Friedel–Crafts Alkylation of Pentafluorobenzene[1,2]

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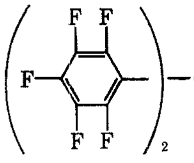
Bis(pentafluorophenyl)methane and tris(pentafluorophenyl)methane were prepared in 77 and 92% yields, respectively, by a Friedel–Crafts reaction of pentafluorobenzene with methylene chloride and chloroform using aluminum chloride as the Lewis acid. Pentafluorotoluene (8% yield) was the sole product isolated in the reaction of methyl chloride with pentafluorobenzene. Pentafluorobenzyl chloride was treated with pentafluorobenzene and benzene to produce bis(pentafluorophenyl)methane and pentafluorophenyl(phenyl)methane, respectively. Spectral properties of the new compounds were consistent with the proposed structures. Addition of small amounts of copper metal and cupric chloride did not drastically change the yields.

Previous investigators have prepared alkyl- or aryl-substituted fluoroaromatics by Grignard synthesis[3] or by the interaction of alkyl- or aryllithium reagents[4] with hexafluorobenzene. To eliminate the handling of air-sensitive organometallics, it was of interest to explore the Friedel–Crafts reactions of pentafluorobenzene as source of pentafluorophenylalkanes.

Initial attempts to alkylate pentafluorobenzene by standard Friedel–Crafts methods were abortive. Refluxing of an excess of pentafluorobenzene with methylene chloride or chloroform for 4 hr in the presence of catalytic or stoichiometric amounts of aluminum chloride[5] gave the starting materials, traces of unidentified oils, and small amounts of a crystalline compound which was identified as hexachlorobenzene.[6] Under these reaction conditions, the change of the solvent to carbon disulfide or nitrobenzene did not give the desired results. A 33% yield of tris(pentafluorophenyl)methane, however, could be obtained from chloroform, aluminum chloride, and an excess of pentafluorobenzene when the refluxing time was prolonged to 21 hr.

Better results were obtained when the experiments were carried out in a steel bomb at 150°, using an excess of pentafluorobenzene as solvent. Under these conditions, methylene chloride and chloroform reacted readily with pentafluorobenzene in the presence of aluminum chloride to form bis(pentafluorophenyl)methane (I) and tris(pentafluorophenyl)methane (II) in 77 and 92% yields, respectively.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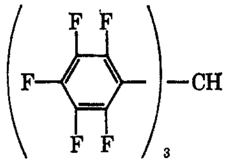
II

The over-all effect of reaction time and ratio of aluminum chloride to haloalkane can be observed from the data in Table I.

TABLE I

REACTION CONDITIONS FOR THE FORMATION OF POLYFLUOROARYLMETHANES AT 150°[a]

Haloalkane Formula	Haloalkane Mole	$AlCl_3$,[b] mole	Reacn at 150°, time (hr)	Product	Crude[c] yield, %	Mp (bp), °C[d]
CH_3Cl	0.21	0.20	6.0	$C_6F_5CH_3$	8[e]	(113–116)
CH_2Cl_2	0.10	0.02	4.5	$(C_6F_5)_2CH_2$	43	63–64
CH_2Cl_2	0.10	0.02	8.0	$(C_6F_5)_2CH_2$	55	63–64
CH_2Cl_2	0.10	0.20	4.5	$(C_6F_5)_2CH_2$	76	63–64
CH_2Cl_2	0.10	0.20	8.0	$(C_6F_5)_2CH_2$	77	63–64
$CHCl_3$	0.052	0.20	4.5	$(C_6F_5)_3CH$	92	165 5–166

[a] All experiments employed 0.29 mole of pentafluorobenzene. [b] Baker Analyzed reagent grade (anhydrous granular). [c] The reaction mixture always contained C_6Cl_6 plus unreacted starting material. [d] Melting points are corrected. [e] Determined by quantitative gas chromatographic analysis.

A reaction which employed methyl chloride as the alkylating agent produced 8% of pentafluorotoluene (III). The low yield of III is not surprising as methyl halides are the least reactive ones in the series of primary halides,[9] and halogenated aromatics are alkylated only with difficulty.[10] Similar reactions using 1,2-dichloroethane gave black tars from which only hexachlorobenzene was isolated.

