[CONTRIBUTION FROM THE MORLEY CHEMISTRY LABORATORY, WESTERN RESERVE UNIVERSITY]

Free Radical Aromatic Substitution. IV. The Reaction of Acyl Peroxides with Benzotrihalides[1]

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The thermal decomposition of benzoyl peroxide in benzotrifluoride has been found to give negligible reaction with the trifluoromethyl group but a 50% yield of a mixture of isomeric phenylbenzotrifluorides (18% *o*-, 40% *m*-, 42% *p*-). In the reactions of benzoyl, *p*-chlorobenzoyl and *p*-nitrobenzoyl peroxide with benzotrichloride, on ascending in electron-seeking character from the phenyl to the *p*-chlorophenyl to the *p*-nitrophenyl free radical, (a) side chain reaction decreases (57, 16 and 0%, respectively) and (b) *meta* substitution (*ortho* is sterically prevented) increases (60, 83 and 100%, respectively). The rule of invariable *ortho-para* substitution is therefore not applicable to all free radicals.

The influence of substituents upon the reactions of aryl radicals has received very little attention. Hey[2] has recently reported that when the nitrobenzene nucleus suffers substitution by phenyl, *p*-bromophenyl and *p*-tolyl free radicals, slight deviations in the course of reaction are observed in that the percentages (averages) of *meta* isomers formed are 9.7, 12.1 and 8.6, respectively. It is obvious that more data are necessary before such reactions may be completely understood.

The benzotrihalides are among the limited number of benzene derivatives in which both the substituent and the aromatic nucleus are capable of undergoing reaction with free radicals. Therefore, if a series of substituted phenyl free radicals react with a single benzotrihalide, a change of the substituent in the free radical may (a) vary the ratio of nuclear to side-chain attack and (b) alter the orientation of substitution in the nucleus of the benzotrihalide.

Therefore, in the present work, it was decided to decompose benzoyl peroxide (a good source of phenyl radicals) in benzotrifluoride and in benzotrichloride to determine which trihalide was the best reference solvent; and then, using the selected solvent, investigate the variations in products obtained with various substituted benzoyl peroxides.

Experimental

All infrared spectra were determined as solutions in a fixed cell of *ca.* 1 mm. thickness with a Perkin-Elmer model 12C infrared spectrometer. The composition of each isomeric mixture was determined by comparison of the spectrum of the unknown to the spectra of known artificial mixtures until duplication was obtained.[3] Comparison measurements were taken between 2 and 15 μ from samples contained in the same cell of fixed thickness. An estimate of the degree of accuracy was determined by experience and recorded as the ± value.

Reagents.—Benzoyl and *p*-chlorobenzoyl peroxide were obtained from Lucidol Corp. and used without further purification, the percentage purity being ascertained iodometrically.[4] *p*-Nitrobenzoyl peroxide was prepared according to the procedure of Price and Krebs.[5] Benzotrichloride (Eastman Kodak white label) was used without further purification. Benzotrifluoride (Eastman Kodak practical) was fractionally distilled at atmospheric pressure to give a fraction of the proper boiling point and refractive index.

Methyl Phenylbenzoates.—Methyl *p*-phenylbenzoate was obtained from Dr. C. B. Coleman, formerly of this Laboratory, m.p. 116–117° (lit.[6] m.p. 117°). Methyl *o*-phenylbenzoate and methyl *m*-phenylbenzoate were obtained from *o*-phenylbenzoic acid, m.p. 114–115° (lit.[7] m.p. 115°), and *m*-phenylbenzoic acid, m.p. 160.5–161° (lit.[8] m.p. 160–161°), respectively, by reaction with diazomethane in ether solution and distillation *in vacuo* of the products. All of the other methyl esters herein described were similarly prepared using diazomethane.

