Aromatic Substitution. XX. Intact and Dealkylating Nitration of Propylated and Butylated Alkylbenzenes with Nitronium Tetrafluoroborate

BY GEORGE A. OLAH AND STEPHEN J. KUHN

RECEIVED SEPTEMBER 20, 1963

Nitration of isomeric cymenes, n-propyltoluenes, diisopropylbenzenes, 1,3,5-triisopropylbenzene, t-butyltoluenes, di-t-butylbenzenes, and 1,3,5-tri-t-butylbenzene with $NO_2^+BF_4^-$ in tetramethylene sulfone solution has been investigated. It was found that, besides intact nitration, direct electrophilic dealkylating nitration also takes place in the case of o- and p-cymene, p-diisopropylbenzene, and 1,3,5-triisopropylbenzene. Similar alkyl replacement has been observed in the nitration of p-di-t-butylbenzene and 1,3,5-tri-t-butylbenzene, but no dealkylation takes place in the nitration of t-butyltoluenes. The mechanism of the nitrations is discussed on the basis of experimental data (including isomer distributions and relative reactivities).

Dealkylation of certain polyalkylbenzenes during nitration has been repeatedly observed by a number of investigators.[1-3] Perhaps the most investigated case is the nitration of p-cymene and its derivatives. The removal of an isopropyl group during the nitration of a p-cymene derivative (p-cymene-o-sulfonic acid) was first observed by Hintikka.[4] Wheeler and co-workers[5,6] have observed the formation of p-nitrotoluene during nitration of p-cymene in strong acid media. Doumani and Kobe[7] have given a detailed consideration of the dealkylation accompanying mononitration of p-cymene. Dealkylation was also observed by other workers during dinitration[8] and trinitration[9] of p-cymene. Allenby and Nicholls[10] have undertaken a thorough investigation to determine the optimum conditions for the preparation of 2,6-dinitro-p-cymene and 2,4-dinitrotoluene.

Other examples of the removal of an alkyl group during nitration are the formation of p-nitro-t-butylbenzene from p-di-t-butylbenzene[11] and the formation of 3,5-di-t-butylnitrobenzene from 1,3,5-tri-t-butylbenzene, as observed by Bartlett and co-workers.[12] All these nitrations have been carried out with nitric acid or mixed acids, or with nitric acid dissolved in acetic acid and acetic anhydride.

Several investigators have put forward theories to explain the nature of the dealkylation process. Claus[1] and Qvist[2] have suggested that the first step is oxidation of the alkyl group to a carboxyl group by nitric acid followed by substitution of the carboxyl group by a nitro group. Smith[3] has postulated that methylbenzenes are first converted to benzyl nitrates by nitric acid and these in turn to nitro compounds by the effect of sulfuric acid.

Doumani and Kobe[7] have concluded that oxidation plays no part in the process, for if p-cymene is properly emulsified during nitration no nitrogen oxides are found. These authors suggested that p-cymene is cleaved directly by nitric acid, the tolyl group appearing in the products as a nitrotoluene and the isopropyl group as 2-propanol. They were able to isolate 2-propanol from the spent mixed acid, though not in quantitative yields. The acid-catalyzed dispropor-

tionation of polyalkylbenzenes seemingly does not play an important role in these reactions, as indicated by the appearance of one principal isomer (p-nitrotoluene) in which the nitro group is in the position previously occupied by the isopropyl group. If disproportionation would take place before nitration, all the three isomeric nitrotoluenes should form. In contrast, if the dealkylation would take place after the nitration, 2- or 3-nitrotoluene should be the products.

