(−34,267°); for IV, trough 288 mμ (−4651°), peak 256 mμ (+28,952°). It is apparent that, similarly to the 7-chloro-7H-yohimbanes, the curves very nearly bear a mirror-image relationship to each other. This phenomenon is therefore not dependent on the presence of the highly polarizable halogen atom. As pointed out earlier,[1] the octant rule,[20] or rather an extended form thereof (taking C═N in lieu of C═O) does not seem to apply[21] in the cases of indolenines such as III and IV (unless one assumes that the benzyl group makes its principal contribution in that conformation in which it is in a front octant[22]).

Experimental Section

Melting points were determined using the Thomas-Hoover capillary melting point apparatus which was calibrated against known standards. The ultraviolet and infrared spectra were obtained, respectively, with a Beckman DK-1 spectrophotometer and a Baird Model 455 double-beam instrument. Unless otherwise stated the nmr spectra were determined in deuterated chloroform with tetramethylsilane as an internal standard using a Varian A-60 spectrometer. Thin layer chromatography was carried out on silica gel G according to Stahl (Merck, Darmstadt) in an ammonia atmosphere using benzene as the eluent. The chromatograms were developed by spraying with aqueous potassium iodoplatinate. The pK_a values were determined by dissolving 0.03 mmole of compound in 5 ml of ethanolic 0.05 *N* HCl and 1 ml of H_2O and titrating with 0.1 *N* NaOH. Rotations were taken in a 1-dm tube, using a Rudolph (800) photoelectric polarimeter. The optical rotary dispersions were obtained with a Cary spectropolarimeter (60) using 5.6% methanol solutions and cells of 0.1-dm path length. The mass spectra were determined with a Consolidated Electronics Corp. mass spectrometer, No. 21-103C. The ionizing current was kept at 10 μa while the ionizing energy was maintained at 70 ev. Samples were heated in an all-glass inlet system at 200°.

Benzylation of Yohimbane.—Sodium (3 g) was added portionwise to liquid ammonia (1.2 l.) and the reaction mixture was stirred for *ca.* 25 min when all the metal had dissolved. Yohimbane (33.6 g) was added in portions and the stirring was continued for 1 hr. A solution of benzyl bromide (22 g) in ether (120 ml) was added dropwise over a period of 2.5 hr. The acetone-Dry Ice cooling bath was removed and ammonia was allowed to evaporate. Water (500 ml) was added and the mixture was extracted with two 500-ml portions of chloroform. The extracts were dried over sodium sulfate, filtered, and evaporated. The oily residue, on crystallization and fractionation from acetonitrile, gave the following fractions. **1-Benzylyohimbane** (II) was obtained: 14.6 g (33%), mp 184–186.5°, $[\alpha]^{25}\text{D}$ −115° (*c* 0.4%, pyridine). *Anal.* Calcd for $C_{26}H_{30}N_2$: C, 84.28; H, 8.16; N, 7.56. Found: C, 84.30; H, 8.27; N, 7.59. **7β-Benzyl-7H-yohimbane** (IV) was obtained: 6.45 g (14.5%); mp 142–144°; $[\alpha]^{25}\text{D}$ −111° (*c* 0.7%, pyridine), −74° (*c* 0.4%, methanol); pK_a = 5.0 ± 0.1; ORD $[\Phi]_{350}$ −673.4, $[\Phi]_{300}$ −3755.5, $[\Phi]_{288}$ −4651 (trough), $[\Phi]_{267}$ +14126, $[\Phi]_{256}$ +28952 (peak), $[\Phi]_{246}$ +14126°; mass spectrum[23] *m/e* (% Σ_{80}) 91 (3.25), 150 (2.85), 182 (5.5), 183 (1.2), 206 (0.73), 218 (0.73), 219 (1.03), 220 (0.88), 221 (3.2), 222 (0.85), 232 (0.75), 233 (1.2), 234 (0.75), 235 (2.9), 236 (0.95), 249 (0.87), 263 (0.76), 273 (0.81), 274 (0.62), 275 (1.08), 276 (3.1), 277 (14.3), 278 (12.7), 279 (17.3), 280 (4.85), 281 (0.76), 303 (1.57), 269 (0.9), 370 (4.8), 371 (1.27). *Anal.* Calcd for $C_{26}H_{30}N_2$: C, 84.28; H, 8.16; N, 7.56. Found: C, 83.98; H, 8.25; N, 7.59. **Methiodide** had mp 246–249°. *Anal.* Calcd for $C_{27}H_{33}IN_2$: C, 63.28; H, 6.49; I, 24.76; N, 5.47. Found: C, 63.20, H, 6.61; I, 24.81; N, 5.44. **7α-Benzyl-7H-yohimbane** (III) was obtained: 4.6 g (10.4%); mp 166–168.5°; $[\alpha]^{25}\text{D}$ +72° (*c* 0.4%, methanol); pK_a = 5.60 ± 0.04; ORD $[\Phi]_{350}$ +647.5 $[\Phi]_{300}$ +3282, $[\Phi]_{288}$ +5187 (peak), $[\Phi]_{267}$ −16206, $[\Phi]_{256}$ −34267 (trough), $[\Phi]_{246}$ −16206°; mass spectrum[23] *m/e* (% Σ_{80}) 91 (3.19), 150 (1.82), 168 (0.78), 169 (0.82), 182 (0.84), 183 (0.82), 218 (0.53), 220 (0.63), 221 (1.37), 232 (0.55), 233 (0.68), 234 (0.63), 235 (1.18), 276 (0.81), 277 (6.32), 278 (15.5), 279 (34), 280 (7.6), 281 (0.8), 291 (1.22), 369 (1.5), 370 (7.9), 371 (2.2). *Anal.* Calcd for $C_{26}H_{30}N_2$: C, 84.28; H, 8.16; N, 7.56. Found: C, 84.09; H, 8.30; N, 7.81. **Methiodide** had mp 258–260°. *Anal.* Calcd for $C_{27}H_{33}IN_2$: C, 63.28; H, 6.49; I, 24.76; N, 5.47. Found: C, 63.25; H, 6.55; I, 24.66; N, 5.69. The mother liquor yielded a mixture containing II, III, IV, and some yohimbane (15.2 g).

