oxo ester and 910 times (k''IV/k_{OH}-IV) greater in the case of the thiono ester. Since it is known that carbonyl oxygen has greater ability to accept hydrogen bonds than does thiocarbonyl sulfur,[20] general acid catalysis by the N-protonated amino group should not be markedly more effective in enhancing the rate of hydroxide ion attack on the thiono ester as compared with its effect on the oxo ester. From the above, one is led to conclude that the most plausible explanation for the enhanced rate of hydrolysis of the tertiary amino esters in moderately basic solutions is intramolecular general base-catalyzed attack of water, mechanism XI.

[20] (a) H. B. Van der Heidje in "Organic Sulfur Compounds," N. Kharasch, Ed., Pergamon Press, Elmsford, N. Y., 1961, p 13; (b) M. H. Krackov, C. M. Lee, and H. G. Mautner, *J. Amer. Chem. Soc.*, **87**, 892 (1965); (c) N. Kulevsky and P. M. Froehlich, *ibid.*, **89**, 4839 (1967).

Solvolyses of Aryldineopentylcarbinyl, Aryl-*tert*-butylneopentylcarbinyl, and Aryldi-*tert*-butylcarbinyl *p*-Nitrobenzoates. Effects of the Bulky Alkyl Groups at the Reaction Center and Substituents in the Aryl Ring

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Abstract: Three series of aryldialkylcarbinyl *p*-nitrobenzoates, in which the aryl rings are variously substituted for the evaluation of substituent effects, were prepared and their solvolysis rates were determined in 70% aqueous acetone at several temperatures. They were aryldineopentylcarbinyl (**6**-Z), aryl-*tert*-butylneopentylcarbinyl (**7**-Z), and aryldi-*tert*-butylcarbinyl (**8**-Z) *p*-nitrobenzoates. For comparison, the corresponding aryldimethylcarbinyl *p*-nitrobenzoates (**5**-Z) and methyldineopentylcarbinyl (**9**), -*tert*-butylneopentylcarbinyl (**10**), and -di-*tert*-butylcarbinyl (**11**) *p*-nitrobenzoates were prepared and similarly solvolyzed. Relative rates for the unsubstituted α-phenyl compounds at 100° are 1 for **5**-H, 0.19 for **6**-H, 0.81 for **7**-H, and 0.093 for **8**-H. Those for the *p*-trifluoromethylphenyl compounds are 6.3×10^{-6} for **5**-CF$_3$, 2.9×10^{-6} for **6**-CF$_3$, 25×10^{-6} for **7**-CF$_3$, and 8.8×10^{-6} for **8**-CF$_3$. The $\rho\sigma^+$ treatment gives straight lines in all the α-aryl systems and the ρ values are -3.74 for **5**-Z, -2.91 for **6**-Z, -2.64 for **7**-Z, and -1.30 for **8**-Z. The reactivity variations with substituents are discussed in terms of steric hindrance to resonance stabilization of the aryl group and relief of strain due to the bulky *tert*-butyl and/or neopentyl groups. Products from **6**-H and **7**-H were comprised of olefins arising simply from β elimination along with some unrearranged alcohols. Those from **8**-H comprised an olefin produced by elimination with methyl rearrangement and a cyclopropane derivative resulting from γ elimination. The solvolysis rates of the phenyldialkylcarbinyl *p*-nitrobenzoates relative to those of the methyldialkylcarbinyl *p*-nitrobenzoates, k_{Ph}/k_{Me}, were found to be 220 for the dimethyl, 0.24 for the dineopentyl, 0.63 for the *tert*-butylneopentyl, and 0.19 for the di-*tert*-butyl system.

Solvolyses of primary, secondary, and tertiary α-arylcarbinyl halides or ionizable esters have been intensively investigated yielding significant results of practical and theoretical interest.[1-3] A *p*-methoxy substituent in the aryldimethylcarbinyl chloride system raises the hydrolysis rate by a factor of 3360, while a *p*-nitro substituent decreases it by a factor of 2.57×10^{-4}. These substituent effects were correlated by Brown and coworkers with electrophilic aromatic substitution reactions by a $\rho\sigma^+$ free energy relationship.[3,4] In a previous paper,[5] we investigated the solvolyses of tertiary α-arylcycloalkyl and -polycycloalkyl chlorides, and the solvolysis reactivities were discussed in terms of the effects of substituents in the aryl rings and relief of torsional and/or steric strain accompanying the change in coordination number of the reaction center from four in the ground state to three in the cationic transition state. The effect of aryl substituents in each cycloalkyl system gave an individual linear $\rho\sigma^+$ relationship, and it was suggested that the smaller ρ value of α-arylcyclopentyl chlorides compared with those of α-arylcyclobutyl and α-arylcyclohexyl chlorides results from strain relief in the transition state.