The present investigation was undertaken to obtain additional information relating to the mechanism of dealkylating nitration of propylated and butylated alkylbenzenes. To avoid possible oxidation during nitration, nitronium tetrafluoroborate, $NO_2^+BF_4^-$, has been used as a nitrating agent[13] which is known not to be an oxidizing agent under the experimental conditions used in this work. Another advantage of the use of $NO_2^+BF_4^-$ is that the reactions can be carried out in organic solvents under homogeneous conditions, and the use of large excess of strong acids can be avoided. Indeed, the acid present in the system can come only from proton elimination from the ring during intact nitration. The scope of the present investigation included the nitration of the isomeric cymenes, n-propyltoluenes, diisopropylbenzenes, 1,3,5-triisopropylbenzene, the isomeric t-butyltoluenes, di-t-butylbenzenes, and 1,3,5-tri-t-butylbenzene. The reactions have been carried out at 25° in tetramethylene sulfone solution using a ratio of 1 mole of $NO_2^+BF_4^-$ to 3 moles of alkylbenzenes. Nitrations, based on $NO_2^+BF_4^-$ used, were practically quantitative. Products were analyzed by gas–liquid chromatography (see Experimental part).

Data obtained are summarized in Tables I and II.

Table I shows that replacement of the isopropyl group takes place in the nitration of p-cymene to the extent of 9.5% and to a much larger extent (41%) in the nitration of o-cymene; but no nitrotoluenes were observed in the nitration of m-cymene. That the nitro group indeed replaces the isopropyl group in o- and p-cymenes was indicated by the appearance of the same isomeric nitrotoluenes in the products, without the presence of any other isomer.

At the same time the intact nitration of the isomeric cymenes is also of interest. p-Cymene gave 94% of the nitrated product with the nitro group ortho to the methyl group and 6% of the isomer with the nitro group ortho to the isopropyl group. Partial rate factors calculated on the basis of the nearly 16:1 isomer ratio are difficult to interpret because the steric ortho effect of the isopropyl group demonstrated in related nitration of cumene to give an isomer distribution of 23.4% o-, 6.9% m-, and 69.7% p-isomers does not seem sufficiently large to explain the experimentally observed isomer ratio in the case of nitration of p-cymene.

(1) P. Claus, J. prakt. Chem., **37**, No. 2, 14 (1888).

(2) W. Qvist, Acta Acad. Aboensis, Math. Phys., **6**, 14 (1932).

(3) (a) L. I. Smith and S. A. Harris, J. Am. Chem. Soc., **57**, 1289 (1935); (b) L. I. Smith and F. L. Taylor, ibid., **59**, 1082 (1937); (c) L. I. Smith and J. W. Horner, ibid., **62**, 1349 (1940); (d) L. I. Smith and C. O. Guss, ibid., **62**, 2635 (1940).

(4) S. V. Hintikka, Teknillien Aikakauslehti, **7**, 27 (1917).

(5) A. S. Wheeler and I. W. Smithy, J. Am. Chem. Soc., **43**, 2611 (1921).

(6) A. S. Wheeler and C. R. Harris, ibid., **49**, 494 (1927).

(7) T. F. Doumani and K. A. Kobe, J. Org. Chem., **7**, 1 (1942).

(8) J. Alfthan, Ber., **53**, 78 (1920).

(9) O. M. Halse and H. Dedichen, Tids. Kemi, **15**, 301 (1918).

(10) O. C. W. Allenby and R. V. V. Nicholls, Can. J. Research, **27**, 655 (1949).

(11) D. I. Legge, J. Am. Chem. Soc., **69**, 2086 (1947).

(12) P. D. Bartlett, M. Roha, and R. M. Stiles, ibid., **76**, 2349 (1954).

(13) G. Olah, S. Kuhn, and S. Mlinko, J. Chem. Soc., 4257 (1956); S. J. Kuhn and G. A. Olah, J. Am. Chem. Soc., **83**, 4564 (1961).