4′-Nitro-2-biphenylcarboxylic acid was prepared from 30 g. (0.015 mole) of *o*-phenylbenzoic acid dissolved in 25 cc. of glacial acetic acid and kept at reflux during the dropwise addition of a mixture of 60 cc. of glacial acetic acid and 45 cc. of fuming HNO_3 over a period of two hours. The reaction mixture was kept at reflux for an additional 1.5 hours and then evaporated to one-half its original volume. After several hours, a crystalline mass formed which was collected on a filter, washed with dilute acetic acid and dried to give 9.2 g. (0.035 mole, 25% yield) of product, m.p. 210–220°. This crude material was recrystallized from ethanol to give 6.7 g. (0.025 mole, 17% yield) of 4′-nitro-2-biphenyl carboxylic acid, m.p. 226–228° (lit.[9] m.p. 222–225°). Upon reaction with diazomethane, this acid gave methyl 4′-nitro-2-biphenylcarboxylate, m.p. 75–76° (after recryst. from ethanol). *Anal.* Calcd. for $C_{14}H_{11}O_4N$: N, 5.45. Found: N, 5.60.

4′-Nitro-3-biphenylcarboxylic acid was prepared by refluxing 5 g. (0.025 mole) of *m*-phenylbenzoic acid with 7 cc. of fuming HNO_3 and 20 cc. of glacial acetic acid for 1.5 hours. The mixture was cooled to give a crystalline precipitate which was collected on a filter, washed and recrystallized from ethanol to give 3.2 g. (0.013 mole, 51% yield) of 4′-nitro-3-biphenylcarboxylic acid, m.p. 232–233°. *Anal.* Calcd. for $C_{13}H_{10}O_4N$: N, 5.75. Found: N, 5.87. This acid reacted with diazomethane to give methyl 4′-nitro-3-biphenylcarboxylate, m.p. 112.5–113° (after recryst. from ethanol). *Anal.* Calcd. for $C_{14}H_9O_4N$: N, 5.45. Found: N, 5.67. This methyl ester did not depress the melting point or show infrared spectral difference from a sample (m.p. 112–114°) isolated after hydrolysis and esterification of the reaction mixture of *p*-nitrobenzoyl peroxide with the benzotrichloride. This proved the *para* orientation of the nitro group.

4′-Nitro-4-biphenylcarboxylic acid, m.p. 339–340° (lit.[10] m.p. 340°) was prepared according to the procedure of Gomberg and Pernert.[11] Methyl 4′-nitro-4-biphenylcarboxylate, m.p. 135–135.5° (after recrystallization from ethanol), was prepared by treating the acid with diazomethane. *Anal.* Calcd. for $C_{14}H_{11}O_4N$: N, 5.45. Found: N, 5.5, 5.85.

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[1] From the thesis submitted by Marvin Sternfeld to the Graduate School of Western Reserve University in partial fulfillment of the requirements for the degree of Doctor of Philosophy. Presented before the Division of Organic Chemistry at the 124th meeting of the American Chemical Society at Chicago, Illinois, September, 1953.

[2] D. H. Hey, *J. Chem. Soc.*, 1977 (1952).

[3] All new spectra have been deposited as Document number 4249 with the ADI Auxiliary Publications Project, Photoduplication Service, Library of Congress, Washington 25, D. C. A copy may be secured by citing the Document number and by remitting in advance $1.25 for photoprints, or $1.25 for 35 mm. microfilm, by check or money order payable to: Chief, Photoduplication Service, Library of Congress.

[4] V. R. Kokatnur and M. Jelling, THIS JOURNAL, **64**, 1432 (1941).

[5] C. C. Price and E. Krebs, *Org. Syntheses*, **23**, 65 (1943).

[6] W. Schlenk and T. Weickel, *Ann.*, **368**, 304 (1909).

[7] E. H. Huntress and M. K. Seikel, THIS JOURNAL, **61**, 816 (1939).

[8] L. Barth and J. Schreder, *Monatsh.*, **3**, 808 (1882).

[9] O. Kubling, *Ber.*, **29**, 166 (1896).

[10] M. K. Seikel and M. F. Pierson, THIS JOURNAL, **67**, 1072 (1945).

[11] M. Gomberg and A. Pernert, *ibid.*, **48**, 1372 (1926).

