

acidity function (H_-) of 0.025 *M* sodium methoxide in mixtures of methanol and dimethyl sulfoxide. They found that H_- varied from 12 to 19 as the mole ratio of methanol in the solvent was decreased from 100 to 5%. In our system the mole ratio of alcohol is about 0.02% and the H_- about 33 if McEwen's^{3b} pK_a values are valid in this system. Hence, removal of the last 5% of alcohol increases the basicity of the medium by a factor of 10^{14} .

In order to explain the foregoing results, we suggest that the inherent acidity of alcohols is very low—less than that of triphenylmethane—and that the apparent acidity is increased drastically by materials which can reduce the activity of the alkoxide. Alcohols can do this by hydrogen bonding and cations by coordination or by forming incompletely ionized alkoxides as has been discussed by Cram⁵ and his co-workers.

(5) D. J. Cram, C. A. Kingsbury, and B. Rickborn, *J. Am. Chem. Soc.*, **83**, 3688 (1961).

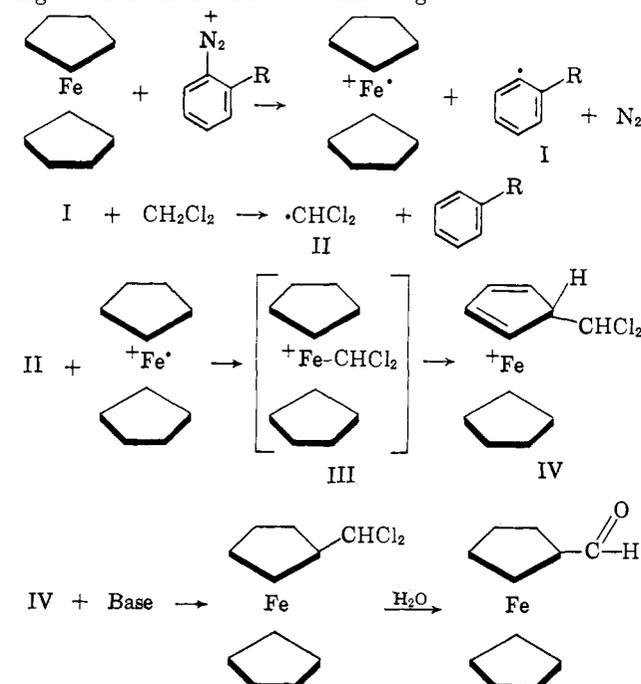
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A Novel Side Reaction Accompanying the Arylation of Ferrocene. An Example of Free Radical Substitution

Sir:

In the course of preparing a series of *o*-substituted phenylferrocenes, we have encountered an unusual side reaction with certain benzenediazonium salts and ferrocene in halohydrocarbon solvents. For example, the diazonium salts derived from *o*-toluidine, *o*-ethyl-aniline, 2,6-xylidine, and mesidine, formed in sulfuric acid and added to a mixture of an aqueous sodium acetate buffer and a solution of ferrocene in methylene chloride or added as dry diazonium fluoroborates to ferrocene in methylene chloride, followed by an aqueous work-up procedure, yielded principally recovered ferrocene and significant amounts of ferrocene monoaldehyde. The formation of the aldehyde can be explained in terms of an attack of the dichloromethyl radical, produced from the solvent, on the ferrocene nucleus, followed by hydrolysis to the aldehyde according to a scheme such as the following.



Similar reactions occurred in other halohydrocarbon solvents. In chloroform, ferrocenoic acid and ethyl ferrocenoate¹ were produced; in ethylidene chloride, acetylferrocene was formed; and in bromotrichloromethane, ferrocenoic acid was the major reaction product. In all cases, large amounts of ferrocene were recovered (from 36 to over 80%). Table I shows the results from typical experiments, with yields based on unrecovered ferrocene.

TABLE I
REACTION OF FERROCENE WITH SOLVENT RADICALS UNDER ARYLATION CONDITIONS

Diazonium salt employed	Solvent	Product	Yield, %
<i>o</i> -Toluenediazonium acetate	CH ₂ Cl ₂	FcCHO	16
Mesitylenediazonium acetate	CH ₂ Cl ₂	FcCHO	23
<i>o</i> -Toluenediazonium acetate	CHCl ₃	FcCO ₂ H	25
2,6-Dimethylbenzenediazonium fluoroborate	CHCl ₃	FcCO ₂ Et ^a	26
		FcCO ₂ H	Trace
2,6-Dimethylbenzenediazonium fluoroborate	CH ₃ CHCl ₂	FcCOCH ₃	10
<i>o</i> -Toluenediazonium fluoroborate	CH ₃ CHCl ₂	FcCOCH ₃	5
		<i>o</i> -CH ₃ C ₆ H ₅ Fc	64
2,6-Dimethylbenzenediazonium acetate	CCl ₃ Br	FcCO ₂ H	43

^a See ref. 1.