In all cases, unreacted pentafluorobenzene and the starting haloalkanes were found in the reaction mixture. Infrared spectral data and gas chromatographic analyses support the formation of minute quantities of mixed polyhalo derivatives.

The successful preparation of I and II in good yields suggested a reinvestigation of our earlier results. The aluminum chloride which was used in our experiments consisted of slightly yellow lumps, and the steel bomb was sealed with a copper ring. Therefore, a series of experiments was carried out using finely powdered aluminum chloride and catalytic amounts of copper powder and cupric chloride, respectively, in order to determine the catalytic influence of the copper ring of the steel bomb on the course of the reaction. The results of these experiments are listed in Table II. These results demonstrate that copper metal or cupric

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(1) This work was supported by the Foundational Research Program of the Naval Ordnance Systems Command.

(2) Presented in part at the 3rd International Fluorine Chemistry Symposium, Munich, Germany, Sept 1965.

(3) W. J. Pummer and L. A. Wall, *Science*, **127**, 643 (1958); R. J. Harper, Jr., and C. Tamborski, *Chem. Ind.* (London), 1824 (1962); A. K. Barbour, M. W. Buxton, P. L. Coe, R. Stephens, and J. C. Tatlow, *J. Chem. Soc.*, 808 (1961).

(4) J. M. Birchall and R. N. Haszeldine, *ibid.*, 3719 (1961); J. M. Birchall, T. Clarke, and R. N. Haszeldine, *ibid.*, 4977 (1962); M. T. Chaudhry and R. Stephens, *ibid.*, 4281 (1963).

(5) Refer to the Experimental Section for detailed information concerning the quality of the aluminum chloride used and the handling conditions.

(6) Hexachlorobenzene was isolated as a by-product from all Friedel–Crafts reactions in low yields in which pentafluorobenzene was used as the aromatic component. Halogen interchange reactions have been noted in the fluorobenzenes by Olah, *et al.*,[7] and in fluoronaphthalene by Vorozhtsov, *et al.*[8]

(7) G. A. Olah, W. S. Tolgyesi, and R. E. A. Dear, *J. Org. Chem.*, **27**, 3441, 3449 (1962).

(8) N. N. Vorozhtsov and N. M. Przhiyalgorskaya, *J. Gen. Chem. USSR*, **24**, 1787, 1961 (1954).

(9) F. A. Drahowzal in "Friedel–Crafts and Related Reactions," Vol. II, G. A. Olah, Ed., Interscience Publishers, Inc., New York, N. Y., 1964, pp 417–475.

(10) Reference 9, p 435.

TABLE II

REACTION CONDITIONS FOR THE FORMATION OF POLYFLUOROARYLMETHANES AT REFLUX TEMPERATURE

Haloalkane								
Formula	Mole	C_6F_5H, mole	$AlCl_3$,[a] mole	Copper[b] reagent	Reflux time, hr	Product	Crude yield, %	C_6F_5H recovered, mole
CH_2Cl_2	0.15	0.5	0.25	. . .	6	I	39[d]	0.37
CH_2Cl_2	0.8[c]	0.85	0.2	. . .	21.5	I	55[d]	0.22
CH_2Cl_2	0.15	0.5	0.25	$CuCl_2$	6	I	34[d]	0.31
CH_2Cl_2	0.15	0.5	0.25	Metal	6	I	30[d]	0.30
$CHCl_3$	0.1	0.5	0.25	. . .	1.5	II	58[e]	[f]
$CHCl_3$	0.1	0.5	0.25	$CuCl_2$	1.5	II	59[e]	[f]
$CHCl_3$	0.1	0.5	0.25	Metal	1.5	II	58[e]	[f]

[a] Fisher Certified Reagent (anhydrous). [b] One gram per experiment. [c] At the beginning 0.3 mole was added; the remainder was added in 3-hr intervals in equal portions. [d] Related to unrecovered C_6F_5H. [e] Related to $CHCl_3$. [f] Not determined.

chloride has no drastic effect on the yields of the reactions.

