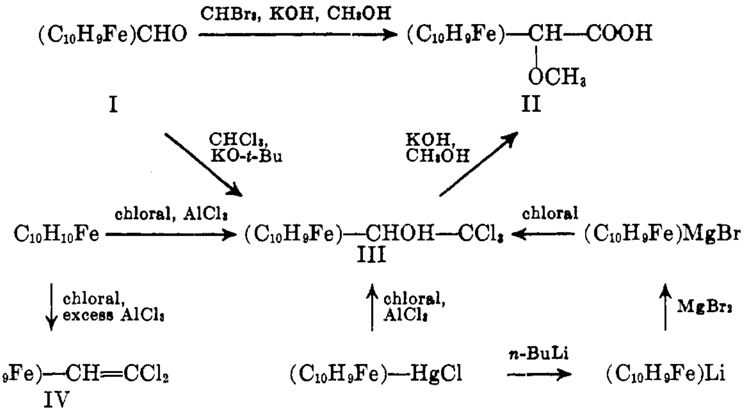
[1] American Cyanamid Teaching Fellow, 1960–1961.

[2] K. Plesske, *Angew. Chem. Intern. Ed. Engl.*, **1**, 323 (1962).

[3] M. D. Rausch, *Can. J. Chem.*, **41**, 1289 (1963).

[4] W. Reeve and E. L. Compere, *J. Am. Chem. Soc.*, **83**, 2755 (1961).

[5] We are indebted to Dr. J. W. Mitchell and co-workers of the U. S. Department of Agriculture, Beltsville, Md., for studying the plant growth regulating properties of this compound.



quent removal of two chlorines by the excess ferrocene acting as a reducing agent. It is known that halobenzenes react with chloral and aluminum chloride to form (1,2,2,2-tetrachloroethyl)halobenzenes under the reaction conditions employed.[6] Spectroscopic evidence for the assigned structure consists of nmr data clearly showing a monosubstituted ferrocene with one side-chain proton. The infrared spectrum bears a close resemblance to that of β,β-dichlorostyrene in that all six of the bands between 935 and 665 cm^{-1} are common to both, and it differs from the spectra of *cis*- and trans-α,β-dichlorostyrene in the presence of a medium intensity band at 870 and the absence of a strong band at 790 cm^{-1}. The only absorption band not present was one at 750 cm^{-1} which is common to all three of the dichlorostyrenes.

The yield of the trichloromethylcarbinol (III) was increased to 25% when the above reaction was carried out in methylene chloride starting with chloromercuriferrocene instead of ferrocene and using 0.25 mole of aluminum chloride per mole chloral. Doubling the amount of aluminum chloride did not change the yield of the product. Olefin IV was not formed in these reactions.

Others have studied the mercuration of ferrocene[7,8] and the transmetalation reaction of chloromercuriferrocene with ethyllithium.[9] In this work, chloromercuriferrocene in ether was treated with slightly more than the theoretical amount of *n*-butyllithium and the reactions of the resulting lithioferrocene reagent were studied. It reacted normally with ethylene oxide, propylene oxide, and styrene oxide to give the expected alcohols. However, with a slight excess of chloral none of the expected ferrocenyl(trichloromethyl)carbinol (III) was obtained, a result which is in accord with the observed failure of phenyllithium to add to the carbonyl group of chloral in the normal manner.[10] Also, like phenyllithium,[10] lithioferrocene reacts with 3,3,3-trichloro-1,2-epoxypropane to yield only 3,3-dichloroallyl alcohol.

Ferrocenylmagnesium bromide has been prepared from bromoferrocene, but the latter comes from lithioferrocene through ferrocenylboronic acid.[11] In this work, an improved method of preparing this Grignard reagent was developed involving the treatment of lithioferrocene with anhydrous magnesium bromide in ether. The reaction occured immediately as evidenced by a change in color of the reaction mixture from red to yellow-orange. Reaction of the freshly prepared Grignard reagent with chloral yielded the trichloromethylcarbinol III in 21% yield. Much ferrocene was also obtained. The formation of the trichloromethylcarbinol is in accord with the known normal addition of arylmagnesium bromides to chloral to form the corresponding trichloromethylcarbinols.[10] Reaction of the Grignard reagent with 3,3,3-trichloro-1,2-epoxypropane yielded only 3-bromo-1,1,1-trichloro-2-propanol, a result in accord with the known reaction of phenylmagnesium bromide with this epoxide.[10] The Grignard reagent reacted normally with carbon dioxide to yield the known ferrocenecarboxylic acid.