Acknowledgment.—We wish to thank Professor E. L. Eliel for helpful discussions, Professor G. I. Fujimoto for recording of the ORD curves, and Dr. D. T. Funke for determination of mass spectra. We are indebted to Mr. A. Lewis and his associates, Mrs. U. Zeek and Mr. R. Puchalski, for analytical and spectral data.

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[20] W. Moffitt, R. B. Woodward, A. Moscowitz, W. Klyne, and C. Djerassi, *J. Am. Chem. Soc.*, **83**, 4013 (1961).

[21] Some caution is advisable, since the ORD curves obtained here as well as those reported earlier[2] may not (and in some instances[2] do not) correspond to a *single* Cotton effect.

[22] This explanation could not apply to chlorine. It suggests that configurational identity of the 7-chloro-7H-yohimbanes with the 7-benzyl-7H-yohimbanes of corresponding Cotton effect cannot necessarily be assumed.

[23] Only peaks ≧0.5% Σ_{80} are recorded. However, for calculation of Σ_{80} all measurable peaks above mass 80 were taken into account.

Synthesis of Nitropolyalkylbiphenyls by Nitrative Coupling of Di- and Trialkylbenzenes

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Nitration of alkyl homologs of benzene is often accompanied by coupling to nitrobiphenyls if the nitric acid is added to the hydrocarbon. This unusual reaction, with one exception, has been overlooked in the chemical literature. *o*-Xylene, *o*-ethyltoluene, *o*-diethylbenzene, and hemimellitene gave an appreciable amount of coupling. The highest yield of isomeric coupled products (47%) has been obtained from *o*-xylene at −25°; of this 82% is 2-nitro-3′,4,4′,5-tetramethylbiphenyl. Both nitration and nitrative coupling appear to proceed through the common intermediate, the nitroaronium ion.

The addition of 90% nitric acid to *o*-xylene has been reported[1] to give not only nitroxylenes, but also small amounts of a by-product identified as 2-nitro-3′,4,4′,5-tetramethylbiphenyl. However, despite its potential value as a synthetic route to nitrobiphenyls, this side reaction, which we call nitrative coupling, has received no attention to date. Therefore, we decided to study it further to determine whether the reaction conditions could be adjusted to favor the formation of larger amounts of coupled products, and whether other aromatics undergo similar reactions.

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[1] A. W. Crossley and C. H. Hampshire, *J. Chem. Soc.*, 721 (1911).

A major effort was devoted to isolating the coupled products and identifying their structures. Identifications based on a combination of gas chromatography and ultraviolet, infrared, nuclear magnetic resonance, and mass spectrometry revealed a number of new and unusual compounds.

Results

Nitrative Coupling with *o*-Xylene.—As found previously,[1] nitrative coupling occurred only when the acid was added to the xylene, not when the xylene was added to the acid.

The course of the reaction at −25° was studied by analyzing samples withdrawn during and after addition of the acid. Other than unreacted *o*-xylene, major components of the reaction mixtures were the nitro-*o*-xylene isomers and isomeric nitrobixylyls. At first, when very little acid had been added, the nitration started but no coupling occurred. However, after an induction period the nitrative coupling also started and then proceeded with a rate comparable to that of the nitration. After all the acid had been added, both reactions declined and stopped simultaneously.

The induction period that precedes the coupling reaction can be explained by the presence of a two-phase system. Apparently nitration but not coupling can occur on the surface of the aqueous acid layer. Coupling was observed to start only after enough acid is available to form a fine emulsion with the hydrocarbon.

The effect of nitric acid concentration was studied at 0°. At the same molar excess of nitric acid, relative to hydrocarbon, the 90% acid gave optimal results, the 80% gave comparable yields but much lower conversion, and the 100% acid gave higher conversion but also extensively nitrated the primary coupled products to dinitrobixylyls.

Because mixtures of sulfuric and nitric acids are generally used to ensure complete nitration of hydrocarbons, the effects of acid mixtures were also observed. Hardly any coupling occurred with either sulfuric acid–nitric acid or acetic anhydride–acetic acid–nitric acid mixtures.

Table I shows the effects of temperature. The highest yield of primary coupled products was obtained at −25°. At higher temperatures, the primary products were further nitrated to dinitrobixylyls. Consequently, the yield of primary coupled products dropped sharply; the total yield of coupled products also dropped, but to a lesser extent. In addition, material losses due to oxidation and oxynitration[2] became significant at room temperature, while another side reaction, the formation of diarylmethanes,[3] appeared to be the most pronounced at −10°.

TABLE I

TEMPERATURE DEPENDENCE OF THE NITRATIVE COUPLING REACTION WITH *o*-XYLENE

Temp, °C	Reacn time, min	Conversion of *o*-xylene, %	Yield of coupled products,[a] %		
			Primary[b]	Further nitrated[b]	Total
−25 ± 1	215	51.5	47.2	1.1	48.3
−10 ± 2	45	57.2	27.8	2.4	30.2[b]
0 ± 2	40	60.3	27.8	2.7	30.5
+20 ± 2	30	79.0	8.8	8.4	17.2

[a] Calculated for reacted *o*-xylene and includes all isomers. [b] At low temperatures trimethyldiphenylmethanes were also among the products in yield which cannot be neglected. Although these too are "coupled" products, only the nitrobixylyls and dinitrobixylyls are included under this heading.

A typical product distribution obtained at −25° is shown in Table II.