When methyl groups in *tert*-butyl chloride or ionizable esters are replaced by such bulky groups as *tert*-butyl and/or neopentyl, the reaction center of the molecules becomes more crowded and the rate of solvolysis becomes larger. The first proposed explanation of these effects was rate-enhancing "B strain."[6,7] For example, the *p*-nitrobenzoates of tri-*tert*-butylcarbinol, di-*tert*-butylneopentylcarbinol, *tert*-butyldineopentyl-

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[1] A recent investigation of the primary system: A. Streitwieser, Jr., H. A. Hammond, R. H. Jagow, R. M. Williams, R. G. Jesaitis, C. J. Chang, and R. Wolf, *J. Amer. Chem. Soc.*, **92**, 5141 (1970).

[2] A study of the secondary system: V. J. Shiner, Jr., E. W. Buddenbaum, B. L. Murr, and G. Lamaty, *ibid.*, **90**, 418 (1968).

[3] A review: L. M. Stock and H. C. Brown, *Advan. Phys. Org. Chem.*, **1**, 35 (1963).

[4] J. E. Leffler and E. Grunwald, "Rates and Equilibria of Organic Reactions," Wiley, New York, N. Y., 1963, pp 194-211.

[5] H. Tanida and T. Tsushima, *J. Amer. Chem. Soc.*, **92**, 3397 (1970).

[6] H. C. Brown, *Science*, **103**, 385 (1946); H. C. Brown and R. S. Fletcher, *J. Amer. Chem. Soc.*, **71**, 1845 (1949); H. C. Brown and H. L. Berneis, *ibid.*, **75**, 10 (1953).

[7] F. Brown, T. D. Davies, I. Dostrovsky, O. J. Evans, and E. D. Hughes, *Nature (London)*, **167**, 988 (1951); P. D. Bartlett, *Bull. Soc. Chim. Fr.*, [5] **18**, 104c (1951).

carbinol, and trineopentylcarbinol were found to react 13,500, 19,400, 68,000, and 560 times faster than *tert*-butyl *p*-nitrobenzoate, respectively, the products predominantly formed from the latter two carbinols having unrearranged carbon skeletons.[8]

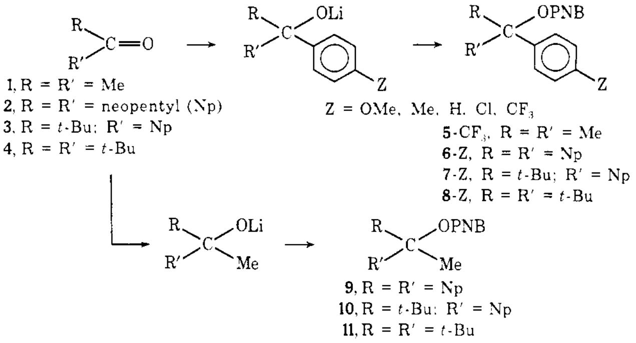
Bulky groups at the reaction center of α-arylcarbinyl systems would similarly increase strain of the above kind; however, since resonance between the developing p orbital of the cationic intermediate and the π system of the aryl ring plays an important part in facilitating solvolysis of these systems,[9] an over-all drop in rate may result if this resonance is disturbed by the bulky groups. A rate decrease resulting from such steric inhibition of the resonance was demonstrated by the introduction of ortho substituents into the aryl ring.[10]

The present research was thus undertaken to study the effects of bulky groups at the reaction center and of a para-substituted aryl ring upon solvolysis of the titled systems which were thought to be good examples of highly crowded aryldialkylcarbinyl derivatives. The results will be discussed in comparison with those from aryldimethylcarbinyl *p*-nitrobenzoates, in which there is minimum crowding, and those from methyldialkylcarbinyl *p*-nitrobenzoates, in which aryl resonance is absent.