4′-Amino-2-biphenylcarboxylic acid was prepared by hydrogenating 10 g. (0.043 mole) of 4′-nitro-2-biphenylcarboxylic acid in ethanol with 1.2 g. of palladium-on-charcoal as catalyst in a Parr low pressure hydrogenator. Eight grams (0.04 mole, 93% yield) of the amino acid formed, m.p. 204–206° (lit.[10] m.p. 217.5–218.5°). This amino acid was diazotized and subjected to the Sandmeyer reaction following the general procedure of Scheid.[12] A total of 3.9 g. (0.016 mole, 40% yield) of 4′-chloro-2-biphenylcarboxylic acid was formed, m.p. 162–164° after recrystallization from ethanol (lit.[7] m.p. 165.5–166°). Upon treatment with diazomethane, the above acid formed methyl 4′-chloro-2-biphenylcarboxylate, a yellow oil, which was purified by chromatographic adsorption on alumina, eluting with a 50-50 chloroform–petroleum ether mixture. *Anal.* Calcd. for $C_{14}H_{11}O_2Cl$: C, 68.1; H, 4.26. Found: C, 67.9; H, 4.5.

4′-Amino-3-biphenylcarboxylic acid was prepared by hydrogenating 8.3 g. (0.03 mole) of 4′-nitro-3-biphenylcarboxylic acid in ethanol with 1.0 g. of palladium-on-charcoal as catalyst in a Parr low pressure hydrogenator to give 6.5 g. (0.024 mole, 80% yield) of the amino acid, light brown crystals melting at 198–199°. *Anal.* Calcd. for $C_{14}H_{11}O_2N$: N, 6.59. Found: N, 6.69. This amino acid was diazotized in a manner analogous to that given for the preparation of the ortho isomer. Three and one-half grams (0.015 mole) of the amino acid gave 0.25 g. (0.001 mole, 70% yield) of 4′-chloro-3-biphenylcarboxylic acid, a yellow solid, m.p. 248–250° after repeated recrystallization from ethanol. *Anal.* Calcd. for $C_{14}H_{11}O_2Cl$: C, 67.10; H, 3.87. Found: C, 67.3; H, 4.1. Methyl 4′-chloro-3-biphenylcarboxylate was prepared from the above acid by treatment with diazomethane and melted at 131–132° after purification by a chromatographic adsorption procedure analogous to that for the *ortho* isomer.

4′-Chloro-4-biphenylcarboxylic acid, m.p. 290–291° (lit.[13] m.p. 290°) was treated with diazomethane to give methyl 4′-chloro-4-biphenylcarboxylate, m.p. 120–121° after recrystallization from ethanol. *Anal.* Calcd. for $C_{14}H_{11}O_2Cl$: Cl, 14.4. Found: Cl, 14.1.

o-Phenylbenzotrifluoride was prepared from *o*-aminobenzotrifluoride[14] by the method of Gomberg.[11] From 12 g. (0.106 mole) of *o*-aminobenzotrifluoride was formed 2.3 g. (0.01 mole, 17% yield) of a clear oil, b.p. 124–126° at 10 mm. *Anal.* Calcd. for $C_{13}H_9F_3$: F, 25.7. Found: F, 25.7.

m-Phenylbenzotrifluoride, m.p. 27–27.5° (lit.[15] m.p. 26–27°), was prepared from *m*-aminobenzotrifluoride (Eastman Kodak) according to the method of Gomberg, exactly analogous to the preparation of the *ortho* isomer.

p-Phenylbenzotrifluoride was obtained by chilling with ice–salt the clear oil fraction obtained by fractionally distilling the reaction mixture of benzoyl peroxide with benzotrifluoride. The resultant slurry was filtered quickly to give white crystals, m.p. 66.0–66.5°. The infrared spectrum of this material gave the characteristic absorption peak for a *para* substituted biphenyl by analogy to other nuclear biphenyl derivatives considered. *Anal.* Calcd. for $C_{13}H_9F_3$: F, 25.7. Found: F, 25.3.

Diphenyldifluoromethane (b.p. 125° at 10 mm.) was prepared according to the method of Henne.[16]

Reaction of Benzoyl Peroxide with Benzotrichloride.—A three-liter, three-necked flask was fitted with a dropping funnel, a reflux condenser, a thermometer and a thermoregulator which controlled a Glas-col heating mantle. At the top of the condenser was attached a train which consisted of (1) a trap cooled by ice–salt, (2) a 500-cc. bulb to trap pyridine, (3) a Milliken absorption bubbler, filled with equal portions of pyridine and water, serving as a trap for HCl, (4) a trap cooled by Dry Ice–acetone, (5) two U-tubes filled with ascarite for carbon dioxide absorption, (6) a CO_2 absorption tube to the atmosphere.