TABLE II

PRODUCT DISTRIBUTION FROM THE REACTION OF NITRIC ACID WITH *o*-XYLENE AT −25 ± 1°

Product	%
o-Xylene	41.5
3-Nitro-*o*-xylene	9.4
4-Nitro-*o*-xylene	21.5
Trimethyldiphenyl methanes and unidentified components, four partially resolved peaks	1.2
Nitrobixylyls	
1[a]	0.2
2, 2-nitro-3,3′,4,4′-tetramethylbiphenyl (V) + probable other isomers with the same retention time	4.4
3, 2-Nitro-3′,4,4′,5-tetramethylbiphenyl IV	20.5
Dinitrobixylyls	
1	Trace
2	Trace
3	0.1
4, 2,2′-dinitro-4,4′,5,5′-tetramethylbiphenyl (VI)	0.2
5, 2,3′-dinitro-4,4′,5,5′-tetramethylbiphenyl (VII)	0.2

[a] Not identified.

Nitrative Coupling of Other Aromatics.—Depending on the yield of coupled products, the other aromatics investigated were classified as shown in Table III. Table IV lists the products identified in the reactions that gave appreciable yields. The effects of temperature were not studied thoroughly. Although the table represents the highest yields obtained for each reaction, it does not necessarily reflect the best conditions. However, in all four reactions, the yield of coupled products was always much lower than that obtained from *o*-xylene.

TABLE III

Appreciable yield	Little or no yield
o-Diethylbenzene	Benzene
o-Ethyltoluene	Toluene
Hemimellitene	*p*-Xylene
Pseudocumene	*m*-Xylene
	Mesitylene
	Prehnitene
	Naphthalene (in pentane solution)
	Tetralin

Identification of the Products.—Table V shows the physical constants and elemental analyses of new nitration products isolated from the reactions. The molecular weights determined by mass spectroscopy are in agreement with the empirical formulas.

Positional assignments of the nitro and methyl groups are based on nmr and ultraviolet spectroscopic data (Table VI). Certain imaginable but improbable

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(2) E. Noelting and B. Pick, *Ber.*, **21**, 3158 (1888).

(3) The formation of diarylmethanes from polyalkylbenzenes in the presence of molybdenum pentachloride has been reported by P. Kovacic and A. K. Sparks, *J. Org. Chem.*, **28**, 972 (1963); their formation in the presence of peroxytrifluoroacetic acid has been observed by H. Hart, personal communication.

TABLE IV

PRODUCT DISTRIBUTION FROM THE REACTION OF NITRIC ACID WITH POLYALKYLBENZENES

Product	%
o-Diethylbenzene at −20 ± 5°	
o-Diethylbenzene	43.8
3-Nitro-*o*-diethylbenzene	10.5
4-Nitro-*o*-diethylbenzene	29.8
Three unidentified products (triethyldiphenylethanes?)	0.3
Nitrotetraethylbiphenyl isomers	
1–5[a]	3.1
6	5.0
Probably dinitrotetraethylbiphenyls (two peaks)	0.4
o-Ethyltoluene at +2 ± 5°[b]	
o-Ethyltoluene	44.9
Nitro-*o*-ethyltoluenes	
1	5.7
2	9.5
3	27.6
Nitrodimethyldiethylbiphenyls	
1–3 (unresolved)	2.3
4	9.5
Hemimellitene at 5 ± 4°	
Hemimellitene	28.1
4-Nitrohemimellitene[c]	31.8
5-Nitrohemimellitene[c]	8.5
4,6-Dinitrohemimellitene (XII)	1.5
4,5-Dinitrohemimellitene (XI)	0.6
2-Nitro-2′,3,3′,4,4′,5-hexamethylbiphenyl (VIII)	8.2
2-Nitro-3,3′,4,4′,5,5′-hexamethylbiphenyl (IX)	5.0
2-Nitro-4,5,6,x′,y′,z′-hexamethylbiphenyl	0.9
Dinitrohexamethylbiphenyls	
1 (X)	0.4
2	Trace
3	0.2
Pseudocumene at −16 ± 1°[d]	
Pseudocumene	36.9
3-Nitropseudocumene[c]	3.1
6-Nitropseudocumene[c]	10.5
5-Nitropseudocumene	22.0
Pentamethyldiphenylmethanes	
1	0.4
2	2.5
3	Trace
Nitrohexamethylbiphenyls	
1	1.8
2	1.8
Unidentified higher boiling components	Traces

[a] As mass spectroscopic identification was on a mixture trapped out from the gas chromatograph, some minor components might not have been recognized as nitrotriethyldiphenylethanes, all of which have the same molecular weight. [b] Conditions of the gas chromatographic analysis were possibly not the best for finding dinitrodimethyldiethylbiphenyls. [c] For identification see M. Dolinsky, J. H. Jones, C. D. Ritchie, R. L. Yates, and M. A. Hall, *J. Assoc. Offic. Agr. Chemists*, **42**, 709 (1959); *Chem. Abstr.*, 54, 4268 (1960). [d] Nitration of pseudocumene appears to be even more dependent on the conditions than nitration of the other alkylbenzenes studied. From experiments at higher reaction temperature gas chromatography indicated the presence of many additional components, some of them identified as products of further nitration, some as products of oxidation.

structures for the biphenyl derivatives were not considered, *e.g.*, if the nitro group would be in *meta* position to the coupling. The following criteria were used for the assignments.