Results

Preparations. The appropriate ketones (acetone **1**, dineopentyl **2**, *tert*-butylneopentyl **3**, or di-*tert*-butyl **4**)[8] were treated with aryllithium and the carbinols formed were, without isolation, esterified with *p*-nitrobenzoyl chloride to give *p*-trifluoromethylphenyldimethylcarbinyl *p*-nitrobenzoate (**5**-CF_3) and the series of aryldineopentylcarbinyl (**6**-Z), aryl-*tert*-butylneopentylcarbinyl (**7**-Z), and aryldi-*tert*-butylcarbinyl (**8**-Z) *p*-nitrobenzoates (Scheme I). The same reactions with methyllithium gave dineopentylmethylcarbinyl (**9**), *tert*-butylneopentylmethylcarbinyl (**10**), and di-*tert*-butylmethylcarbinyl (**11**) *p*-nitrobenzoates. *p*-Nitrobenzoates of some aryldimethylcarbinols (**5**-OCH_3, -CH_3, -H, and -Cl) were prepared by treatment of the corresponding carbinols with *p*-nitrobenzoyl chloride in pyridine. Infrared hydroxyl-stretching frequencies and nmr spectral parameters in various solvents for most of the crowded α-arylcarbinols described here have been presented elsewhere together with some other physical constants.[11]

Scheme I



Rates. Solvolysis rates of the *p*-nitrobenzoates were measured (in a solvent prepared by mixing seven parts of acetone and three parts of water at 25–26°) by potentiometric titration of the *p*-nitrobenzoic acid formed during the reaction. The ampoule technique was used to prevent the development of acid titer by the aqueous acetone solvent at high temperatures.[12] Theoretical infinity values were obtained in all runs after about 10 half-lives at the reaction temperatures. In each experiment the reaction was followed to 80% completion. The first-order rate constants were calculated by means of the least-squares method with a FACOM 270-20 computer, the correlation coefficients of all the plots being 0.999 ± 0.001. The rate constants and activation parameters thus obtained are listed in Table I. Although the effect of the solvent on the solvolysis rate would be germane to the present discussion, because of the very low solubility of the *p*-nitrobenzoates, we could find no suitable solvents other than aqueous acetone.

Hydrolysis Products. Product studies were carried out by heating the *p*-nitrobenzoates (**6**-H, **7**-H, **8**-OCH_3, **8**-H, and **8**-CF_3) in 70% aqueous acetone containing an equivalent amount of sodium hydroxide. The presence of base had no effect on product isomerization as the ratio of products was the same in absence of base.[13] The hydrocarbons produced were separated and collected by vpc. That they were products of elimination of *p*-nitrobenzoic acid was clarified by mass spectrometry and elementary analysis. Thermolysis of the *p*-nitrobenzoates rather than hydrolysis was found to be a more convenient and practical method for synthesis of the hydrocarbons. Minor formations of the original unrearranged carbinols[11] from **6**-H and **7**-H were determined by retention time analysis on vpc using two or three kinds of columns. On the other hand, **8**-H showed no formation of carbinol. Total yields of the solvolysis products, determined by vpc with an internal standard, were roughly quantitative. The product structures established are shown with yields in Chart I.

Two olefins, **12** and **13**, were obtained from **6**-H. A trisubstituted styrene structure is designated for both **12** and **13** from the presence of a styrene-type chromophore in the uv spectra and one vinyl proton, two *tert*-butyl groups, two methylene protons, and five aromatic protons in the nmr spectra. Further, since the signal patterns of the methylene protons (a broad singlet for the major **12** and a doublet of $J = \sim 1$ Hz for the minor **13**) and the vinyl protons (a broad singlet for **12** and a triplet of $J = \sim 1$ Hz for **13**) are indicative of an allylic coupling, but not of a geminal coupling, the olefins must be derivatives of a $-CH_2CR{=}CHR$ type. Therefore, the geometric isomers of 2-*tert*-butyl-1-neopentylstyrene (**12** and **13**) are visualized, which are consistent with results of the simplest reaction mechanism, elimination of one of the β protons from the α-aryl carbonium intermediate. Catalytic hydrogenations of both the olefins gave the same saturated hydrocarbon, which revealed only one benzylic proton in the nmr

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[8] P. D. Bartlett and T. T. Tidwell, *J. Amer. Chem. Soc.*, **90**, 4421 (1968).

[9] E. L. Eliel, "Steric Effects in Organic Chemistry," M. S. Newman, Ed., Wiley, New York, N. Y., 1956, Chapter 2, pp 88–90.