TABLE I

NITRATION OF PROPYLATED ALKYLBENZENES WITH NO₂⁺BF₄⁻ IN TETRAMETHYLENE SULFONE SOLUTION AT 25°

Aromatic hydrocarbon	Intact nitration		Dealkylating nitration	
	Yield, %	Isomer distribution	Yield, %	Isomer distribution
Cumene	100	1,2-, 23.4%; 1,3-, 6.9%; 1,4-, 69.7%		
p-Cymene	90.5	94.2% 2-Nitro-4-isopropyltoluene	9.5	100% p-Nitrotoluene
		5.8% 3-Nitro-4-isopropyltoluene		
m-Cymene	100	81.8% 6-Nitro-3-isopropyltoluene		
		10.8% 4-Nitro-3-isopropyltoluene		
		5.9% 5-Nitro-3-isopropyltoluene		
		1.5% 2-Nitro-3-isopropyltoluene		
o-Cymene	59	42.2% 4-Nitro-2-isopropyltoluene	41	100% o-Nitrotoluene
		38.2% 6-Nitro-2-isopropyltoluene		
		18.6% 5-Nitro-2-isopropyltoluene		
		1.0% 3-Nitro-2-isopropyltoluene		
n-Propylbenzene	100	1,2-, 51%; 1,3-, 2.3%; 1,4-, 46.7%		
p-n-Propyltoluene	100	35.5% 3-Nitro-4-n-propyltoluene		
		64.5% 2-Nitro-4-n-propyltoluene		
m-n-Propyltoluene	100	52.5% 6-Nitro-3-n-propyltoluene		
		32.6% 4-Nitro-3-n-propyltoluene		
		13.9% 2-Nitro-3-n-propyltoluene		
		1.0% 5-Nitro-3-n-propyltoluene		
o-n-Propyltoluene	100	44.1% 4-Nitro-2-n-propyltoluene		
		26.0% 6-Nitro-2-n-propyltoluene		
		15.6% 5-Nitro-2-n-propyltoluene		
		14.3% 3-Nitro-2-n-propyltoluene		
o-Diisopropylbenzene	100	3.3% 3-Nitro-o-diisopropylbenzene	Traces	o-Nitrocumene
		96.7% 4-Nitro-o-diisopropylbenzene		
p-Diisopropylbenzene	44	100.0% 2-Nitro-p-diisopropylbenzene	56	100% p-Nitrocumene
m-Diisopropylbenzene	100	52.5% 4-Nitro-m-diisopropylbenzene		
		47.5% 5-Nitro-m-diisopropylbenzene		
1,3-Dimethyl-5-isopropylbenzene	100	57.0% 3,5-Dimethyl-4-nitroisopropylbenzene		
		43.0% 3,5-Dimethyl-2-nitroisopropylbenzene		
1,3,5-Triisopropylbenzene			100	100% 5-Nitro-m-diisopropylbenzene

TABLE II

NITRATION OF BUTYLATED ALKYLBENZENES WITH NO₂⁻BF₄⁻ IN TETRAMETHYLENE SULFONE SOLUTION AT 25°

Aromatic hydrocarbon	Intact nitration		Dealkylating nitration	
	Yield, %	Isomer distribution	Yield, %	Isomer distribution
t-Butylbenzene	100	1,2-, 14.3%; 1,3-, 10.7%; 1,4-, 75.0%		
p-t-Butyltoluene	100	95.3% 2-Nitro-4-t-butyltoluene		
		4.7% 3-Nitro-4-t-butyltoluene		
m-t-Butyltoluene	100	78.0% 6-Nitro-3-t-butyltoluene		
		13.0% 5-Nitro-3-t-butyltoluene		
		7.7% 4-Nitro-3-t-butyltoluene		
		1.2% 2-Nitro-3-t-butyltoluene		
o-t-Butyltoluene	100	77.0% 4-Nitro-2-t-butyltoluene		
		13.0% 6-Nitro-2-t-butyltoluene		
		10.0% 5-Nitro-2-t-butyltoluene		
		1.0% 3-Nitro-2-t-butyltoluene		
p-Di-t-butylbenzene	80	100.0% 2-Nitro-p-di-t-butylbenzene	20	100% p-Nitro-t-butylbenzene
m-Di-t-butylbenzene	100			
o-Di-t-butylbenzene	100	100% 4-Nitro-o-di-t-butylbenzene[a,b]		
1,3-Dimethyl-5-t-butylbenzene	100	67.9% 3,5-Dimethyl-4-nitro-t-butylbenzene		
		32.1% 3,5-Dimethyl-2-nitro-t-butylbenzene		
1,3,5-Tri-t-butylbenzene			100	100% 5-Nitro-m-di-t-butylbenzene