These reactions, while as yet of little synthetic value, are of interest in view of the evidence recently presented by Rosenblum² that neither ferrocene nor the ferricenium ion is susceptible to radical substitution. There seems to be no doubt that phenyl radicals are produced in the reaction between ferrocene and diazonium salts,^{2,3} and there are numerous reports of the reaction of phenyl radicals with halohydrocarbon solvents^{4,5} to produce solvent radicals. The usual order of abstraction in such reactions is Br > H > Cl,⁴ as observed here.⁶

While we have no evidence that the radical attack occurs on the ferricenium ion rather than on neutral ferrocene (both are present in the reaction mixture), Beckwith and Leydon³ have recently reported that azobisisobutyronitrile attacks the ferricenium ion, by a radical process, but does not react with neutral ferrocene under conditions that preclude the formation of the ferricenium ion. The existence of intermediate III has not been demonstrated, but it seems reasonable since the ferricenium ion contains an unpaired electron, and suggestions of the involvement of the metal atom in electrophilic substitution^{2,7,8} seem plausible. Direct attack on the carbocyclic ring⁹ remains a possibility, however.

The rapid hydrolysis of the intermediate chloroalkylferrocene (V) would be expected, since it is known

(1) Ethyl ferrocenoate was produced when dry diazonium fluoroborates were added to dry chloroform solutions of ferrocene. The chloroform used contained 0.5% of ethanol as a preservative. This amount was more than enough to account for the ethyl ester produced.

(2) M. Rosenblum, W. G. Howells, A. K. Banerjee, and C. Bennett, *J. Am. Chem. Soc.*, **84**, 2726 (1962).

(3) A. L. J. Beckwith and R. J. Leydon, *Tetrahedron Letters*, **6**, 385 (1963).

(4) For examples and references, see C. Walling, "Free Radicals in Solution," John Wiley and Sons, Inc., New York, N. Y., 1957, p. 247 ff.

(5) D. H. Hey and J. Peters, *J. Chem. Soc.*, 79 (1960).

(6) Hey and Peters⁵ have reported that sodium benzenediazoate at 0° and other phenyl radical sources, such as *N*-nitrosoacetanilide and benzoyl peroxide, at higher temperatures react with chloroform to form principally, and usually exclusively, CCl₃ radicals, but at 0° benzenediazonium acetate abstracts chlorine rather than hydrogen. We have looked carefully for ferrocenemonoaldehyde among the reaction products in chloroform solvent, but have not found this compound to be present.

(7) J. H. Richards, presented at the 135th National Meeting of the American Chemical Society, Boston, Mass. April, 1959; cf. Abstracts, p. 86-O.

(8) M. Rosenblum and W. G. Howells, *J. Am. Chem. Soc.*, **84**, 1167 (1962); M. Rosenblum, J. O. Santer, and W. G. Howells, *ibid.*, **85**, 1450 (1963).

(9) W. F. Little and A. K. Clark, *J. Org. Chem.* **25**, 1979 (1960).

that solvolysis of acetates of α -ferrocenyl alcohols is rapid¹⁰ and α -halomethylferrocenes are unstable.¹¹

An alternate mechanistic possibility involving the decomposition of the diazonium salts to phenonium ions, which might abstract hydride from the halo-hydrocarbons to produce electrophilic carbonium ions, is excluded by the last experiment in Table I, wherein bromotrichloromethane solvent gives rise to ferrocenoic acid. Bromotrichloromethane is known to react readily with phenyl radicals to produce trichloromethyl radicals.⁴

We have found that ordinarily methylene chloride is a good solvent for arylation of ferrocene with diazonium salts other than *o*-alkylbenzenediazonium salts, which give significant amounts of the aldehyde to the exclusion of normal arylation products.¹² The anomalous reaction of *o*-alkylbenzenediazonium salts is not due to steric effects alone, for the aldehyde is not produced from reaction with the diazonium salts derived from *o*-nitroaniline, *o*-bromoaniline, 2-methyl-6-nitroaniline, or 2-methyl-4-nitroaniline, though it is produced in small amounts with the salts from *o*-iodoaniline, *o*-aminobiphenyl, 2,6-dimethyl-4-nitroaniline, and 2,4-dimethyl-6-nitroaniline. These substrates all give reasonable yields of normal arylation products. In general, the presence of a nitro group in an *o*-alkylbenzenediazonium salt discourages the aldehyde formation, but electronic effects alone are not responsible. No aldehyde was obtained from *o*-anisidine or *o*-phenetidine and only a trace amount of the aldehyde was obtained from *p*-toluidine. Most likely, a combination of both electronic and steric effects of substituents on the diazonium salts are responsible for the preferential reaction with the solvent.

The aldehyde¹³ was identified by its melting point and its infrared, ultraviolet, and n.m.r. spectra; ferrocenoic acid¹⁴ and acetylferrocene¹⁵ were identified by mixture melting points and the identity of their infrared spectra to those of authentic samples.

Acknowledgment.—The authors wish to thank the donors of the Petroleum Research Fund, administered by the American Chemical Society, for financial assistance.

(10) E. A. Hill and J. H. Richards, *J. Am. Chem. Soc.*, **83**, 4216 (1961).

(11) R. A. Benkeser and W. P. Fitzgerald, Jr., *J. Org. Chem.*, **26**, 4179 (1961).