[10] G. Baddeley, J. Chadwick, and H. T. Taylor, *J. Chem. Soc.*, 2405 (1954).

[11] F. H. Hon, H. Matsumura, H. Tanida, and T. T. Tidwell, *J. Org. Chem.*, 37, 1778 (1972).

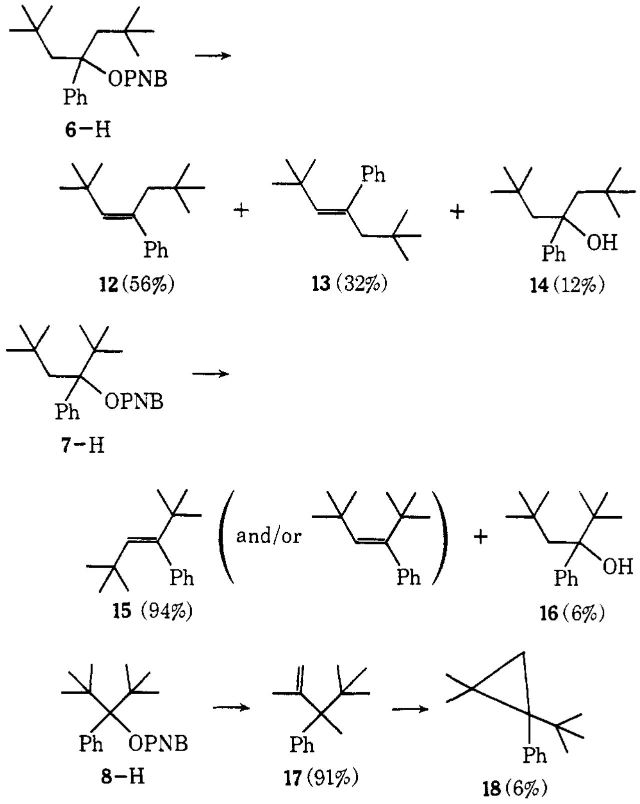
[12] M. S. Silver, *J. Amer. Chem. Soc.*, **83**, 404 (1961); H. L. Goering and E. F. Silversmith, *ibid.*, **77**, 6249 (1955).

[13] Similarly, no effect of base was reported in ref 8.

Table I. Rate Constants and Activation Parameters from the Hydrolysis of the *p*-Nitrobenzoates in 70% Aqueous Acetone