Experimental Section

All melting and boiling points are corrected. Analyses are by Dr. Franz J. Kasler. The infrared spectra were determined on a Beckman IR-5. The nmr spectra were determined on a Varian Associates A-60 spectrometer except for olefin IV which was determined by Dr. E. Becker of the National Institutes of Health on a Varian Associates HR-60 spectrometer.

α-Methoxyferroceneacetic Acid from Aldehyde I.—To an ice-cold solution of ferrocenecarboxaldehyde[12] (5 g, 0.023 mole) and freshly distilled bromoform (7.1 g, 0.028 mole) in 75 ml of methanol was added a solution of potassium hydroxide (6.6 g, 0.117 mole) in 100 ml of methanol over a period of 1 hr. The temperature of the reaction mixture did not exceed 5°. Nearly all of the solvent was removed under reduced pressure and the residue was taken up in ether and water (50 ml). On acidification of the ice-cold water layer, there was precipitated 5.0 g (73% of theory) of α-methoxyferroceneacetic acid monohydrate as yellow crystals, mp 65–66°. The analytical sample was crystallized from 25% ethanol and melted at 66–67.

Anal. Calcd for $C_{13}H_{14}FeO_3 \cdot H_2O$: C, 53.45; H, 5.52; neut equiv, 292. Found: C, 53.51; H, 5.52; neut equiv, 292.

An 82.7-mg sample lost 4.8 mg (theory, 5.1 mg) after vacuum drying in a desiccator over phosphorus pentoxide, and the dried sample had the theoretical neutralization equivalent of 274. Absorption bands at 3390, 2410, and 1946 cm^{-1} were present in the infrared spectra of the hydrate but absent in the dried sample. The anhydrous acid was a brownish, apparently amorphous solid: ν_{max}^{Nujol} 1720 (carbonyl), 1295, 1250, 1215, 1115 and 950 (monosubstituted ferrocene), 1035, 937, 822, and 715 cm^{-1}.

α-Methoxyferroceneacetic Acid from Carbinol III.—Three grams of ferrocenyl(trichloromethyl)carbinol (III) was allowed to react with 2.5 g of potassium hydroxide in 60 ml of methanol at 50° for 2 hr. The solvent was removed under reduced pres-

---

[6] W. Reeve, J. P. Mutchler, and C. L. Liotta, *Can. J. Chem.*, **44**, 575 (1966).

[7] A. N. Nesmeyanov, E. G. Perevalova, R. V. Golovnya, and O. A. Nesmeyanova, *Dokl. Akad. Nauk SSSR*, **97**, 459 (1954); *Chem. Abstr.*, **49**, 9633 (1955).

[8] M. Rausch, M. Vogel, and H. Rosenberg, *J. Org. Chem.*, **22**, 900 (1957).

[9] D. Seyferth and J. F. Helling, *Chem. Ind.* (London), 1568 (1961).

[10] W. Reeve and L. W. Fine, *J. Am. Chem. Soc.*, **86**, 880 (1964).

[11] H. Shechter and J. F. Helling, *J. Org. Chem.*, **26**, 1034 (1961).

[12] A. I. Titov, E. S. Lisitsyna, and M. R. Shemtova, *Dokl. Akad. Nauk SSSR*, **130**, 341 (1960); *Chem. Abstr.*, **54**, 10986 (1960).

sure, and the residue was washed from the flask with alternate 10-ml portions of ether and water. Acidification of the aqueous layer yielded 1.5 g (57% of theory) of the α-methoxyferroceneacetic acid monohydrate.