Benzotrichloride (400 g.) was heated to 75°. A slurry of 123.3 g. of benzoyl peroxide (0.500 mole) in 382 g. of benzotrichloride was added to the reaction flask over a period of ten hours. The reaction mixture thus contained 0.500 mole of benzoyl peroxide and 4 moles of benzotrichloride. The temperature was maintained at 75 ± 2°. At the end of 100 hours, carbon dioxide-free air was swept through the apparatus by aspirating the system gently. The carbon dioxide evolved weighed 25.5 g. (0.58 mole). The HCl collected (3.0 g.) was not an accurate measure of the HCl evolved due to its high solubility in benzotrichloride.

The reaction mixture was fractionally distilled at reduced pressure until solid appeared in the condenser. The distillate consisted of 32.4 g. of chlorobenzene (derivative 2,4-dinitrochlorobenzene, m.p. 52°) and 703.1 g. of excess benzotrichloride. The residue from this distillation was refluxed with three 500-cc. portions of 10% aqueous NaOH (methanolic NaOH gave identical results), giving an alkaline solution and a reddish-brown inert residue. The alkaline layers were combined and acidified with 20% H_2SO_4. The resultant acid precipitate was collected on a filter and air-dried. The filtrate was extracted with ether, this ethereal solution evaporated, and the solid that remained combined with the acid precipitate. The total of 55.2 g. of acids (dried over P_2O_5) was reacted with excess diazomethane in ether to convert all the acids quantitatively to their methyl esters. Distillation of this mixture of methyl esters gave 24.5 g. of methyl benzoate and 33.2 g. of residue. Infrared analysis of this ester residue by comparison to artificial mixtures revealed that 11.6 g. (35.0%) was methyl *p*-phenylbenzoate, 18.6 g. (53%) was methyl *m*-phenylbenzoate, and 4.0 g. (12%) was methyl benzoate. Methyl *o*-phenylbenzoate was absent. Benzoic acid, generally a reaction product in benzoyl peroxide decompositions, is converted to benzoyl chloride in the presence of benzotrichloride. The methyl benzoate could therefore originate from either benzoyl chloride (formed from the peroxide fragmentation) or from benzotrichloride not removed in the distillation preceding hydrolysis. No attempt was made to determine the source of this ester. As only small quantities of phenylbenzoic acids are produced from benzoyl peroxide fragments under conditions similar to those described in the present paper,[17] it was assumed that all of the methyl phenylbenzoates had as their common source phenylbenzotrichlorides. Proof that this methyl esterified acid fraction did not contain methyl hydroxylbenzoates (obtained by attack of benzoyloxy radical upon benzotrichloride) was given by comparison of the infrared spectra of the methyl hydroxybenzoates with the infrared spectrum of the reaction mixture. From these qualitative observations, methyl hydroxybenzoates were judged absent.

The red-brown inert material (61.6 g.) left after alkaline hydrolysis was extracted with hot petroleum ether (b.p. 85–100°) to leave 2.0 g. of a dark residue. Evaporation of the solvent from the extract left 59.6 g. of an orange-red solid. An aliquot of this orange-red solid was chromatographed on an alumina column ($15 \times {}^3/_4''$) with petroleum ether and upon elution gave 68.3% of a compound melting at 156–158°. This corresponds to 40.8 g. of the total orange-red fraction (diphenyltetrachloroethane, m.p. 161–162°[18]). Derivative 1,2-difluoro-1,2-diphenylethylene, m.p. 122–123° (lit.[19] m.p. 122–123°). The 31.5% (18.8 g. in the original fraction) of material which remained on the alumina column was eluted with $CHCl_3$, m.p. 85–120°, mol. wt. 371 (Rast method).

The duplicate reaction involved identical conditions as the reaction already described with the exception that the molar ratio of benzoyl peroxide to benzotrichloride was 1:16 rather than 1:8. The infrared spectrum of the methyl phenylbenzoate fraction previously obtained was duplicated in the check reaction and the products checked reasonably well. Therefore, the products are apparently not sensitive to reasonable changes of solvent to peroxide ratios.