Compd				Calcd at 100°		
System	Para substituent	Temp, °C	k_1, sec^{-1}	$\Delta H^{\ddagger}$, kcal	$\Delta S^{\ddagger}$, eu	Rate constant
5	OCH_3	−5.00	2.78×10^{-5}	19.87	−5.02	1.42×10^{0}
		10.00	1.87×10^{-4}			
		24.80	1.34×10^{-3}			
	CH_3	35.10	3.20×10^{-5}	22.41	−6.48	2.22×10^{-2}
		40.20	5.72×10^{-5}			
		50.00	1.69×10^{-4}			
		60.20	4.97×10^{-4}			
		65.00	9.52×10^{-4}			
	H	64.95	4.52×10^{-5}	24.30	−6.81	1.48×10^{-3}
		80.00	2.14×10^{-4}			
		95.05	9.52×10^{-4}			
	Cl	75.00	5.19×10^{-5}	25.29	−5.85	6.28×10^{-4}
		90.00	2.25×10^{-4}			
		105.00	1.03×10^{-3}			
	CF_3	109.90	2.35×10^{-5}	28.05	−6.89	8.97×10^{-6}
		125.00	1.09×10^{-4}			
		140.00	3.89×10^{-4}			
		155.00	1.28×10^{-3}			
6	OCH_3	34.80	3.22×10^{-5}	24.65	0.93	4.52×10^{-2}
		50.10	2.27×10^{-4}			
		65.20	1.34×10^{-3}			
	CH_3	65.00	4.60×10^{-5}	26.69	0.33	2.13×10^{-3}
		80.10	2.69×10^{-4}			
		95.00	1.28×10^{-3}			
	H	84.80	5.23×10^{-5}	28.45	1.11	2.79×10^{-4}
		100.00	2.79×10^{-4}			
		115.00	1.28×10^{-3}			
	Cl	89.90	3.50×10^{-4}	29.05	0.74	1.09×10^{-4}
		104.60	1.84×10^{-4}			
		115.00	5.20×10^{-4}			
		119.90	8.12×10^{-4}			
	CF_3	119.90	3.89×10^{-5}	31.75	1.50	4.15×10^{-6}
		134.60	1.66×10^{-4}			
		144.80	4.39×10^{-4}			
		149.90	7.62×10^{-4}			
7	OCH_3	20.00	2.38×10^{-4}	22.96	−1.25	1.48×10^{-1}
		35.00	1.80×10^{-4}			
		50.10	1.05×10^{-3}			
	CH_3	45.00	1.48×10^{-5}	25.61	0.08	8.08×10^{-3}
		50.00	3.98×10^{-5}			
		65.00	2.06×10^{-4}			
		74.80	6.04×10^{-4}			
		80.00	1.06×10^{-3}			
	H	69.90	4.30×10^{-5}	27.55	1.48	1.20×10^{-3}
		84.90	2.33×10^{-4}			
		100.00	1.23×10^{-3}			
	Cl	79.95	4.47×10^{-5}	28.20	1.10	4.10×10^{-4}
		95.00	2.42×10^{-4}			
		109.95	1.13×10^{-3}			
	CF_3	100.00	3.54×10^{-5}	31.27	4.52	3.62×10^{-6}
		105.15	6.51×10^{-5}			
		119.90	3.41×10^{-4}			
		135.00	1.42×10^{-3}			
8	OCH_3	70.00	2.40×10^{-5}	28.59	3.36	7.55×10^{-4}
		85.00	1.41×10^{-4}			
		100.00	7.63×10^{-4}			
	CH_3	85.00	4.13×10^{-4}	29.44	3.27	2.29×10^{-4}
		100.00	2.34×10^{-4}			
		115.05	1.10×10^{-3}			
	H	90.00	4.48×10^{-5}	29.59	2.66	1.38×10^{-4}
		104.85	2.34×10^{-4}			
		119.75	1.08×10^{-3}			
	Cl	99.95	4.30×10^{-5}	29.71	0.59	4.16×10^{-5}
		115.00	1.87×10^{-4}			
		129.95	9.17×10^{-4}			
	CF_3	115.00	6.49×10^{-5}	30.94	1.50	1.25×10^{-5}
		129.95	3.02×10^{-4}			
		144.95	1.23×10^{-3}			
9		69.80	4.60×10^{-5}	26.51	−1.36	1.17×10^{-3}
		85.00	2.50×10^{-4}			
		100.00	1.17×10^{-3}			
10		65.30	6.32×10^{-5}	25.11	−3.81	2.23×10^{-3}
		80.10	3.07×10^{-4}			
		89.70	8.16×10^{-4}			
		95.00	1.42×10^{-3}			
11		75.10	5.09×10^{-5}	26.49	−2.38	7.13×10^{-4}
		90.10	2.69×10^{-4}			
		104.80	1.12×10^{-3}			

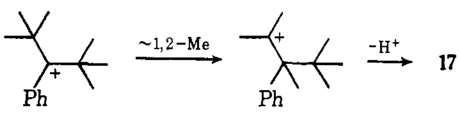
Chart I

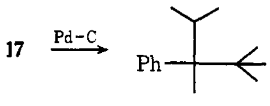


spectra. These data are compatible with the structures of **12** and **13**. Steric hindrance of conjugation between the double bond and the phenyl ring is perhaps greater in **13** than in **12**. On the basis of this assumption, the structure **12** was assigned to the olefin of 56% yield, which shows a relatively stronger uv maximum (237 $m\mu$, ϵ 12,000), and **13** was assigned to the olefin of 32% yield which shows a weaker uv maximum (230 $m\mu$, ϵ 7000). The fact that the cis allylic coupling constant for **13** is larger than the trans coupling for **12** is further confirmation of this assignment.