Ferrocenyl(trichloromethyl)carbinol (III) from Ferrocenecarboxaldehyde (I).—To 10 g (0.047 mole) of ferrocenecarboxaldehyde, 40 ml of sodium-dried benzene, and 20 ml (0.24 mole) of chloroform, there was added 0.06 mole of potassium *t*-butoxide in *t*-butyl alcohol dropwise over a period of 45 min at between −5 and 0°. The reaction mixture was stirred for 90 min near 0° and then poured onto a mixture of 6 ml of concentrated hydrochloric acid and some ice. The organic layer was washed with 5% sodium bicarbonate solution and water and dried overnight over anhydrous magnesium sulfate. The crude product amounted to 13 g. From this, 2.5 g (32% yield) of ferrocenyl(trichloromethyl)carbinol was recovered, either by crystallization from benzene or by chromatography on Fisher adsorption alumina using dry benzene as the solvent. A small amount of ferrocenecarboxaldehyde, appearing as a darker band, preceded the yellow carbinol band. The carbinol melted at 145° dec, but, after recrystallization from 50:50 ethanol–water, it melted at 157–158° without immediate decomposition if the sample was placed in the melting point bath at 145°: $\nu_{\max}^{\text{Nujol}}$ 3435 (OH), 1295, 1255, 1225, 1190, 1110 and 1005 (monosubstituted ferrocene), 1075, 1030, 925, 820 ($Cl_3CCHROH$), 700, and 670 cm^{-1}; nmr ($\nu_{\max}^{\text{DCCl}_3}$) δ 4.95 (doublet, J = 4 cps, one proton, $C\mathit{H}OH$), 4.55 (broad singlet, two protons, ring protons, presumably those adjacent to side chain), 4.35 (singlet, seven protons, remaining ring protons), 3.17 (doublet, J = 4 cps, one proton, $CHO\mathit{H}$).

Anal. Calcd for $C_{12}H_{11}Cl_3FeO$: C, 43.22; H, 3.33; Cl, 31.90. Found: C, 43.25; H, 3.60; Cl, 32.08.

Ferrocenyl(trichlorcmethyl)carbinol (III) from Ferrocene.—To a mixture of 37 g (0.2 mole) of ferrocene and 59 g (0.4 mole) of anhydrous chloral dissolved in 400 ml of methylene chloride was added 13.4 g (0.1 mole) of anhydrous aluminum chloride in portions over a 3-hr period at 0° under a nitrogen atmosphere. The mixture was allowed to stand for 2 hr at room temperature and then decomposed with an ice and hydrochloric acid mixture. Ten grams of ferrocene was recovered from the blue aqueous layer by reduction with stannous chloride. The methylene chloride layer was washed with dilute hydrochloric acid and with water and dried, and the solvent was evaporated. The residue consisted of 34 g of dark material. This was dissolved in dry benzene and chromatographed on adsorption alumina. The first band consisted of 11 g of ferrocene. The second band yielded 14 g of ferrocenyl(trichloromethyl)carbinol (21% of theory, 49% allowing for recovered ferrocene). A final yellow band (2 g) was eluted with a mixture of ether and acetone; this was shown to be the symmetrically disubstituted trichloromethylcarbinol of ferrocene.

The 14-g fraction of ferrocenyltrichloromethylcarbinol melted at 145° dec, initially, and at 157–158° after crystallization from 50:50 ethanol–water.

The final 2-g band, after crystallization from ethanol–water, yielded the yellow **1,1′-di(2,2,2-trichloro-1-hydroxyethyl)ferrocene**, mp 170–171° dec (2% yield). The structure was assigned on the basis of the absence of characteristic monosubstitution bands at 1108 and 1002 cm^{-1} in the infrared spectrum and the presence of bands at 3390 (hydroxyl), 820, 702, and 665 cm^{-1} [the latter three are similar to those observed in ferrocenyl(trichloromethyl)carbinol]; nmr ($\nu_{\max}^{\text{DMSO}}$) δ 7.12 (doublet, J = 7 cps, two protons, $CHO\mathit{H}$), 5.07 (doublet, J = 7 cps, two protons, $C\mathit{H}OH$), 4.50 (doublet, J = 15 cps, eight protons, ring protons). In dimethyl sulfoxide solvent, the CHOH part of the spectrum of phenyltrichloromethylcarbinol is almost identical with the above.

Anal. Calcd for $C_{14}H_{12}Cl_6FeO_2$: C, 34.97; H, 2.52; Cl, 44.25. Found: C, 35.20; H, 2.80; Cl, 43.97.