[a] Isomer distribution based on observation of one isomer. Owing to lack of reference pure 3-nitro-o-di-t-butylbenzene, the possible presence of the latter in small amount could not be checked. [b] Substantial disproportionation and isomerization was also observed with subsequent formation of nitro-t-butylbenzenes but isomer distribution is identical with that obtained in nitration of t-butylbenzene.

In p-cymene the methyl and isopropyl groups compete in their directing effects during substitution. The electric dipole moment of a molecule is a measure of the permanent inductive (I) effect. It is therefore of interest to note its value for p-cymene, since it should indicate (μ_{CH_3} being opposed to $\mu_{isopropyl}$) which of the alkyl groups has the larger I effect.

LeFevre[14] reported the dipole moment of p-cymene to be 0.1×10^{-18} e.s.u., i.e., effectively zero, indicating that $\mu_{CH_3} = \mu_{isopropyl}$. Therefore p-cymene should give on monosubstitution equal amounts of 2- and 3-

isomers, if only the inductive effect determines the isomer distribution.

Consideration of hyperconjugation possibilities suggests that the position ortho to the methyl group should be more susceptible to electrophilic attack than the position ortho to the isopropyl group.[15] However, the effect of hyperconjugation cannot be considered decisive.[16] Undoubtedly the steric effect of the isopropyl group also plays an important role in directing the entering substituent mainly to the 2-position.

(15) J. W. Baker and W. S. Nathan, ibid., 1844 (1935).
(16) M. J. S. Dewar, "Hyperconjugation," Ronald Press, New York, N. Y., 1962.

(14) R. J. W. LeFevre, J. Chem. Soc., 980 (1933).
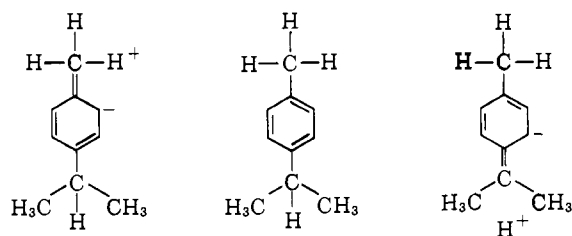
three forms   one form

Though no 3-nitro-4-isopropyltoluene has been isolated from the nitration of p-cymene prior to this investigation, LeFevre predicted, assuming that the velocities of nitration of toluene, ethylbenzene, and isopropylbenzene are approximately the same (as indeed was found in our previous work[17]), that in the nitration of p-cymene (4-isopropyltoluene) 91% 2-isomer and 9% 3-isomer should be formed, which is very close to the values found experimentally in the present work.

To gain further information on the mechanism of the nitration of cymenes with $NO_2^+BF_4^-$, we determined their reactivities relative to benzene, using competitive experiments in a manner described previously.[17] Table III shows the data obtained.

TABLE III

COMPETITIVE NITRATION OF CYMENES AND BENZENE WITH $NO_2^+BF_4^-$ IN TETRAMETHYLENE SULFONE SOLUTION AT 25°

	Obsd. relative rate	Rel. rate corrected for amt. of dealkylating nitration
Benzene	1.0	1.0
o-Cymene	1.15	1.95
m-Cymene	2.80	2.80
p-Cymene	2.25	2.49

Data of Table III indicate that in a manner similar to the previously investigated nitration of other alkylbenzenes, cymenes also nitrate through a π- and not a σ-complex substrate rate-determining step (acting as π-donor entities) followed by a second, σ-complex lower-energy-level transition state leading to stabilization of the nitro group in the o-, m-, and p-positions. The second transition state (which should be different for the individual isomers) thus accounts for the dealkylation, when an isopropyl group instead of a proton is eliminated from the σ-complex.

amount of diisopropyltoluene based on the degree of dealkylating nitration.