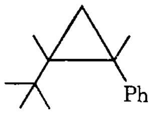
Vpc showed only one olefinic product from **7**-H. Although the uv spectrum does not indicate the presence of an unsaturation conjugated with a phenyl ring, the nmr revealed one vinyl proton as a sharp singlet, with protons due to two *tert*-butyl groups and one phenyl ring. The hydrocarbon obtained by saturation of this olefin shows one benzylic proton in the nmr spectrum. Therefore, the assignable structure is the cis or trans isomer of 1,2-di-*tert*-butylstyrene (**15**). Since vpc employed in the present product study may not be able to separate these isomers, there is a possibility that the product is a mixture of both the isomers.[14]

Hydrolysis of **8**-H resulted in the formation of a 94:6 mixture of one unsaturated hydrocarbon **17** and one saturated hydrocarbon **18**. For **17**, the presence of one *tert*-butyl group (singlet), two geminal vinyl protons (doublet and quintet), one methyl group (unsplit), and another methyl group (split by ~2 Hz) is evidenced by the nmr spectra and the absence of an unsaturation conjugated with an aromatic ring is shown by the uv spectra. These data are compatible with 3-phenyl-2,3,4,4-tetramethylpentene-1 (**17**), which can be mechanistically considered as a result of methyl migration from an originally formed cationic intermediate followed by proton elimination. As further proof, **17** was reduced to the hydrocarbon **19**, whose structure was designated by the appearance of two methyl groups of a doublet type and one methine group as a quintet in the nmr spectrum. Absence of unsaturation in the minor hydrocarbon **18** is demonstrated by the uv and nmr spectra. The nmr spectrum reveals two protons of a cyclopropyl methylene type as two doublets, one *tert*-butyl group as a singlet, and two methyl groups as two singlets. These data lead to the structure **18** which from a mechanistic viewpoint may be considered to result from 1,3-elimination. The structure of 1,2-dimethyl-2-*tert*-butyl-1-phenylcyclopropane (**20**), though consistent with the spectral data, is mechanistically unreasonable. To investigate the substituent effects upon the relative yields ratio of **17** and **18**, **8**-OCH_3 and **8**-CF_3 were hydrolyzed; the results are presented in the Experimental Section.





19



20

Hammett Treatments. As shown in Figure 1, straight lines were obtained by the $\rho\sigma^+$ treatment of the rate constants at 100° in each of the systems. The ρ values obtained are -3.74 (correlation coefficient 0.9998) for the **5** system, -2.91 (0.9998) for **6**, -2.64 (0.9974) for **7**, and -1.30 (0.9794) for **8**. The ρ value of -4.54 has been reported for the solvolysis of aryldimethylcarbinyl chloride in 90% acetone at 25°.[3,4] Treatment of the rates by the Yukawa–Tsuno equation, $\log k/k_0 = \rho(\sigma^0 + \gamma\Delta\bar{\sigma}_R)$,[15] gave linear relationships yielding the following ρ and γ: -3.69 and 1.03 for **5** (correlation coefficient 1.0000); -3.02 and 0.931 for **6** (1.0000); -2.65 and 0.990 for **7** (0.9975); -1.79 and 0.491 (0.9934) for **8**.

Discussion

It is seen from Table I and Figure 1 that the rate constants in each highly crowded system (**6**-Z, **7**-Z, and **8**-Z) do not change with variation of substituents so widely as those in the aryldimethylcarbinyl system (**5**-Z) and that the change of the rate constants in the di-*tert*-butylaryl system (**8**-Z) is abnormally narrow. For example, rate acceleration by a *p*-methoxy substituent is 960 times (100°) in **5**-Z and 5.5 times in **8**-Z, and the rate deceleration factors of a *p*-trifluoromethyl substituent are 0.0061 in **5**-Z and 0.091 in **8**-Z. The magnitude of the ρ values, which is a measure of the

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(14) A referee suggested that the nmr spectra of *cis*- and *trans*-**15** would be quite different, so surely only one isomer (presumably trans on steric grounds) is present.

(15) Y. Yukawa and Y. Tsuno, *J. Chem. Soc. Jap., Pure Chem. Sect.*, **86**, 873 (1965); Y. Yukawa, Y. Tsuno, and M. Sawada, *Bull. Chem. Soc. Jap.*, **39**, 2274 (1966).