Using more aluminum chloride (0.1 mole of ferrocene, 0.02 mole of chloral, 200 ml of methylene chloride, and 0.1 mole of aluminum chloride) under identical conditions, practically no ferrocenyl(trichloromethyl)carbinol was obtained. The major product was 4 g (14% yield) of an olefin, mp 51–53° after crystallization from ethanol–water, to which was assigned the structure **(2,2-dichlorovinyl)ferrocene (IV)**: $\nu_{\max}^{\text{Nujol}}$ 3050, 1615 (unsaturation), 1410, 1280, 1245, 1190, 1105 and 1005 (monosubstituted ferrocene), 1050, 1035, 935, 900, 870, 833 to 813, 715, and 665 cm^{-1}; nmr ($\nu_{\max}^{\text{DCCl}_3}$) δ 6.39 (singlet, one proton, $C\mathit{H}{=}$), 4.32 (doublet, J = 17 cps, four protons of substituted ring), 4.08 (singlet, five protons of unsubstituted ring).

Anal. Calcd for $C_{12}H_{10}Cl_2Fe$: C, 51.30; H, 3.58; Cl, 25.20; Fe, 19.80. Found: C, 51.15; H, 4.25; Cl, 24.50; Fe, 19.80.

Chloromercuriferrocene.—The mixed chloromercuriferrocenes prepared from ferrocene in benzene, mercuric acetate in ethanol, and lithium chloride in methanol in the usual way[8] were extracted with methylene chloride[13] using a Soxhlet extractor. The extracted chloromercuriferrocene, mp 194–196°, was free of the disubstitution product but contained 5 to 10% of ferrocene. It was used without further purification in all of the following preparations.

Ferrocenyl(trichloromethyl)carbinol (III) from Chloromercuriferrocene.—To a stirred mixture of 5.1 g (0.012 mole) of chloromercuriferrocene, 3.7 g (0.025 mole) of chloral, and 50 ml of methylene chloride, there was added at 0° under an oxygen-free nitrogen atmosphere 0.8 g (0.006 mole) of aluminum chloride over a period of 2 hr. The mixture was stirred an additional 2 hr at 25° and decomposed with ice-cold hydrochloric acid. The methylene chloride layer was washed with water and dried over magnesium sulfate, the solvent was evaporated, and the crude material was chromatographed on alumina using dry benzene as the solvent. There was obtained 1 g (25% yield) of ferrocenyl(trichloromethyl)carbinol having the same properties as the material which was prepared from the ferrocenecarboxaldehyde.

Ferrocenyl(trichloromethyl)carbinol (III) from Ferrocenylmagnesium Bromide.—An ether solution of ferrocenylmagnesium bromide (0.02 mole), prepared as described below, was cooled to −40° under an oxygen-free nitrogen atmosphere and allowed to react with 3.7 g (0.025 mole) of chloral dissolved in 20 ml of ether added dropwise over a 5-min period. The reaction mixture was allowed to warm to 25° and was stirred for 2 hr at this temperature. It was then chilled and decomposed with cold hydrochloric acid. Chromatography of a benzene solution of the crude product on an alumina column yielded much impure ferrocene and 1.5 g (21% over-all yield based on starting chloromercuriferrocene) of ferrocenyl(trichloromethyl)carbinol identical with the material described above.

Reaction of Lithioferrocene with Ethylene Oxide.—Lithioferrocene was prepared by treating 9 g (0.021 mole) of the chloromercuriferrocene, described above, in 45 ml of ether with 0.046 mole of an approximately 1 *M* solution of *n*-butyllithium in ether under an oxygen-free nitrogen atmosphere, and stirring the reaction mixture for 45 min at room temperature.

The reaction mixture was cooled to 0° and 5 ml (0.1 mole) of ethylene oxide in 20 ml of ether was added over a 10-min period. Stirring was continued for 1 hr at 0° and then for an additional 30 min at 25°. After decomposition of the reaction mixture with cold hydrochloric acid, the ether layer was washed with water and dried, the solvent was volatilized, and the residue was chromatographed on alumina using benzene as the solvent. An initial yellow ferrocene band was followed by a red band due to an unsaturated compound, not further characterized. The third band was yellow-orange in color and gave 1.5 g (31% of theory) of ferroceneethanol, mp 49–51° after crystallization from a mixture of petroleum ether (bp 30–60°) and ethyl ether. Previous preparations have involved the lithium aluminum hydride reduction of ferroceneacetic acid.[14] The infrared spectrum (Nujol mull) showed absorption bands at 3225, 1340, 1110, 1040, 1000, 825, 805, and 725 cm^{-1}; nmr ($\nu_{\max}^{\text{DCCl}_3}$) δ 4.17 (singlet, five protons, unsubstituted ring protons), 4.13 (singlet, four protons, substituted ring protons), 3.70 (triplet, J = 7 cps, two protons, $C\mathit{H}_2OH$), 2.53 (triplet, J = 7 cps, two protons, $Fc\text{-}C\mathit{H}_2$), 2.12 (singlet, one proton, $CH_2O\mathit{H}$).