Reaction of Benzoyl Peroxide with Benzotrifluoride.—This reaction was performed in a manner identical with the preceding experiment. From the reaction of 935 g. of benzotrifluoride and 97.3 g. (0.400 mole) of benzoyl peroxide was obtained 27.2 g. (0.62 mole) of carbon dioxide.

The reaction mixture was distilled at atmospheric pressure through a helices-packed column to give 3.2 g. of fluorobenzene (derivative 4,4-difluorodiphenylsulfone, m.p.

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[12] K. Scheid, *Ber.*, **34**, 1901 (1913).

[13] C. Musante and V. Parrini, *Gazz. chim. ital.*, **79**, 453 (1949).

[14] R. G. Jones, THIS JOURNAL, **69**, 2346 (1947).

[15] M. R. Pettit and J. C. Tatlow, *J. Chem. Soc.*, 3459 (1951).

[16] A. L. Henne and H. M. Leicester, THIS JOURNAL, **60**, 864 (1938).

[17] R. L. Dannley, E. C. Gregg, Jr., R. E. Phelps and C. B. Coleman, *ibid.*, **76**, 445 (1954).

[18] R. C. Fuson, *ibid.*, **55**, 722 (1933).

[19] W. T. Bolen and T. M. Tinker (the du Pont Co.) U. S. 2,238,242 (April 15, 1941).

96–98°[20]) and 899 g. of excess benzotrifluoride. The distilland left after removal of excess benzotrifluoride weighed 101.2 g. Distillation of this material gave 50.4 g. of a clear oil boiling at 90–100° at 8 mm. and 49.8 g. of residue. This distillate was extracted with three 50-cc. portions of 10% NaOH to give an alkaline layer and a clear oil (43.9 g.). Acidification with 20% H_2SO_4 of the aqueous alkaline layer gave 6.5 g. of benzoic acid.

The clear oil (43.9 g.) was analyzed by comparison of its infrared spectrum to the spectra of known artificial mixtures and was found to contain 18 ± 1% *o*-phenylbenzotrifluoride, 40 ± 1% *m*-phenylbenzotrifluoride, 42 ± 1% *p*-phenylbenzotrifluoride and a trace of diphenyldifluoromethane.

Further evidence that diphenyldifluoromethane was contained in this fraction was obtained by hydrolyzing a portion of the oil with concd. H_2SO_4 and treating this acid mixture with 2,4-dinitrophenylhydrazine to give a few milligrams of 2,4-dinitrophenylhydrazone, m.p. 240–242°, which corresponds to that of benzophenone, the expected product from the hydrolysis of diphenyldifluoromethane.

All attempts to quantitatively hydrolyze phenylbenzotrifluoride proved in vain. A number of methods[21] which have been found applicable to the hydrolysis of benzotrifluoride were tried. A sample of this fraction was combined with 30% alcoholic KOH in a sealed tube and heated to 250° for two days, but this also failed to give the desired hydrolysis.

An aliquot of the residue (49.8 g.) was chromatographed on alumina, but gave no separable product. The residue was a gummy material which became solid on standing, m.p. 67–120° after a portion was recrystallized from ethanol. Presumably this residue is a polyphenylated product and contains within it some polymerized diphenyldifluoroethylene. The latter product might be expected for diphenyltetrafluoroethane has never been reported and syntheses which might be expected to yield it give only diphenyldifluoroethylene. It has recently been reported[22] that phenyldifluoroethylene polymerizes at 70° with benzoyl peroxide. This probably accounts for the failure to separate the expected side-chain products in the present work.

The duplicate reaction involved identical experimental conditions with the exception that the temperature was maintained at the reflux temperature of benzotrifluoride (100°) rather than 75°. The infrared spectrum of the phenylbenzotrifluoride fraction was duplicated in this reaction and the products checked reasonably well. Therefore, the reaction is apparently not sensitive to a reasonable change (25°) in decomposition temperature.

Since the reaction of benzoyl peroxide with benzotrifluoride gave only a small amount of side-chain product (fluorobenzene), and the expected diphenyldifluoroethylene apparently polymerizes, it was decided to use benzotrichloride as the reference solvent.