In one experiment, methylene chloride was added in portions during the prolonged reflux time of 21.5 hr to compensate for possible losses during the reaction. The yield was considerably higher in this case, indicating that in the other experiments some of the low-boiling methylene chloride had evaporated through the reflux condenser. All attempts to isolate pentafluorophenylchloromethane, pentafluorophenyldichloromethane, or bis(pentafluorophenyl)chloromethane were unsuccessful, which suggests that these intermediates react more rapidly with pentafluorobenzene than the starting haloalkanes methylene chloride or chloroform. This view is supported by the Friedel–Crafts reaction of pentafluorobenzyl chloride with pentafluorobenzene which produced I in 45% yield. A similar reaction between pentafluorobenzyl chloride and benzene gave pentafluorophenyl(phenyl)methane in 64% yield, whereas the Friedel–Crafts reaction between benzyl chloride and pentafluorobenzene did not produce this compound at our conditions, probably owing to rapid polycondensation of the benzyl chloride.[11]

Spectra.—The spectral data are listed in the Experimental Section. The methyl proton magnetic resonance spectra of compounds I–IV and their nonfluorinated analogs are listed in Table III; they were obtained in hexafluorobenzene[12] with TMS as internal standard.

The F^{19} bands assigned to the *para* fluorines consisted of triplets with uniform spin-coupling constants of 20 cps; the chemical shifts of the triplets are listed in Table IV.

The bands owing to the *ortho* and *meta* fluorines of I–IV showed more complicated patterns.

TABLE III

METHYL PROTON MAGNETIC RESONANCE SPECTRA OF I–IV AND THEIR NONFLUORINATED ANALOGS[a]

Compd	τ, ppm	Compd	τ, ppm
$C_6F_5CH_3$[b] (III)	7.57	$C_6H_5CH_3$ (CCl_4)[c]	7.68
$(C_6F_5)_2CH_2$ (I)	5.58	$(C_6H_5)_2CH_2$	6.05
$(C_6F_5)_3CH$ (II)	3.38	$(C_6H_5)_3CH$[d]	4.52
$C_6F_5CH_2C_6H_5$[e] (IV)	5.83		

[a] In hexafluorobenzene at 27°, except for II which was determined at 85° because of its low solubility. [b] Multiplet reported 2.30 ppm relative to TMS: A. G. Massey, E. W. Randall, and P. Shaw, *Chem. Ind.* (London) 1244, (1963). [c] Reference 14. [d] Reported τ 4.54 (in CCl_4): D. E. Webster, *J. Chem. Soc.*, 5132, (1960). [e] Triplet, coupling constant about 1 cps.

TABLE IV

CHEMICAL SHIFTS OF THE *para* TRIPLETS OF I–IV (RELATIVE TO C_6F_6)

Compd	Chemical shift, cps		
$C_6F_5CH_3$ (III)[a,b]	255	235	215
$C_6F_5CH_2C_6H_5$ (IV)[a]	391	370	350
$(C_6F_5)_2CH_2$ (I)[a]	455	435	415
$(C_6F_5)_3CH$ (II)[c]	708	689	668

[a] In acetone. [b] In agreement with published values: I. J. Lawrenson, *J. Chem. Soc.*, 1117, (1965). [c] In SO_2Cl_2.

Experimental Section

The aluminum chloride used throughout these experiments was either Baker Analyzed reagent grade (anhydrous granular) called aluminum chloride (B) in this paper, or Fisher Certified Reagent (anhydrous) called aluminum chloride (F). The storage bottles were kept in a drybox; otherwise, usual precaution methods were followed in handling the aluminum chloride. Rigorous anhydrous conditions were not attempted.

Melting points are corrected. Yields are those of the crude products. The elemental analyses were performed by Galbraith Laboratories, Knoxville, Tenn. A 1-m silicon grease column in a Perkin-Elmer Model 154 gas chromatograph at 100° was used in the determination of pentafluorotoluene. Infrared spectra were recorded as solutions in carbon tetrachloride on a Perkin-Elmer 421 grating spectrophotometer. Ultraviolet absorption maxima were obtained from measurement of dilute isopropyl alcohol or *n*-hexane solutions of the polyfluorophenylalkanes on a Beckman DU spectrophotometer. Nmr spectra were taken using a Varian DP-60 spectrometer. F^{19} spectra were taken from 10% acetone solutions of the polyfluorophenylalkanes with hexafluorobenzene as external standard unless otherwise stated. The proton spectra were recorded from 10% solutions of the polyfluoroalkanes in hexafluorobenzene with tetramethylsilane as internal reference.