Reaction of Lithioferrocene with Propylene Oxide.—This followed the same procedure as in the case of ethylene oxide. There was obtained 1.5 g (29% of theory) of yellow **1-ferrocenyl-2-propanol** which melted at 37–39° after crystallization from a mixture of petroleum ether (bp 30–60°) and ethyl ether. The infrared spectrum (Nujol mull) showed absorption bands at 3485, 1280, 1125, 1105, 1035, 1005, 945, 925, and 815 cm^{-1}; nmr ($\nu_{\max}^{\text{DCCl}_3}$) δ 4.18 (singlet seven ring protons), 4.1 to 3.0 (poorly defined multiplet three protons, two ring protons plus $C\mathit{H}OH$), 2.50 (doublet, J = 6.2 cps, two protons, $FcC\mathit{H}_2$), 1.93 (singlet, one proton, $CHO\mathit{H}$), 1.17 (doublet, J = 6.2 cps, three protons, $C\mathit{H}_3CHOH$).

---

[13] Dr. J. F. Helling's procedure (personal communication).

[14] K. L. Rinehart, R. J. Curby, and P. E. Sokol, *J. Am. Chem. Soc.*, **79**, 3420 (1957); D. Lednicer, J. K. Lindsay, and C. R. Hauser, *J. Org. Chem.*, **23**, 653 (1958).

Anal. Calcd for $C_{13}H_{16}FeO$: C, 63.96; H, 6.61. Found: C, 63.68; H, 6.41.

Reaction of Lithioferrocene with Styrene Oxide.—This followed the same procedure as in the case of ethylene oxide. There was obtained 1.5 g (23% of theory) of **2-ferrocenyl-1-phenyl-1-ethanol** which melted at 82–84° after crystallization from a mixture of petroleum ether and ethyl ether. The infrared spectrum (Nujol mull) showed absorption bands at 3225, 1110, 1045, 1005, 820, 810, 775, 755, and 700 cm^{-1}; nmr ($\nu_{max}^{DCCl_3}$) δ 7.45 (singlet, five protons, C_6H_5), 4.8 (poorly defined multiplet, one proton, CHOH), 4.18 (singlet, nine protons, ferrocene ring protons), 2.80 (doublet, J = 8 cps, two protons, $FcCH_2$), and 2.18 (poorly defined singlet, one proton, CHOH).

Anal. Calcd for $C_{18}H_{18}FeO$: C, 70.61; H, 5.92. Found: C, 70.32; H, 5.97.

Ferrocenylmagnesium Bromide.—Lithioferrocene (0.021 mole) was prepared as described above and to it was added rapidly under a dry, oxygen-free nitrogen atmosphere an ether solution of 0.025 mole of magnesium bromide from 6 g of magnesium turnings and 4.7 g of ethylene dibromide. The magnesium bromide ether "solution" was actually composed of two layers: a brown lower layer and a milky-white upper layer. Both layers were added rapidly to the stirred solution of the lithioferrocene. The color changed immediately from red to yellow-orange. The reaction mixture was stirred for 15 min at room temperature before using.

Carbonation of the Grignard reagent with excess Dry Ice yielded the known **ferrocenecarboxylic acid**, mp 195–205° dec, in 72% yield after recrystallization from a mixture of petroleum ether and ethyl ether.

Acknowledgment.—The financial support provided by the American Cyanamid Company is deeply appreciated.