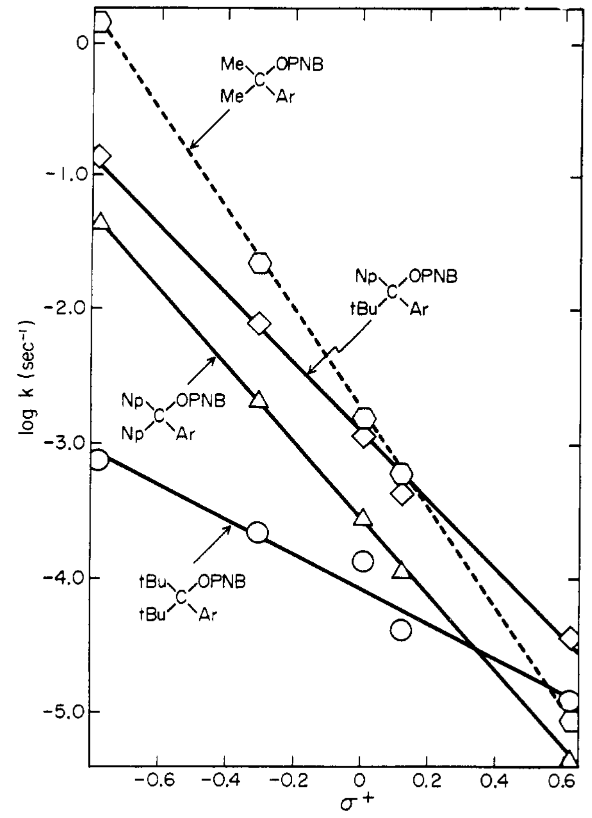
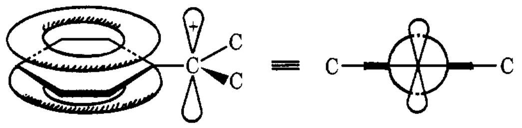
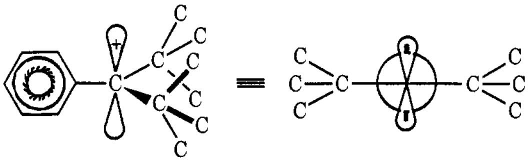


Figure 1. Hammett-Brown $\rho\sigma^+$ plot: ○, **5**-Z, −3.74; ◇, **7**-Z, −2.64; △ **6**-Z, −2.91; ○, **8**-Z, −1.30.

electron demand in the transition state, increases in the order **8**-Z < **7**-Z < **6**-Z < **5**-Z. It is observed that when the para substituents are electron supplying, the highly crowded compounds are less reactive than the corresponding aryldimethylcarbinyl derivatives; so rate enhancement expected from the relief of strain cannot be found in apparent rate constants until the para substituent becomes strongly electron withdrawing. An important factor determining the reactivities of α-arylcarbinyl systems which form the benzyl cation is doubtless the resonance effect of the aryl ring, which stabilizes the carbonium ion. The rate enhancement of 1000 (25° in 90% acetone) which was observed in the solvolysis of phenyldimethylcarbinyl chloride relative to *tert*-butyl chloride has been attributed to the resonance stabilization effect of the phenyl ring.[16,17] The conformation where the carbonium sp^2 orbital and the aryl ring are coplanar contributes most effectively to the stabilization of the carbonium ion. Though in the phenyldimethylcarbinyl cation structure there is no serious steric hindrance to the assumption of this planar conformation, as the molecule becomes more crowded around the cationic center, so will the cation be less able to assume the planar conformation and will be twisted. Catalin molecular models of both aryldineopentylcarbinyl and -*tert*-butylneopentylcarbinyl cations can barely take the planar conformation, while that of aryldi-*tert*-butylcarbinyl cation cannot assume the planar conformation because the two inflexible *tert*-butyl groups prevent the aryl ring from rotating around the sp^2–aryl bond. Inspection of the models shows that the least crowded conformation is the one in which the carbonium ion and the aryl ring are perpendicular to one another. It is rather difficult to get information about the relative magnitude of strain in the ground states of the crowded nitrobenzoates **6**, **7**, and **8**. Though models of these nitrobenzoates can be assembled, they are very compact. However, the greatest hindrance to rotation of the aryl ring is seen in the model of **8**. In Table II, the relative rates of **5**-H, **6**-H, **7**-H, and **8**-H, and the methyldialkylcarbinyl *p*-nitrobenzoates (*tert*-butyl-OPNB, **9**, **10**, and **11**) are summarized taking the rate of **5**-H as a standard, together with the derived rate ratios of the phenyl- and methyldialkylcarbinyl *p*-nitrobenzoates, $k_{\mathrm{Ph}}/k_{\mathrm{Me}}$. Comparable reactivities of the methyl-substituted **9**, **10**, and **11** (factors of 0.79, 1.5, and 0.48, respectively) suggest that if a common major factor governing reactivity exists in these compounds, it must be of similar magnitude in each.[18] There is almost no doubt that the factor is the relief of steric and/or torsional strain. It may be that the relative importance of this strain factor is not so different in the phenyl-substituted **6**-H, **7**-H, and **8**-H. Despite the lack of precise data about the strain, the decreases in reactivities of **6**-H, **7**-H, and particularly **8**-H below that of **5**-H are compatible with the decreased