A. **Reactions at 150°. Bis(pentafluorophenyl)methane** (I).—Pentafluorobenzene (49 g, 0.29 mole), methylene chloride (8.5 g, 0.1 mole), and aluminum chloride (B) (26.7 g, 0.2 mole) were heated in a steel bomb at 150° for 4.5 hrs. The reaction mixture in the bomb was allowed to cool to room temperature and then decomposed with ice–hydrochloric acid, followed by several extractions with xylene. The organic layers were combined, washed with water, sodium bicarbonate solution, and again with water, and dried over sodium sulfate. Evaporation of the solvent gave 26.5 g (76%) of white crystals, mp 58–61°. Sublimation at 50–55° (0.05 mm) gave crystalline I: mp 63–64°; ν_{max} (CCl_4) 2948, 2647 (sh), 2634, 2449, 2083, 2069, 1734, 1653, 1516–1502, 1447, 1429, 1378, 1333, 1310, 1294, 1244, 1129,

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(11) G. A. Olah and M. W. Meyer in "Friedel–Crafts and Related Reactions," Vol. I, G. A. Olah, Ed., Interscience Publishers, Inc., New York, N. Y., 1964, p 650.

(12) The complex formation of toluene with hexafluorobenzene[13] causes a shift of the aromatic proton signal (τ 3.23 in C_6F_6, 2.94 in CCl_4) and of the methyl proton signal (τ 7.76 in C_6F_6, τ 7.68 in CCl_4).[14] As no complex could be isolated from hexafluorobenzene and diphenylmethane, triphenylmethane, and IV, respectively, a possible chemical shift of the methyl protons of these compounds in hexafluorobenzene as solvent was neglected.

(13) W. A. Duncan and F. L. Swinton, *Trans. Faraday Soc.*, **62**, 1082 (1966).

(14) L. M. Jackman ["Application of Nuclear Magnetic Resonance Spectroscopy in Organic Chemistry," Pergamon Press Ltd., London, 1963, p 58] reported τ 7.66 for toluene in CCl_4.

1120, 1032, 976, 943, 900, 677, 627, 618 cm^{-1}; λ_{max} (I)[15] 219.5 (sh) mμ (ε 6444), 260.5 mμ (ε 991). The proton nmr spectrum consisted of a singlet at τ 5.58. The F^{19} nmr spectrum in acetone consisted of multiplets centered at 1238 (*ortho*), 435 (*para*, triplet), 72 (*meta*) cps, downfield from hexafluorobenzene singlet. *Anal.* Calcd for $C_{13}H_2F_{10}$: C, 44.85; H, 0.58; F, 54.57; mol wt, 348. Found: C, 44.58; H, 0.64; F, 54.26; mol wt, 331 (benzene).

Tris(pentafluorophenyl)methane (II).—In a manner similar to the procedure described above, pentafluorobenzene (49 g, 0.29 mole), chloroform (6.2 g, 0.052 mole), and aluminum chloride (B) (26.7 g, 0.2 mole) produced 24.5 g (92%) of II as white needles. Recrystallization from ethanol–benzene (3:1) gave 20.29 g (76%) of white, cotton-like needles, mp 157–159°. From the mother liquor 0.9 g of hexachlorobenzene was isolated. A sublimed sample of II melted at 165.5–166°: ν_{max} (CCl$_4$) 2941, 2647, 2426, 2070, 1647, 1481, 1424, 1381, 1335, 1307, 1150, 1125, 1000, 900, 681, 619 cm^{-1}; λ_{max} (I) 219 sh mμ (ε 16,474), 263.5 mμ (ε 1861); λ_{max} (H) 218.5 sh mμ (ε 16,214), 264 mμ (1793). The proton nmr spectrum consisted of a singlet at τ 3.38. The F^{19} nmr spectrum which was obtained by examination of a saturated solution of II in sulfuryl chloride consisted of multiplets centered at 1344 (*ortho*), 689 (*para*, triplet), 231 (*meta*) cps downfield from hexafluorobenzene singlet. *Anal.* Calcd for $C_{19}HF_{15}$: C, 44.38; H, 0.20; F, 55.43; mol wt, 514. Found: C, 44.19; H, 0.24; F, 55.67; mol wt, 512 (benzene).