Reaction of *p*-Chlorobenzoyl Peroxide with Benzotrichloride.—*p*-Chlorobenzoyl peroxide (155.6 g., 0.500 mole, 99.8% pure) was decomposed in 1564 g. (8 moles) of benzotrichloride in a manner exactly analogous to that described in the reaction of benzoyl peroxide with benzotrichloride.

A white precipitate was evident after the first day. The reaction mixture was heated for 160 hours. The ascarite tubes gained 27.4 g. in weight.

The reaction mixture was chilled and filtered. The white precipitate (43.8 g.) was *p*-chlorobenzoic acid, m.p. 240–241° (lit. m.p. 243°). The red-brown filtrate was fractionally distilled at reduced pressure to give 10.6 g. of chlorobenzene (0.09 mole), 20.6 g. of a semi-solid fraction, benzotrichloride and 149.6 g. of a clear red residue. The semi-solid fraction proved to be principally *p*-dichlorobenzene (11.6 g.), m.p. 52–53°, after extraction with aqueous NaOH to remove benzoyl chloride; derivative 1,4-dichlorobenzenesulfonamide-2, m.p. 177–178° (lit.[20] m.p. 179.5–180°).

The clear red residue was refluxed with 1000 cc. of 30% NaOH to give an alkaline solution and 69.4 g. of a dark residue. The alkaline solution was acidified with 20% H_2SO_4 to give 60.0 g. of a mixture of acids which were esterified with diazomethane in the usual way. The methyl esters thus formed were dissolved in 70 cc. of petroleum ether, leaving 11.4 g. of occluded inorganic material. The extracted material weighed 52.0 g. after evaporation of the solvent. Chromatography on an alumina column of an aliquot of this extracted material with 200 cc. of a 50-50 mixture of chloroform–petroleum ether gave 89% of a yellow semi-solid (46.4 g. in total fraction). The reddish material remaining on the column (5.6 g. in total fraction) was shown to be higher phenylated esters, average mol. wt. 570 (Rast).

The yellow semi-solid material was analyzed by comparing its spectrum to artificial mixtures of methyl 4′-chloro-2-, -3- and -4-biphenylcarboxylates. This analysis showed the composition to be less than 1% methyl 4′-chloro-2-biphenylcarboxylate, 83 ± 1% methyl 4′-chloro-3-biphenylcarboxylate, and 17 ± 1% methyl 4′-chloro-4-biphenylcarboxylate. Methyl *p*-chlorobenzoate, an expected impurity, was shown to be absent. Apparently, all the *p*-chlorobenzoic acid precipitates from the reaction mixture.

The dark inert residue (69.4 g.) after alkaline hydrolysis was extracted with hot petroleum ether, leaving 57.8 g. of a dark residue. Evaporation of the extract gave 11.6 g. of an orange-red solid which crystallized slowly on standing and which by chromatography of an aliquot upon an alumina column (exactly analogous to the procedure used in the reaction of benzoyl peroxide with benzotrichloride) proved to contain 5.7 g. (0.08 mole) of impure tetrachlorodiphenylethane. Recrystallization of this 5.7 g. from ethanol gave 2.8 g. of diphenyltetrachloroethane, m.p. 159–160° (lit. m.p. 161–162°) which did not depress the melting point of the diphenyltetrachloroethane obtained in the first reaction.

The dark insoluble residue (57.8 g.) resisted all attempts to separate identifiable products.

A duplicate reaction involving identical reaction conditions and quantities checked the figures reported. The infrared spectrum was also duplicated.

Reaction of *p*-Nitrobenzoyl Peroxide with Benzotrichloride.—*p*-Nitrobenzoyl peroxide (82.7 g., 0.250 mole, 99.4%) was decomposed in 782.0 g. (4 moles) of benzotrichloride in a manner analogous to that described in the reaction of benzoyl peroxide with benzotrichloride with the exception that the temperature was maintained at 100° in order to decompose this peroxide. The reaction proceeded for 170 hours, during which time the reaction mixture changed in color from yellow to a reddish-brown. The ascarite tubes gained 12.83 g. in weight.