In the nmr spectra of nitropolymethylbiphenyls, the aromatic protons located adjacent to a nitro group are shifted downfield by approximately 0.5–0.8 ppm in deuteriochloroform and hence are readily distinguishable.[4] The methyl protons of alkylbenzenes neighboring a nitro group absorb at somewhat lower field than the rest of the methyl protons. However, this criterion is not characteristic because chemical shifts are also observed with methyl protons *meta* or *para* to a nitro group, and there is an overlap for the expected resonance values.[5] Much more significant is the shielding of the *o*-methyl protons of a biphenyl by a nitro group located in *ortho′* position. This shielding is approximately 0.2 ppm. Thus, in deuteriochloroform one of the methyl protons of 2-nitro-2′,3,3′,4,4′,5-hexamethylbiphenyl (VIII) gives resonance at τ 7.95, while the others are in the τ range 7.66–7.80. Comparable examples of long-range shielding by the nitro group have been reported.[5,6]

Steric hindrance to rotation by *ortho* substituents in biphenyl derivatives is best detected by ultraviolet spectroscopy.[7] A single *ortho* substituent usually has only minor effects; but in *o,o′*-disubstituted biphenyls, the 250-mμ biphenyl band either undergoes a hyposochromic shift with reduction of intensity or completely disappears, depending on the size of the substituents. The influence of a nitro substituent, although significant,[8] especially if in *para* position, does not prevent the use of these principles in the structural assignment. The *o*-nitrobiphenyls can easily be differentiated from their *meta* and *para* isomers.[8]

Minor structural details interfering with the nitro group resonance could also be noticed in biphenyl derivatives; the steric hindrance in *o*-nitrotoluene is known to bring about a hypsochromic shift and decreased absorption intensity compared with the *meta* and *para* isomers.[9] Thus, the lower molecular extinction coefficient in nitrobixylyl isomer V compared with that in isomer IV may be attributed to this effect.

The C–H out-of-plane deformation vibrations[10] of the infrared spectra also agree with the structures assigned to our products. However, interference from other bands in this region prevented unambiguous assignment by means of infrared spectroscopy.

For the nitrobixylyl IV the structural assignment is straightforward from nmr and ultraviolet data. Possible 2-nitro-2′,3′,4,5-tetramethylbiphenyl and 4-nitro-2,3,3′,4′-tetramethylbiphenyl assignments are ruled out by the intense ultraviolet absorption and by the absence of coupling with the low-field aromatic proton, respectively. Although the original assignment of IV by Crossley and Hampshire[1] was tentative only, they provided chemical evidence which also eliminated the possibility of these alternative formulas.

Similarly, there is only one formula (V) which agrees with the spectroscopic data of the other isolated nitrobixylyl.

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[4] Compare to the effect of nitro substitution on the proton frequency of benzene: J. A. Pople, W. G. Schneider, and J. H. Bernstein, "High-Resolution Nuclear Magnetic Resonance," McGraw-Hill Book Co., Inc., New York, N. Y., 1959, p 259.

[5] I. Yamaguchi, *Mol. Phys.*, **6**, 105 (1963).

[6] K. Tori and K. Kuriyama, *Tetrahedron Letters*, **52**, 3939 (1964), and references cited therein.

[7] "Steric Effects in Organic Chemistry," M. S. Newman, Ed., John Wiley and Sons, Inc., New York, N. Y., 1956, p 481, and references cited therein.

[8] D. L. F. DeTar and J. H. Scheifele, *J. Am. Chem. Soc.*, **73**, 1445 (1951).

[9] D. W. Sherwood and M. Calvin, *ibid.*, **64**, 1350 (1942); W. G. Brown and H. Reagan, *ibid.*, **69**, 1032 (1947).

[10] L. J. Bellamy, "The Infrared Spectra of Complex Molecules," John Wiley and Sons, Inc., New York, N. Y., 1956, pp 75–81.

TABLE V

THE PHYSICAL CONSTANTS AND ELEMENTAL ANALYSES OF THE NEW NITRATION PRODUCTS

Compound	Formula no.	Mp, °C	Formula	Anal, % C Calcd	C Found	H Calcd	H Found	N Calcd	N Found
2-Nitro-3,3′,4,4-tetramethylbiphenyl	V	99–100	$C_{16}H_{17}NO_2$	75.29	75.41	6.66	6.78	5.49	5.43
2,2′-Dinitro-4,4′,5,5′-tetramethylbiphenyl	VI	250–252	$C_{16}H_{16}N_2O_4$	63.99	63.74	5.37	5.65	9.33	9.18
2,3′-Dinitro-4,4′,5,5′-tetramethylbiphenyl	VII	173–174	$C_{16}H_{16}N_2O_4$	63.99	64.53	5.37	5.56	9.33	8.73
2-Nitro-2′,3,3′,4,4′,5-hexamethylbiphenyl	VIII	157	$C_{18}H_{21}NO_2$	76.29	76.39	7.47	7.40	4.94	5.36
2-Nitro-3,3′,4,4′,5,5′-hexamethylbiphenyl	IX	168–169	$C_{18}H_{21}NO_2$	76.29	75.59	7.47	7.71	4.94	4.87
2,2′-Dinitro-3,3′,4,4′,5,5′-hexamethylbiphenyl	X	280–282	$C_{18}H_{20}N_2O_4$	65.84	66.47	6.14	6.27	8.53	8.14
4,5-Dinitrohemimellitene	XI	152	$C_9H_{10}N_2O_4$	51.43	50.97	4.76	4.96	13.33	13.34
4,6-Dinitrohemimellitene	XII	112–113	$C_9H_{10}N_2O_4$	51.43	51.92	4.76	4.82	13.33	13.35