Nucleophilic Displacement Reactions on Organophosphorus Esters by Grignard Reagents. II. Evidence for Competitive Displacement on Carbon and Phosphorus in the Reaction of Grignard Reagents with Simple Phosphates[1]

K. DARRELL BERLIN AND MELBERT E. PETERSON[2]

Department of Chemistry, Oklahoma State University, Stillwater, Oklahoma

Received August 16, 1966

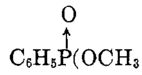
In the reaction of trimethyl phosphate (1) with phenyl Grignard reagent (2) all products of displacement reactions, namely, dimethyl phenylphosphonate (3), methyl diphenylphosphinate (4), and triphenylphosphine oxide (5), were not found. Surprisingly, careful investigation of various reaction mixtures have revealed only the presence of 4 and 5. In no case was 3 detected. Interestingly, with the comparatively small Grignard reagent, the C-alkylation product, toluene, was detected in all condensations of 1 and 2. In addition small amounts of ethylbenzene were found when triethyl phosphate was treated with 2. A reaction mechanism is proposed for both C alkylation and displacement on phosphorus.

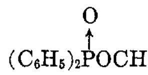
Several instances of reaction of trialkyl and triaryl phosphorus esters with Grignard reagents have appeared in the literature. Gilman and Vernon[3] reported that triphenylphosphine oxide (5) and phenol were produced from triphenyl phosphate (6) when treated with phenyl Grignard reagent (2) (4:1 mole ratio of reactants). Reaction of the propyl Grignard reagent with triphenyl phosphite at 95° gave tri-*n*-propylphosphine.

Condensation of triethyl phosphate with 2 was reported to yield diethyl phenylphosphonate (16%) and diphenylphosphinic acid (17%).[4] Reaction of *n*-propyl Grignard reagent with 6 (4:1 mole ratio) in boiling ether for 6 hr gave no reaction, whereas apparently some of the expected phosphine oxide was obtained when the above mixture was heated in ether–toluene at 95°.[3] Tri-*p*-tolyl phosphate reacted with 2 at 105° for 5 hr to give 3 (50%).[3] Treatment of 1 with the bulky mesityl Grignard reagent led to C alkylation rather than attack on phosphorus.[5] This result has been attributed to the bulkiness of the Grignard reagent which retarded approach of the reagent to phosphorus.

$(CH_3O)_3P{\rightarrow}O$
1

C_6H_5MgBr
2


$C_6H_5\overset{O}{\overset{\uparrow}{P}}(OCH_3)_2$
3


$(C_6H_5)_2\overset{O}{\overset{\uparrow}{P}}OCH_3$
4

$(C_6H_5)_3P{\rightarrow}O$
5

$(C_6H_5O)_3P{\rightarrow}O$
6

In the above-cited examples no systematic study was made of the effects of varying concentration of the Grignard reagent with respect to the ester. In addition no detailed analysis with gas chromatography was reported. A meticulous examination was made recently on the reaction of Grignard reagents on phosphites.[1b] We now report an extensive related study with organic phosphates.

We have examined the reaction of 1 with controlled amounts of 2 (Table I). We had anticipated that information concerning the mechanism of this displacement reaction would be revealed by careful analysis of the relative amounts of mono, di, and tri displacement products. Analysis of the reaction mixture was accomplished by gas chromatography (gc) in a manner analogous to that reported earlier.[1b,6]

In several respects the reaction of the phosphate 1 was quite different from that of trimethyl phosphite as reported previously.[1b] When 2 was treated with 1 (1:4 mole ratio) in ether–benzene at 60° for 1 hr, 5 was obtained in low yield (10%) in contrast with the quantitative yield of triphenylphosphine realized from the phosphite.[1b] It should be noted that under com-

---

[1] (a) We gratefully acknowledge support by the Directorate of Chemical Sciences, Air Force Office of Scientific Research, under Grant AF-AFOSR-132-65. (b) For the preceeding paper, see K. D. Berlin, T. H. Austin, and K. L. Stone, *J. Am. Chem. Soc.*, **86**, 1787 (1964).

[2] National Science Foundation Faculty Fellow, 1964–1965; National Science Foundation Cooperative Fellow, 1965–1966.

[3] H. Gilman and C. C. Vernon, *J. Am. Chem. Soc.*, **48**, 1063 (1926).

[4] H. Gilman and J. D. Robinson, *Rec. Trav. Chim.*, **48**, 328 (1929).

[5] H. Gilman and B. J. Gaj, *J. Am. Chem. Soc.*, **82**, 6326 (1960).

[6] K. D. Berlin, T. H. Austin, M. Nagabhushanam, M. E. Peterson, J. Calvert, L. A. Wilson and D. Hopper, *J. Gas Chromatog.*, **3**, 256 (1965).