The red-brown reaction mixture (849.2 g.) was fractionally distilled at reduced pressure to give 749.8 g. of excess benzotrichloride, 26.0 g. of *p*-nitrobenzoyl chloride and 69.4 g. of a reddish-brown residue. The 26.0 g. of *p*-nitrobenzoyl chloride was treated with excess ethanol to give the theoretical yield of ethyl *p*-nitrobenzoate, m.p. 57–58°. This precluded the existence of *p*-nitrochlorobenzene (an expected product if side-chain reaction had occurred), since *p*-nitrobenzoyl chloride and *p*-nitrochlorobenzene would distil together.

A portion of the reddish-brown residue was distilled at 0.02 mm. pressure in an atmosphere of N_2 to give a fuming oil which crystallized slowly, m.p. 145–150° when recrystallized from petroleum ether. *Anal.* Calcd. for $C_{13}H_8Cl_3O_2N$: Cl, 33.7. Found: Cl, 33.9. This confirms the fact that the intermediate nuclear product subsequently hydrolyzed is actually a nitrophenylbenzotrichloride.

The reddish-brown residue (69.4 g.) was refluxed with 100 cc. of 30% NaOH to give an alkaline solution and 15.9 g. of a dark residue. Acidification of the alkaline solution with 20% H_2SO_4 gave 45.4 g. of acids which when dissolved in chloroform left 6.8 g. of occluded inorganic material. Evaporation of the chloroform solution and extraction of the resulting solid with ether left 14.8 g. of dark colored acids, neut. equiv., 1200 ± 20, indicating that they are polynuclear compounds. The extract was treated with diazomethane in the usual way to give 20.2 g. of orange-colored methyl esters. These esters dissolved completely in a mixture of 250 cc. of petroleum ether and 25 cc. of chloroform, and were adsorbed on an alumina column. Elution with a mixture of 800 cc. of petroleum ether and 80 cc. of chloroform gave 16.8 g. (77.6%) of a light colored solid, m.p. 63–102°. These chromatographic conditions were determined by experiments performed with known samples of isomeric methyl 4′-nitrobiphenylcarboxylates. The material remaining on the alumina (22.4%) was eluted with $CHCl_3$ and hydrolyzed with base to give an acid material of

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[20] E. H. Huntress and F. H. Carten, THIS JOURNAL, **62**, 511 (1940).

[21] (a) E. T. McBee and M. R. Frederick, *ibid.*, **71**, 1490 (1949); (b) E. Wertyporoch, *Ann.*, **493**, 1536 (1932); (c) R. G. Jones, THIS JOURNAL, **69**, 2346 (1947); (d) G. M. LeFave, *ibid.*, **71**, 4148 (1949).

[22] M. Prober, *ibid.*, **75**, 972 (1953).

neut. equiv. 453. The 16.8 g. of light colored acids was analyzed by comparison of the infrared spectrum of the methyl esters (prepared from diazomethane) with artificial mixtures of methyl 4′-nitro-2-, -3- and -4-biphenylcarboxylates and methyl *p*-nitrobenzoate (an expected impurity). Examination of the spectrum in acetonitrile solution demonstrated the absence of the *ortho* isomer and examination of the spectrum in chloroform solution revealed the absence of the *para* isomer. Analysis showed the composition to be 76 ± 1% methyl 4′-nitro-3-biphenylcarboxylate and 24 ± 1% methyl *p*-nitrobenzoate. The *ortho* and *para* esters could not be detected and hence could not exceed 1% in concentration.

The dark residue (15.9 g.) after alkaline hydrolysis was extracted with hot petroleum ether, leaving 11.5 g. of a dark residue. The petroleum ether extract, upon evaporation, gave 4.4 g. of an orange solid which, when chromatographed using the procedure previously described for the isolation of diphenyltetrachloroethane, failed to give any isolatable product. The dark residue, likewise, gave no separable product.

A duplicate reaction involved identical reaction conditions and quantities. The infrared spectrum was also duplicated.

Results and Conclusions.—Table I lists the principal products obtained in the present work.