TABLE VI

NMR AND ULTRAVIOLET ABSORPTIONS OF THE NEW NITRATION PRODUCTS

	Nmr values, τ			Ultraviolet absorptions in isooctane or in dichloromethane[b]			
	in Deuteriochloroform		in benzene, methyl protons[a]	Biphenyl absorption		Other absorption bands	
Formula no.	Aromatic protons[a]	Methyl protons[a]		λ_{max}, mμ	ϵ_{max}	λ_{max}, mμ	ϵ_{max}
IV	2.44 (1)	7.74 (9)	8.04 (6)			Shoulder only	
	2.90	7.78 (3)	8.23 (3)	240	18,950	(305	2020)
	2.98		8.26 (3)				
V	2.80	7.65 (3)	8.08 (6)	241	16,700		
	2.85	7.74 (6)	8.17 (3)				
	2.92	7.78 (3)	8.23 (3)				
VI	1.99 (2)	Approx 7.6 (unresolved)	8.32 (12)	End absorption only[b]			
	2.99 (2)			(240	13,800)	280	14,100[b,c]
VII	2.23 (1)	Approx 7.6 (unresolved)	8.13 (3)	End absorption only[b]			
	2.41 (1)		8.25 (6)	(240	22,400)		
	2.71 (1)		8.33 (3)				
	2.83 (1)						
VIII	3.08 (3)	7.66 (3)	7.92 (3)				
		7.71 (6)	7.96 (3)	End absorption only			
		7.75 (3)	8.10 (9)	(235	9,460)		
		7.80 (3)	8.35 (3)				
		7.95 (3)					
IX	2.95 (1)	7.68 (3)					
	3.01 (2)	7.72 (6)					
		7.78 (6)		243	15,500		
		7.84 (3)					
X	3.02 (2)	7.68 (6)		End absorption only			
		7.74 (12)		(240	13,500)		
XI	2.14 (1)	7.56 (3)	8.41 (3)				
		7.67 (3)	8.47 (3)				
		7.74 (3)	8.66 (3)				
XII		7.49 (6)	8.29 (6)				
	1.99 (1)	7.53 (3)	8.71 (3)				

[a] Numbers in brackets indicate the number of protons. Where number of protons is not given the τ values correspond to the main peaks of partially resolved multiplets. [b] Superscript *b* indicates the use of dichloromethane as solvent. [c] This absorption, in spite of its high intensity, cannot be attributed to biphenyl resonance but rather to the resultant absorption of two separate 4-nitro-*o*-xylene entities as suggested by the wavelength. Compare to 4-nitro-*o*-xylene absorption: J. Burgers, M. A. Hoefnagel, P. E. Verkade, H. Visser, and B. M. Wepster, *Rec. Trav. Chim.*, **77**, 493 (1958).

Two dinitrobixylyls have been isolated of the five isomers detected by gas chromatography (Table II). The nmr spectrum of one of the isolated dinitrobixylyls indicates a symmetrical molecule possessing two aromatic protons adjacent to nitro groups. Formula VI corresponds to this compound. Its ultraviolet spectrum is analogous to that of 2,2′-dinitrobiphenyl,[11] in agreement with the assignment. The other isolated dinitrobixylyl has a ultraviolet spectrum very similar to that of 2,3′-dinitrobiphenyl;[11] its nmr spectrum indicates two aromatic protons flanked by nitro groups but in a slightly different environment. Consequently, formula VII was assigned to it.

There can be no doubt about the structures of the nitrobihemimellityls VIII and IX on the basis of nmr and ultraviolet spectroscopy. The isolated dinitrobihemimellityl is most likely X.

The nmr spectrum of one of the isolated dinitrohemimellitenes indicates a symmetrical molecule; it must be 4,6-dinitrohemimellitene. 4,5-Dinitrohemimellitene assignment is left for the other isomer.

The reaction of nitric acid with polyalkylbenzenes at low temperatures also gave small quantities of polyalkyldiphenylmethanes. Although they were not isolated in pure form, mass spectroscopic analyses of samples derived from *o*-xylene and pseudocumene trapped out from the gas chromatograph (usually as isomeric mixtures) unambiguously established the diphenylmethane assignment; the characteristic fragmentation pattern of *o*-methyldiphenylmethanes[12] was

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[11] D. L. F. DeTar and A. A. Kazimi, *J. Am. Chem. Soc.*, **77**, 3843 (1955).

[12] S. Meyerson, H. Drews, and E. K. Fields, *ibid.*, **86**, 4964 (1964).

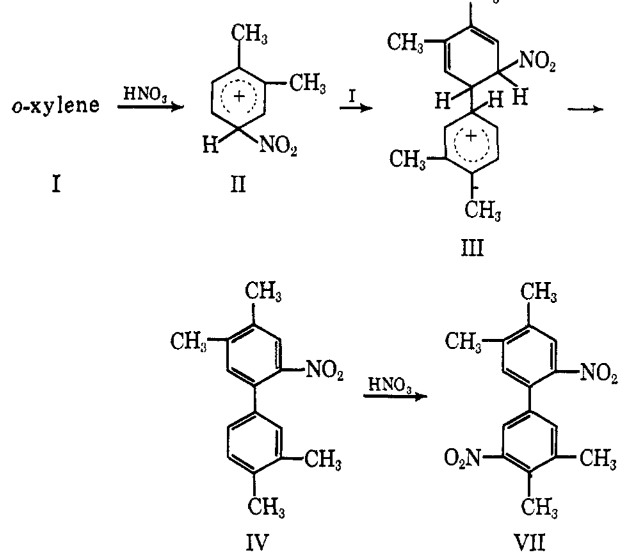
unmistakable. Additional evidence for the diphenylmethane structure was obtained by isolating the isomeric mixture of pentamethyldiphenylmethanes from the pseudocumene–nitric acid reaction and recording the nmr spectrum. The CH_2 groups appeared at τ 6.11 and 6.25. Diphenylmethane formation from polyalkylbenzenes has been previously observed under the influence of other reagents.[3]

The rest of the new products listed in Tables II and IV (with a few exceptions) were identified by their molecular weights in mass spectra of samples trapped out from the gas chromatograph.

Discussion

The mechanism we postulate to explain the products is summarized in Scheme I (only one isomer is depicted for the sake of brevity). The similar rates of nitration and nitrative coupling suggest that the same intermediate species are involved in the two reactions. The formation of nitroaronium ions during nitration is well established.[13] We believe that the nitroxylonium ions are the intermediates common to both nitration and nitrative coupling.

Scheme I



Electrophilic attack on o-xylene (I) by the nitroxylonium ion (II) could give the intermediate nitrotetramethyldihydrobiphenylonium ion (III) which loses a proton and subsequently, on oxidation by nitric acid or nitrous fumes, hydrogens to yield the corresponding biphenyl (IV). 3,4- and 1,4-dihydrobiphenyls are known to be readily oxidized by air;[14] the instantaneous oxidation of the nitrodihydrobiphenyl intermediates in strong oxidizing medium would be expected.