Pentafluorotoluene (III).—Pentafluorobenzene (49 g, 0.29 mole), methyl chloride (10.6 g, 0.21 mole), and aluminum chloride (B) (26.7 g, 0.20 mole) were heated in a steel bomb at 150° for 6 hr. The reaction mixture was allowed to cool to room temperature, decomposed with ice–hydrochloric acid, and extracted several times with ether. The organic layers were combined, washed with water, sodium bicarbonate solution, and again with water, and dried over sodium sulfate, and the ether was distilled off using a short column. Gas chromatographic analysis of the remaining liquid showed the presence of about 8% of III. Repeated fractional distillations gave III (0.44 g, 1.2%): bp 113–117° (lit.[16] bp 117–118°); λ_{max} (I) 219 mμ (ε 1763), 258 mμ (ε 300). The proton nmr spectrum consisted of a multiplet centered at τ 7.57. The F^{19} nmr spectrum consisted of multiplets centered at 1190 (*ortho*), 235 (*para*, triplet), and −23 (*meta*) cps, downfield from hexafluorobenzene singlet.

B. Reactions at Reflux Temperature. Bis(pentafluorophenyl)methane (I). (1) **Without Copper or Cupric Chloride.**—Pentafluorobenzene (84 g, 0.5 mole) and methylene chloride (12.7 g, 0.15 mole) were added to aluminum chloride (F) (33.4 g, 0.25 mole). The resulting orange mixture was heated to a gentle reflux and refluxed for 6 hr. After the mixture was cooled to ambient temperature and decomposed with ice–hydrochloric acid, the organic phase was separated and treated as described before. Distillation gave pentafluorobenzene (61.3 g, 0.37 mole). The distillation residue was extracted with cold ethanol, the undissolved hexachlorobenzene separated, and the ethanol slowly evaporated giving various fractions of I of different purity. The aqueous layer from the hydrolysis was extracted with benzene, the benzene solution was washed and dried, the solvent was evaporated, and the residue was treated as described before. Total yield was 9.27 g of I (39% based upon consumed pentafluorobenzene), mp 57–61° (mp 64–65° after sublimation), and 0.63 g of hexachlorobenzene, mp 227–230°.

In another experiment using pentafluorobenzene (143 g, 0.85 mole) and aluminum chloride (F) (26.7 g, 0.2 mole), methylene chloride (68 g, 0.8 mole) was added in 5-ml portions during 18 hr to the refluxing mixture. After 21.5 hr of refluxing, the mixture was worked up as described before giving methylene chloride (18 g, 0.21 mole), pentafluorobenzene (36.5 g, 0.22 mole), and I (60.71 g, 55%, based upon consumed pentafluorobenzene).

(2) **With Cupric Chloride.**—Pentafluorobenzene (84 g, 0.5 mole), methylene chloride (12.7 g, 0.15 mole), and anhydrous cupric chloride (1.3 g, 0.01 mole) were added to aluminum chloride (F) (33.4 g, 0.25 mole) and the resulting orange mixture was heated to gentle reflux. After 6 hr the mixture was worked up as described before giving pentafluorobenzene (52 g, 0.31 mole), I (11.4 g, 34%, based upon consumed pentafluorobenzene), and hexachlorobenzene (0.8 g, mp 224–227°).

(3) **With Copper Powder.**—A mixture as described under 2, but with copper powder (1 g) substituted for cupric chloride, was refluxed for 6 hr and worked up as described above giving pentafluorobenzene (50.4 g, 0.30 mole), I (10.6 g, 30%, based upon consumed pentafluorobenzene), and hexachlorobenzene (0.56 g, mp 226–230°).