In the basic solvent (tetramethylene sulfone) the by-product acid is not capable of effecting disproportionation of any of the isomeric cymenes, as was proved by experiments designed to reproduce exactly the experimental conditions of nitration. There is also no evidence of any oxidation or formation of benzyl nitrates. It therefore must be suggested that dealkylating nitration of o- and p-cymenes is indeed a direct electrophilic substitution process in which the dimethylcarbonium ion and not a proton is eliminated. This also explains why m-cymene undergoes only intact nitration.

The isomeric n-propyltoluenes when nitrated with $NO_2^+BF_4^-$ under identical conditions give only intact nitration. Absence of dealkylating nitration is to be expected since cleavage of a primary carbonium ion $(CH_3CH_2CH_2^+)$ would be necessary. The isomeric diisopropylbenzenes gave similar results to those obtained with the cymenes.

In the nitration of p-diisopropylbenzene one of the isopropyl groups is replaced by a nitro group yielding p-nitrocumene to an extent of 56%. No replacement of the isopropyl group has been observed in the nitration of m-diisopropylbenzene and only traces of o-nitrocumene have been detected in the nitration of o-diisopropylbenzene (possibly for steric reasons).

Nitration of 1,3,5-triisopropylbenzene resulted only in dealkylating nitration giving 5-nitro-m-diisopropylbenzene. Intact nitration seems to be hindered by the adjacent isopropyl groups and therefore, even if in a very slow reaction, dealkylating nitration in the m-position is the only nitration. That this is indeed the case was demonstrated by the nitration of 1,3-dimethyl-5-isopropylbenzene. In this instance no dealkylating nitration was observed.

Acid-catalyzed isomerization and disproportionation of t-butylbenzenes and t-butyltoluenes takes place readily. In view of the ease of these reactions it seemed surprising that the nitration of t-butyltoluenes did not yield any nitrotoluenes (Table II). A possible explanation is that owing to the large steric hindrance exhibited by the t-butyl group the activation energy required for the nitronium ion (as contrasted to the smaller proton) to approach closely enough the carbon atom carrying the alkyl group to form the necessary geminal benzenonium ion and replace the t-butyl group

NITRATION OF p-CYMENE
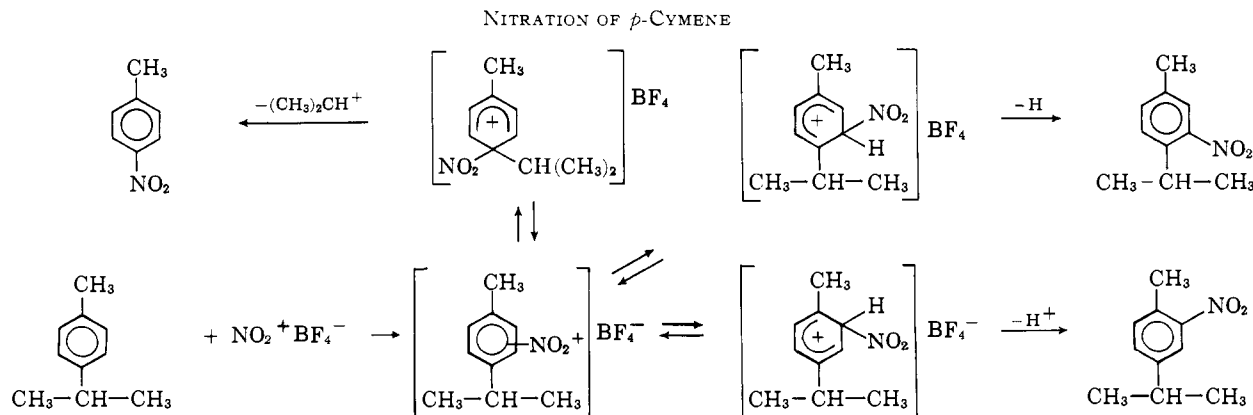
The eliminated dimethylcarbonium ion $(CH_3)_2CH^+$ can isopropylate another molecule of cymene. Gas–liquid chromatographic analysis of the reaction mixtures was able to account for a practically theoretical

is much greater than that required for attack at a position adjacent to the methyl group resulting in formation of 2-nitro-4-t-butyltoluene. Therefore intact nitration only takes place.