Coupling does not occur when xylene is added to excess nitric acid because nitric acid forms a π complex with xylene that may be converted to the σ complex and then nitroxylene, but is not susceptible to attack by the nitroaronium ion. The excess nitric acid prevents coupling by converting all of the xylene to the complex.

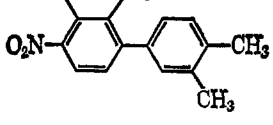
Why coupling does not take place with sulfuric–nitric or acetic–nitric acid mixtures is more difficult to explain. Dilution by sulfuric or acetic acid[15] cannot alone be responsible. Perhaps different species of nitroaronium ions exist in different media, as suggested by Tsang, *et al.*[16] In the acid mixtures, the nitroaronium ions may either lose protons more readily to yield the expected uncoupled nitration products, or be sterically hindered from coupling because they are solvated.

The suggested mechanism predicts the possible formation of many isomeric coupled products. In addition to the previously described[1] coupled product IV, we also isolated another coupled product and identified it as 2-nitro-3,3′,4,4′-tetramethylbiphenyl (V). Only one more peak was detected by gas chromatography—which might be an isomeric nitrobixylyl—when the nitration mixture was chromatographed. However, after the mixture was hydrogenated, it yielded five aminobixylyls, indicating that other isomers also formed but were not resolved by our column.

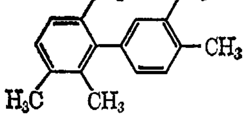
Certain rules appear to govern the nitrative coupling reaction. These could explain why only a few polyalkylbenzenes give nitrative coupling and why the formation of coupled products is often restricted to a few isomers.

1. At least two methyl (or alkyl) groups must activate the benzene nucleus to produce a reasonably stable nitroaronium ion which can act as an electrophile in a bimolecular coupling reaction. Methyl groups seem to be the most activating for the coupling reaction.

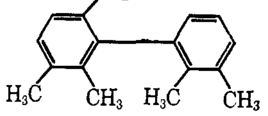
2. *ortho* coupling is the rule, *i.e.*, the ionic charge of the nitroaronium ion localized in *ortho* position to the nitro group is the attacking species. We have found no evidence of *para* coupling. The rule of *ortho* coupling can probably be ascribed to two factors: either the *para* position is blocked or steric factors prevent *para* coupling. However, the presence of XIII in the nitration mixture of o-xylene is possible; this would be an example of *para* coupling.



XIII



XIV



XV

3. Coupling preferentially occurs only when two neighboring unsubstituted positions are available on

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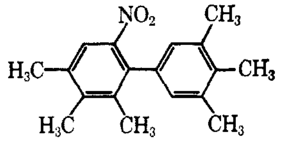
[13] C. K. Ingold, "Structure and Mechanism in Organic Chemistry," Cornell University Press, Ithaca, N. Y., 1953, pp 279–282, and references cited therein.

[14] W. Hückel, and H. Bretschneider, *Ann.*, **540**, 173 (1939); W. Hückel and R. Schwen, *Ber.*, **89**, 150 (1956).

[15] For simplicity, chemical interactions between nitric and sulfuric acids and between nitric and acetic acids [A. Pictet and P. Genequand, *ibid.*, **35**, 2526 (1902)] have been neglected.

[16] S. M. Tsang, A. P. Paul, and M. P. DiGiaimo, *J. Org. Chem.*, **29**, 3387 (1964).

one side of the nitro group (steric factor). In less activated hydrocarbons, such as *o*-xylene, isomers like XIV and XV could not be formed in substantial quantities. However, with the more activated trialkylbenzenes, the nitroaronium ions are capable of attacking another electron-rich aromatic nucleus even with a sterically hindered active site. Thus, the coupled products from hemimellitene must also include isomer XVI.



XVI

4. Some nitrative coupling reactions are prevented by unfavorable energy conditions when the abovementioned rules would predict coupling. Thus, we failed to observe coupling with *m*-xylene. The great stability of the *m*-xylonium ion is well known;[17] it is the most stable of the isomeric xylonium ions. A similar stability should be valid also for the nitroxylonium ions. Owing to the low-lying energy state of the *m*-nitroxylonium ion, the activation energy requirement for the coupling reaction might be too high.

5. The position of attack on the polyalkylbenzene by the nitroaronium ion is also restricted by activation energy requirements; certain isomers cannot be formed.

Experimental Section

Melting points are corrected. Ultraviolet spectra were obtained on a Cary Model 11 recording spectrophotometer; nmr spectra were recorded on a Varian Associates HR-60 spectrometer at 52 Mc with trimethylsilane as an internal standard and mass spectra on a modified CEC Model 21-130 mass spectrometer.

Gas-liquid partition chromatographic analyses were carried out on a temperature-programmed Wilkins Aerograph, Model 202, with a thermal conductivity detector, helium carrier gas, and 4.5 ft × 0.25 in. columns packed with 45-60 mesh nonacid-washed Chromosorb P (Johns Manville) containing 20% SE-30 silicone gum rubber (G.E.). Usually, mesitylene was used as an internal standard. In the analyses of high-boiling components, thermal decomposition was a problem. However, with the column programmed to a maximum of 250-255° and the detector held at 270-275°, determination or estimation of correction factors permitted analyses with an estimated accuracy of ±10%. The correction factors used for the various components were: dinitropolyalkylbenzenes, 1.50; nitropolyalkylbiphenyls, 1.40-1.80; dinitropolyalkylbiphenyls, 1.80-2.40; 3- and 4-nitro-*o*-xylenes, 1.21 and 1.25, respectively; other nitropolyalkylbenzenes, 1.20-1.26.