(4) **From Pentafluorobenzyl Chloride.**—To a stirred mixture of pentafluorobenzene (33.6 g, 0.2 mole) and aluminum chloride (F) (2.67 g, 0.02 mole) was added dropwise 2,3,4,5,6-pentafluorobenzyl chloride [4.35 g, 0.02 mole (prepared from 2,3,4,5,6-pentafluorotoluene)[16]] at room temperature. Stirring was continued for 1 hr, then the mixture was refluxed for 2.5 hr and poured onto ice–hydrochloric acid, the organic phase was separated and dried (calcium chloride), and the solvent was distilled off. The solid residue (2.24 g) was treated with cold ethanol and the undissolved hexachlorobenzene (0.5 g) was separated, the solvent was evaporated, and the residue was recrystallized from heptane giving I (1.87 g, mp 62–64°). Quantitative analysis by gas chromatography of the solvent showed the presence of unreacted pentafluorobenzyl chloride (1.5 g, 34%) and I (0.17 g). Total yield of I (based upon consumed pentafluorobenzyl chloride) was 2.04 g (45%).

Tris(pentafluorophenyl)methane (II). (1) **Without Copper or Cupric Chloride.**—Aluminum chloride (F) (33.4 g, 0.25 mole), pentafluorobenzene (84 g, 0.5 mole), and chloroform (12 g, 0.1 mole) were refluxed for 1.5 hr. The resulting dark pink mixture which solidified completely on cooling was treated with ice–hydrochloric acid and extracted with benzene, and the solvent was evaporated leaving II (30.0 g, 58%, based upon chloroform).

A similar experiment using aluminum chloride (B) after 21 hr of refluxing gave II (17.0 g, 33%, based upon chloroform).

(2) **With Cupric Chloride.**—A mixture as described above, using aluminum chloride (F), was refluxed together with anhydrous cupric chloride (1.3 g, 0.01 mole) for 1.5 hr. Work-up of the dark red mixture gave II (30.7 g, 59%, based upon chloroform).

(3) **With Copper Powder.**—A mixture as described under 2, but with copper powder (1 g) substituted for cupric chloride, was refluxed for 1.5 hr. Work-up of the violet-red mixture gave II (30.2 g, 58%, based upon chloroform).

Pentafluorophenyl(phenyl)methane (IV).—To a stirred mixture of benzene (15.6 g, 0.2 mole) and aluminum chloride (F) (2.67 g, 0.02 mole) was added dropwise 2,3,4,5,6-pentafluorobenzyl chloride (2.17 g, 0.01 mole) at room temperature. The mixture immediately became warm and evolved hydrogen chloride. After refluxing for 2.5 hr the reddish brown mixture was worked up as described giving IV (1.65 g, 64%, based upon pentafluorobenzyl chloride): mp 56–57° (ethanol); ν_{max} (CCl$_4$) 3101 sh, 3085, 3062, 3028, 2939, 2873, 2853, 2633, 2472, 2412, 2068, 1956, 1941, 1873, 1797, 1721, 1651, 1601, 1514, 1500, 1452, 1420, 1372, 1302, 1291, 1181, 1121, 1079, 1030, 995, 961, 916, 899, 724, 697, 661, 608 cm^{-1}; λ_{max} (I) 217 sh mμ (ε 10,332), 252 (1053), 258 (789), 263 sh (656), 268 sh (413), 306 (102). The proton nmr spectrum consisted of a triplet centered at τ 5.83 (aliphatic). The F^{19} nmr spectrum in acetone consisted of multiplets centered at 1199 (*ortho*), 370 (*para*, triplet), 82 (*meta*) cps, downfield from hexafluorobenzene singlet. *Anal.* Calcd for $C_{13}H_7F_5$: C, 60.47; H, 2.73; F, 36.79. Found: C, 60.47; H, 2.61; F, 36.94.

Registry No.—I, 5736-46-9; II, 4780-60-3; CH_3Cl, 74-87-3; III, 771-56-2; CH_2Cl_2, 75-09-2; $CHCl_3$, 67-66-3; C_6F_5H, 363-72-4; hexachlorobenzene, 118-74-1; pentafluorobenzyl chloride, 653-35-0; 1,2-dichloroethane, 107-06-2; pentafluorophenyldichloromethane, 652-30-2; bis(pentafluorophenyl)chloromethane, 5736-48-1; diphenylmethane, 101-81-5; triphenylmethane, 519-73-3; IV, 7484-19-7.

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[15] Ultraviolet spectral solvents: I, isopropyl alcohol; H, *n*-hexane.

[16] J. M. Birchall and R. N. Haszeldine, *J. Chem. Soc.*, 3719 (1961).