(12) With 2,6-dimethylbenzenediazonium fluoroborate and *o*-toluenediazonium fluoroborate some arylation products were also obtained.

(13) M. Rosenblum, *Chem. Ind. (London)*, 72 (1957).

(14) W. F. Little and R. Eisenthal, *J. Am. Chem. Soc.*, **82**, 1577 (1960).

(15) V. Weinmayr, *ibid.*, **77**, 3009 (1955).

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A New Synthesis of α,β -Dihydroxy- γ -ketoesters and of α,β -Dihydroxyketones via Cyclic Oxyphosphoranes¹

Sir:

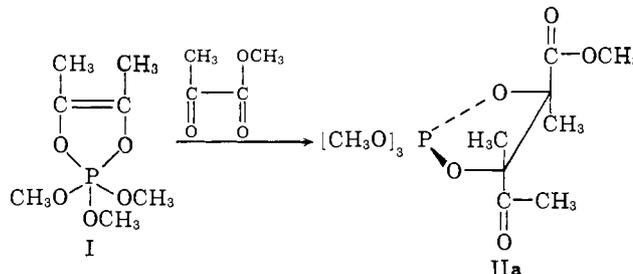
This communication generalizes further a new carbon-carbon condensation reaction recently described.² The reaction is induced by trialkyl phosphites, involves as intermediates compounds with pentavalent phosphorus, and produces polyoxygenated functions in acceptable yields. The previous examples² dealt with the formation of diketols from two molecules

(1) Work supported by the Cancer Institutes of the National Institutes of Health (CY-4769), the National Science Foundation (G 19509), and the Petroleum Research Fund of the American Chemical Society (286-A).

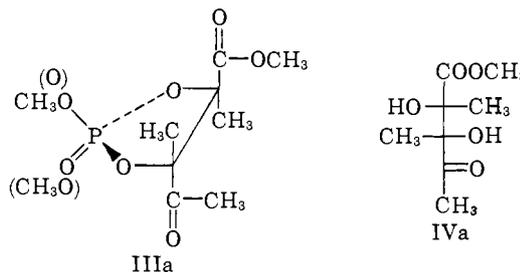
(2) (a) F. Ramirez, N. Ramanathan, and N. B. Desai, *J. Am. Chem. Soc.*, **84**, 1317 (1962); (b) F. Ramirez, N. B. Desai, and N. Ramanathan, *Tetrahedron Letters*, No. 5, 323 (1963).

of an α -diketone, and of tartaric esters from two molecules of an α -ketoester.

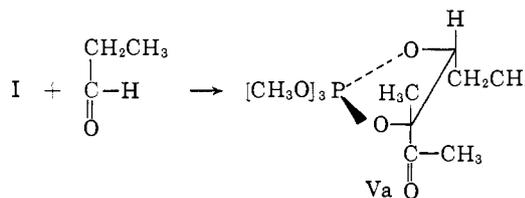
Biacetyl and trimethyl phosphite form a 1:1 adduct (I) very rapidly.^{2a} Adduct I reacted further with methyl pyruvate and yielded the crystalline cyclic saturated oxyphosphorane IIa, isolated in 60% yield. The material balance is a noncrystalline mixture of the two possible diastereomers: IIa, with the acetyl *trans* to the carbomethoxy, and IIb, with the acetyl *cis* to the carbomethoxy.



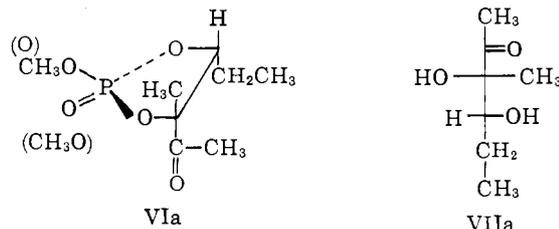
The *trans*-oxyphosphorane IIa reacted very rapidly with one mole equivalent of water in benzene solution at 20° and gave a crystalline cyclic phosphate ester IIIa. This compound (or the parent oxyphosphorane IIa) was converted into DL-*threo*-methyl- α,β -dimethyl- α,β -dihydroxylevulinate (IVa) in aqueous solution at pH 4–4.5 (6 hr. at 100°).



The biacetyl-trimethyl phosphite 1:1 adduct I reacted with anhydrous propionaldehyde and yielded mainly the liquid oxyphosphorane Va.



Hydrolysis of the oxyphosphorane Va with one mole equivalent of water in benzene solution (20°) gave a liquid cyclic phosphotriester, VIa. The phosphate VIa, or the oxyphosphorane Va, were converted into DL-*threo*-3-methylhexane-3,4-diol-2-one (VIIa) in aqueous solution at pH 4–4.5 (6 hr. at 100°).



Benzaldehyde also reacted with the 1:1 adduct I and gave predominantly the oxyphosphorane VIIIa in which the acetyl is *cis* to the phenyl.

The P³¹ n.m.r. spectra of the oxyphosphoranes IIa, Va,^{2a} and VIIIa had one peak at ca. +50 p.p.m. to high-

(2a) NOTE ADDED IN PROOF.—The P³¹ n.m.r. spectrum of Va at 40.5