Nitrative Coupling. General Procedure.—The reaction vessel was a round-bottomed, three-necked flask equipped with a mechanical stirrer, a thermometer, and a dropping funnel. In most experiments, the flask containing 0.2 mole of the hydrocarbon was immersed in a thermostated bath and brought to the desired temperature. Then 28.2 ml of 90% nitric acid (about 0.6 mole) was added dropwise, slowly enough to control the exothermic reaction. After all the acid had been added (usually 30-50 min), the mixture was stirred for an additional 5-10 min and immediately poured onto a mixture of ethanol-free ether and ice to quench the reaction. Products were extracted into the ether layer, which was then washed with a 10% solution of sodium hydroxide and with water, dried with saturated sodium chloride solution, and evaporated in a Rotavapor (R/NCO Instrument Co.) at room temperature. The residues were analyzed by gas chromatography.

Sometimes larger amounts of reactants were used, with correspondingly longer reaction times, to permit easier isolation and identification of the products (*e.g.*, the −25° reactions in Tables I and II).

Isolation of Products from the *o*-Xylene Reaction. Nitrobixylyls IV and V.—At −23°, 282 ml of 90% nitric acid was added to 2 moles (212 g) of *o*-xylene in 110 min. The mixture was stirred for an additional 30 min and then was quenched and extracted as described above. The product mixture was distilled at 0.3 mm to remove unreacted *o*-xylene and the nitroxylenes, and the residue was crystallized from cold methanol containing a small amount of ether. The crystals were filtered off, redissolved in methanol, treated with activated carbon, and recrystallized to give yellowish prisms (32.1 g) of **2-nitro-3′,4,4′,5-tetramethylbiphenyl (IV)**, mp 114.5-116°. Recrystallization from hexane raised the melting point to 116-117°. The mother liquors were freed from solvent *in vacuo* and heated at 100° (0.1 mm) for 2 hr to remove low-boiling by-products. The residue was recrystallized repeatedly from ethanol at 0° and finally from hexane to give colorless crystals of **2-nitro-3,3′,4,4′-tetramethylbiphenyl (V)**.

Dinitrobixylyls VI and VII.—At −25°, 141 ml of 90% nitric acid was added to 1 mole of *o*-xylene in 90 min. With continuous stirring, the mixture was allowed to warm gradually to 24° in 90 min (rapid warming could cause an uncontrollable exothermic reaction), was kept at that temperature for 30 min, and then was quenched and extracted. Crystals of dinitrobixylyls that formed in the ether extract were filtered off (13.2 g), and the extract was distilled at 0.3 mm to remove unreacted *o*-xylene and nitroxylenes. The tarry residue was crystallized from 1:1 methanol-ether, and the crystals (11.9 g) were filtered off and combined with the first batch. The mother liquors contained all five dinitrobixylyls plus some nitrobixylyls. The mixed crystals, which contained the three major dinitrobixylyls, were separated by fractional crystallization from acetone and dimethylformamide to give **2,2′-dinitro-4,4′,5,5′-tetramethylbiphenyl (VI)**, mp 249-251°, and **2,3′-dinitro-4,4′,5,5′-tetramethylbiphenyl (VII)**, mp 168-171°. The former is fairly insoluble in most cold organic solvents, including chloroform; the latter is fairly soluble in cold chloroform. For analysis, they were recrystallized from dimethylformamide and dimethyl sulfoxide, respectively, to the melting points shown in Table V.

Isolation of Products from Hemimellitene Reaction.—At 5°, 141 ml of 90% nitric acid was added to 1 mole of hemimellitene in 60 min. After being quenched and extracted, the reaction mixture was separated from the hemimellitene and some of the nitrohemimellitene at 20 mm and then was vacuum distilled. At 0.8 mm up to 118°, nitrohemimellitene distilled with some dinitrohemimellitene. The fraction distilling at 130-170° was a mixture of dinitrohemimellitenes and nitrobihemimellityls which were separated by fractional crystallization to give 12.8 g of **2-nitro-2′,3,3′,4,4′,5-hexamethylbiphenyl (VIII)**, mp 157° (from methanol); **4,5-dinitrohemimellitene (XI)**, mp 152° (from ethyl acetate, sparingly soluble in hexane and chloroform); **4,6-dinitrohemimellitene (XII)**, mp 112-113° (from methanol); and **2-nitro-3,3′,4,4′,5,5′-hexamethylbiphenyl (IX)**, mp 168-169° (from hexane or methanol-carbon tetrachloride, very soluble in chloroform and benzene). The residue from the high-vacuum distillation was crystallized from acetone, and the crystals were filtered off and recrystallized twice from dimethylformamide to give **2,2′-dinitro-3,3′,4,4′,5,5′-hexamethylbiphenyl (X)**, mp 280-282°.

Identification of Pentamethyldiphenylmethanes from Pseudocumene.—At −9°, 282 ml of 90% nitric acid was added to 2 moles of pseudocumene in 180 min. The mixture was stirred for an additional 30 min and then was quenched, extracted, and distilled at 0.1 mm. A 13.6-g fraction boiling at 167-180° was a mixture of pentamethyldiphenylmethanes and nitrohexamethylbiphenyls. It was chromatographed on 160 g of basic alumina (Woelm, activity grade I) in hexane, and the syrupy mixture of products (4.6 g) eluted with the first 130 ml of hexane was analyzed by gas chromatography. The analysis showed three diphenylmethanes in concentrations of 0.7, 94.9, and 4.4%. Attempts to crystallize the mixture failed. However, its nmr spectrum in deuteriochloroform showed the CH_2 resonance as a

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[17] L. F. Fieser and M. Fieser, "Advanced Organic Chemistry," Reinhold Publishing Corp., New York, N. Y., 1961, pp 622-626.

"doublet" at τ 6.11 and 6.25, whereas even unsymmetrically substituted polymethyldiphenylmethanes[18] show only one peak for the CH_2 group. Apparently, therefore, the isomeric mixture was more complex than indicated by gas chromatography.