TABLE I

MOLES PRODUCT PER MOLE OF (p-$AC_6H_4COO)_2$

A	X(of C_6H_5-CX_3)	CO_2	AC_6H_4X	$C_6H_5CX_2$–$CX_2C_6H_5$	AC_6H_4-$C_6H_4CX_3$
H	F	1.55	0.03	Not isolated	0.50
H	Cl	1.16	.57	0.26	.21
Cl	Cl	1.25	.16	.02	.36
NO_2	Cl	1.16	0	0	.20

The side-chain derivative ($C_6H_5CCl_2CCl_2C_6H_5$) is probably obtained by the reactions

$$AC_6H_4\cdot + C_6H_5CCl_3 \longrightarrow AC_6H_4Cl + C_6H_5CCl_2\cdot$$
$$2C_6H_5CCl_2\cdot \longrightarrow C_6H_5—CCl_2—CCl_2—C_6H_5$$

Therefore the yield of AC_6H_4Cl should be twice that of the diphenyltetrachloroethane. This is seen to be qualitatively true in the reaction (benzoyl peroxide with benzotrichloride) which produced major quantities of such products. However, diphenyltetrachloroethane is unstable and tends to dehalogenate and polymerize. Therefore, the yield of this compound can be expected to be uniformly low, and the yield of AC_6H_4X has been taken as a more reliable measure of side-chain reaction.

Benzotrifluoride gave a negligible quantity of side-chain reaction with the phenyl radical and therefore was judged to be a poor reference material in the present work. This decision was strengthened by the difficulty of preparing for spectroscopic purposes the individual biphenyl derivatives containing this group. The tremendously greater amount of side-chain attack by the phenyl radical observed on proceeding to benzotrichloride is logical in that the carbon to chlorine bond is much weaker than the carbon to fluorine bond.

In the reactions with benzotrichloride, on proceeding from phenyl to chlorophenyl to nitrophenyl radicals, it is observed that the ratio of side-chain to nuclear attack decreases from 2.7 to 0.46 to 0. Obviously, all aryl free radicals may not be placed in a single category but must be classified in their reactions. If we consider the ability of these substituents to withdraw electrons from the aromatic nucleus, a logical explanation of the data is possible. The chlorine atom, which must be released by the trichloromethyl group in side-chain attack, is itself primarily an electron acceptor. Consequently it should be least susceptible to attack by the similarly powerful electron-seeking nitrophenyl radical and most susceptible to reaction with the phenyl radical. When reaction with the chlorine atom is not preferred, nuclear substitution occurs as an alternative.

The compositions of the mixtures of isomeric biphenyls obtained by nuclear substitution are listed in Table II. The complete lack of *ortho* substitution in benzotrichloride while 18% of the substitution in benzotrifluoride occurs in this position may be readily explained by steric hindrance and is supported by the data reported in the reaction of benzoyl peroxide with the alkylbenzenes.[23]

TABLE II

% OF ISOMERS IN BIARYL FRACTIONS

Radical	Solvent	Ortho, %	Meta, %	Para, %
Phenyl	$C_6H_5CF_3$	18	40	42
Phenyl	$C_6H_5CCl_3$	0	60	40
Chlorophenyl	$C_6H_5CCl_3$	0	83	17
Nitrophenyl	$C_6H_5CCl_3$	0	100	0

The predominant *meta* substitution observed with the chlorophenyl and nitrophenyl radicals is obviously not in accord with the so-called rule of invariable *ortho–para* substitution. The increase in yield of *meta* isomer on passing from phenyl to chlorophenyl to the strongly electron-seeking nitrophenyl radical is logical on the basis that the *meta* position of the benzotrihalides is known from ionic substitution studies to have a higher electron density than the *para* position.

In fact, it seems highly probable that substitution in aromatic nuclei by radicals highly deficient in electrons (*e.g.*, *p*-nitrophenyl) may follow the rules for orientation and activation influences established for ionic nucleophilic reagents. Conversely, radicals rich in electrons (*e.g.*, *p*-anisyl) may obey the rules established for electrophilic ionic reagents.

The rule of invariable *ortho–para* substitution was based upon limited data which usually were concerned with the reactions of the phenyl radical itself. The phenyl radical is actually the poorest representative with which to work, for it is intermediate in the scale of electron-seeking and electron-donating radicals.

The work presented in the present paper is not sufficient to establish the hypothesis just presented, in that it concerned substitution in a benzene derivative in which *ortho* substitution was sterically prevented. Other experiments are being performed to test the orientation and activation influences which have been predicted.

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[23] R. L. Dannley and B. Zaremsky, Abstracts of Papers, 124th meeting of the American Chemical Society, Chicago, Ill., September, 1953, p. 36-O.