Seemingly a different situation exists in the case of p-di-t-butylbenzene. The presence of two large t-

(17) G. A. Olah, S. J. Kuhn, and S. H. Flood, J. Am. Chem. Soc., 83, 4571 (1961).

butyl group in p-positions on the ring stericly hinders to some extent substitution of the four equivalent ring positions; thus the activation energy for substitution on these carbon atoms can be close to the activation energy required for the also hindered replacement of the t-butyl group by the nitro group. Experimental results have shown that 20% dealkylating nitration to 4-nitro-t-butylbenzene and 80% intact nitration giving 2-nitro-p-t-butylbenzene takes place in the nitration of p-di-t-butylbenzene. The cleaved t-butyl group alkylates another molecule of p-di-t-alkylbenzene, the one isomer formed being 1,3,5-tri-t-butylbenzene.
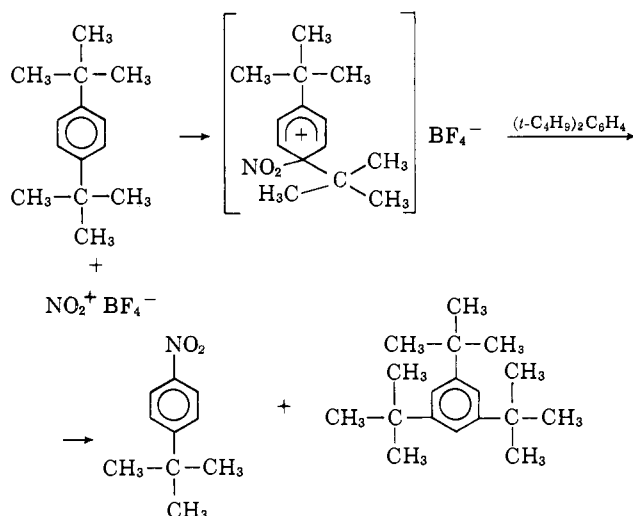
Steric hindrance prohibits intact nitration of 1,3,5-tri-t-butylbenzene; dealkylating nitration giving 1,3-di-t-butyl-5-nitrobenzene only is observed.

Experimental

Nitronium tetrafluoroborate was prepared from nitric acid, BF_3, and anhydrous HF as previously described.[13,18]

Tetramethylene sulfone (Shell Chemical Co.) was purified by vacuum distillation. n-Propylbenzene, n-propyltoluenes, o- and m-cymene, 1,3-diisopropylbenzene, 1,4-diisopropylbenzene, 1,3,5-triisopropylbenzene, 1-methyl-3-t-butylbenzene, 1-methyl-4-t-butylbenzene, and 1,4-di-t-butylbenzene were American Petroleum Institute standard materials and were used without further purification.

We are grateful for samples of 1-methyl-2-t-butylbenzene to Dr. B. S. Friedmann of Sinclair Research Inc., of 1,3,5-tri-t-butylbenzene, 1,3-dimethyl-5-t-butylbenzene, and 1,3-dimethyl-5-isopropylbenzene to Mr. D. A. McCaulay of American Oil Co. and of o-di-t-butylbenzene to Prof. L. C. R. Barclay, Mt. Allison University. p-Cymene and cumene were Eastman organic chemicals. o-Diisopropylbenzene was received from The Dow Chemical Co., Midland, Mich. They were purified by preparative gas–liquid chromatography. m-Di-t-butylbenzene was prepared in this laboratory by the isomerization of p-di-t-butylbenzene and subsequent separation of the isomers by preparative gas–liquid chromatography.

(18) S. J. Kuhn, Can. J. Chem., **40**, 1660 (1962).