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[18] High Resolution NMR Spectra Catalog by Varian Associates, Palo Alto, Calif., 1962, Spectrum No. 357.

Anal. Calcd for $C_{18}H_{22}$: C, 90.70; H, 9.30. Found: C, 90.72; H, 9.45.

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Photoamidation. IV.[1] The Light-Induced Amidation of α,β-Unsaturated Esters

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The acetone- and benzophenone-initiated photochemical amidation of α,β-unsaturated esters with formamide is described. The reaction led to the corresponding alkylated succinic acid derivatives in yields of up to 90%. Ethyl cinnamate yielded 2-carbamoyl-3,4,4-triphenyl-γ-butyrolactone (when benzophenone was used as a photosensitizer), whereas addition of formamide to benzal diethyl malonate led to ethyl 2-ethoxycarbonyl-3-carbamoylhydrocinnamate. It was found that in the present case (i) the α,β-unsaturated ester and (ii) formamide compete for the excited (triplet) carbonyl compound: the reaction with i leads to *cis–trans* isomerization of the unsaturated ester and involves a genuine energy-transfer step; whereas the reaction with ii leads to addition of formamide to the double bond and involves a hydrogen atom abstraction step from formamide.

The light-induced addition of formamide to isolated double bonds (terminal, nonterminal, and cyclic) has been reported by us in previous papers of this series.[3] It was shown that this reaction could be induced directly by light or initiated photochemically by acetone with higher yields. The direct light-induced addition of formamide to ethyl maleate and fumarate has been reported by us in a preliminary communication.[4] We have found since then that this addition reaction of formamide to α,β-unsaturated esters could be initiated photochemically by ketonic photosensitizers, and the present paper gives full details of the reactions and the products obtained, using (mainly) benzophenone as a photosensitizer.[5]

Results

Formamide has been found to undergo acetone and benzophenone-initiated photochemical addition to aliphatic α,β-unsaturated esters to yield the derivatives of the corresponding alkylated succinic acids (Scheme I). The reaction product in the case of ethyl cinnamate, while using benzophenone as a sensitizer, was 2-carbamoyl-3,4,4-triphenyl-γ-butyrolactone, whereas benzal diethyl malonate gave ethyl 2-ethoxycarbonyl-3-carbamoylhydrocinnamate. The reactions studied and the major products obtained are summarized in Table I.

TABLE I

ADDITION PRODUCTS OF FORMAMIDE AND α,β-UNSATURATED ESTERS[a] (INITIATED BY BENZOPHENONE)

Ester	Product (1:1 adduct)	%	Source of light
Ethyl maleate	Diethyl carbamoylsuccinate	90[b]	Sun
		82	Ultraviolet[c]
Ethyl fumarate	Diethyl carbamoylsuccinate	86	Ultraviolet[c]
Methyl 2-octenoate	Methyl 3-carbamoyloctanoate	80	Sun
		81	Ultraviolet[c]
Methyl 2-nonenoate	Methyl 3-carbamoylnonanoate	79	Ultraviolet[c]
Methyl 2-decenoate	Methyl 3-carbamoyldecanoate	93	Sun
		77	Ultraviolet[c]
Ethyl cinnamate	2-Carbamoyl-3,4,4-triphenyl-γ-butyrolactone	17	Sun
		21	Ultraviolet[c]
Benzal diethyl malonate	Ethyl 2-ethoxycarbonyl-3-carbamoylhydrocinnamate	40	Ultraviolet[c]

[a] Mole ratio of formamide/α,β-unsaturated ester was 1:250. [b] Yields are based on the ester employed. [c] Hanau Q 81 high-pressure mercury vapor lamps were used as radiation sources for these reactions.

Products were isolated by standard procedures and identified by means of their physical properties and elemental analyses as well as by spectroscopic data. They were further hydrolyzed to the corresponding alkylated succinic acids, which were compared with authentic samples. 2-Carbamoyl-3,4,4-triphenyl-γ-butyrolactone was hydrolyzed to the corresponding acid which was then decarboxylated to yield 3,4,4-triphenyl-γ-butyrolactone. Ethyl 2-ethoxycarbonyl-3-carbamoylhydrocinnamate was hydrolyzed and decarboxylated to yield phenylsuccinic acid which was compared with an authentic sample. Products resulting from reactions between the benzophenone moiety and formamide were also isolated in most cases, though in poor yields. The major product of these reactions was the amide of benzilic acid.

Discussion

The mechanism of the addition reaction of formamide to olefins was discussed in our previous publications[3] and was shown to be a free-radical chain reaction involving carbamoyl·$CONH_2$ radicals. As

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(1) Part III: D. Elad and J. Rokach, *J. Org. Chem.*, **30**, 3361 (1965).

(2) In partial fulfillment of the requirements for a Ph.D. degree submitted to the Feinberg Graduate School of The Weizmann Institute of Science.

(3) (a) D. Elad and J. Rokach, *J. Org. Chem.*, **29**, 1855 (1964); (b) D. Elad and J. Rokach, *J. Chem. Soc.*, 800 (1965); (c) D. Elad and J. Rokach, *J. Org. Chem.*, **30**, 3361 (1965).

(4) D. Elad, *Proc. Chem. Soc.*, 225 (1962).

(5) According to the mechanism proposed for the interaction of the photoactivated benzophenone molecule with formamide in the addition of the latter to isolated olefins,[3a] the ketonic compound should be termed a "photoinitiator" rather than a "photosensitizer." However, interaction of the excited carbonyl compound and the α,β-unsaturated esters in the present case (*vide infra*) is a genuine energy-transfer step and thus the ketonic compound acts here as a photosensitizer.[6]

(6) G. S. Hammond, J. Saltiel, A. A. Lamola, N. J. Turro, J. S. Bradshow, D. O. Cowan, R. C. Counsell, V. Vogt, and C. Dalton, *J. Am. Chem. Soc.*, **86**, 3197 (1964), and references cited therein.