Isomeric nitropropylbenzenes and nitrobutylbenzenes were isolated from nitration mixtures of the pure alkylbenzene isomers by preparative scale gas–liquid chromatography (using a Wilkens Aerograph Model A-700 Autoprep chromatograph) and were identified by infrared spectroscopy.

General Method of Nitration.—The aromatic hydrocarbon (0.1 mole) was dissolved in 30 g. of tetramethylene sulfone and 0.033 mole of $NO_2{}^+BF_4{}^-$ dissolved in 55 g. of tetramethylene sulfone was added dropwise into the rapidly stirred solution. The reaction temperature was kept at 25° during the reaction. After the addition of the $NO_2{}^+BF_4{}^-$ solution was completed, the reaction mixture was stirred for an additional 15 min., then diluted with 200 ml. of water. The organic layer was separated. The aqueous layer was extracted with 30 ml. of methylene chloride. The combined organic layer and methylene chloride extract was washed with 50 ml. of water, dried over $CaCl_2$, and analyzed by gas–liquid chromatography.

Competitive Nitration of Cymenes and Benzene.—Cymene (0.1 mole) and 0.1 mole of benzene were dissolved in 30 g. of tetramethylene sulfone and the reaction flask was placed in a constant temperature bath (25°). Into the rapidly stirred mixture 0.02 mole of $NO_2{}^+BF_4{}^-$ dissolved in 40 g. of tetramethylene sulfone was added dropwise while the temperature of the reaction mixture was kept at 25°. The addition of the $NO_2{}^+BF_4{}^-$ solution required 10–15 min. After the addition of the $NO_2{}^-BF_4{}^-$ solution, the reaction mixture was stirred for an additional 5 min. at 25°, then diluted with 150 ml. of water. The organic layer was separated. The aqueous layer was extracted with 40 ml. of methylene chloride. The combined organic layer and methylene chloride extract was washed with 50 ml. of water, dried over $CaCl_2$, and analyzed by gas–liquid chromatography.

Gas–Liquid Chromatographic Analyses.—The analyses of all nitrations were carried out by gas–liquid chromatography on a Perkin–Elmer Model 154-C vapor fractometer, equipped with an electronic printing integrator. A 4-m. by 0.25 in. stainless steel column packed with polypropylene glycol (UCON LB 500-X) supported on diatomaceous earth was used. A column temperature of 190° and a flow rate of the carrier gas of 25 ml./min. were used. Characteristic retention times are summarized in Table IV.

TABLE IV
RETENTION TIMES

	Min.		Min.
o-Nitrotoluene	14	t-Butyltoluene	
n-Nitrotoluene	17	4-Nitro-2-	50
p-Nitrotoluene	19	6-Nitro-2-	44
p-Nitro-t-butylbenzene	48	2-Nitro-5-	48
p-Nitroisopropylbenzene	36	4-Nitro-5-	33
Isopropyltoluene		2-Nitro-3-	57
2-Nitro-4-	34	5-Nitro-m-xylene	27
3-Nitro-4-	27	2-Nitro-p-di-t-butylbenzene	66
3-Nitro-2-	35	5-Nitro-m-di-t-butylbenzene	72
4-Nitro-2-	43	n-Propyltoluene	
6-Nitro-2-	50	5-Nitro-2-	24
4-Nitro-3-	33	6-Nitro-2-	33
6-Nitro-3-	46	4-Nitro-2-	39
Diisopropylbenzene		2-Nitro-3-	23
4-Nitro-o-	62	4-Nitro-3-	35
3-Nitro-o-	45	6-Nitro-3-	43
5-Nitro-m-	50	2-Nitro-4-	39
2-Nitro-p-	48	3-Nitro-4-	34
t-Butyltoluene		Nitrobenzene	
2-Nitro-4-	56	2,6-Dimethyl-4-isopropyl-	33
3-Nitro-4-	43	2,6-Dimethyl-4-t-butyl-	43
5-Nitro-2-	37	2,6-Dimethyl-6-t-butyl-	40