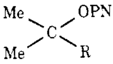
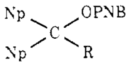
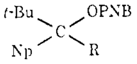
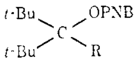


5 ion model



8 ion model

Table II. Relative Rates for Phenyldialkylcarbinyl *p*-Nitrobenzoates[a]

Compd	R = Ph	R = Me	$k_{\mathrm{Ph}}/k_{\mathrm{Me}}$
	1	0.0046[b]	220
	0.19	0.79	0.24
	0.81	1.5	0.63
	0.093	0.48	0.19

[a] In 70% acetone at 100°. [b] k_1 = 6.81 × 10^{-6} sec^{-1}, cited from C. F. Wilcox, Jr., and M. E. Mesirov, *J. Amer. Chem. Soc.*, **84**, 2757 (1962).

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[16] H. C. Brown, R. Bernheimer, and K. J. Morgan, *J. Amer. Chem. Soc.*, **87**, 1280 (1965).

[17] The rate data are cited from A. H. Fainberg and S. Winstein, *ibid.*, **78**, 2770 (1956); Y. Okamoto, T. Inukai, and H. C. Brown, *ibid.*, **80**, 4972 (1958).

[18] The results are, in appearance, similar to those from *tert*-butyldialkylcarbinyl system. Thus, the reported relative reactivities (at 50° in 60% dioxane) are 1 for tri-*tert*-butylcarbinyl *p*-nitrobenzoate, 1.5 for di-*tert*-butylneopentylcarbinyl *p*-nitrobenzoate, and 4.8 for *tert*-butyldineopentyl *p*-nitrobenzoate.[8]

stabilization effect of the aryl ring apparent from the molecular model. The resonance stabilization effect is, however, definitely present in the solvolyses of **6**-Z, **7**-Z, and **8**-Z. This is evidenced by the fact that the $\rho\sigma^+$ treatments yield good straight lines, whereas the $\rho\sigma$ treatments show upward curvature for substituents ranging from *p*-methyl to *p*-methoxy, and also because the linear correlations by the Yukawa–Tsuno equation[15] yield significantly large resonance parameters (γ), the minimum γ being 0.491 for **8**-Z. It follows that the presence of two *tert*-butyl groups at the α-arylcarbinyl position as in **8**-Z cannot eliminate resonance. In contrast to the fact that **5**-H is 220 times more reactive than *tert*-butyl-PNB, **6**-H, **7**-H, and **8**-H are somewhat less reactive than the corresponding methyldialkylcarbinyl *p*-nitrobenzoates ($k_{\mathrm{Ph}}/k_{\mathrm{Me}}$ in Table II). This is also a result of the decreased resonance stabilization in the crowded carbonium ion derived from **6**-H, **7**-H, and **8**-H.

Noteworthy is the fact that the activation entropies for **6**-, **7**-, and **8**-Z (except for **7**-CH_3O) are positive while those for **5**-Z are negative (Table I). We attribute the increased $\Delta S^{\ddagger}$ in **6**-, **7**-, and **8**-Z to the very enhanced steric inhibition to solvation at their reaction sites. The activation enthalpies for **5**-, **6**-, and **8**-Z vary with substituents accompanying very small changes in $\Delta S^{\ddagger}$ (maximum $T\Delta\Delta S^{\ddagger}$ is 0.7 kcal). For **7**-Z the substituent effects on $\Delta H^{\ddagger}(\Delta\Delta H^{\ddagger})$ is nearly proportional to those on $\Delta S^{\ddagger}$ ($\Delta\Delta S^{\ddagger}$). Therefore, $\Delta H^{\ddagger}$ and $\Delta S^{\ddagger}$ show a linear correlation either with each other or with σ^+.

When the electron-supplying capability of a para substituent of the aryldialkylcarbinyl systems increases to an extreme, the resonance effect will be the dominant contributor to the reactivity, other factors becoming less important. In this case, the planar conformation of α-aryl carbonium ion will be the predominant criterion for reactivity, so that the difference in reactivities between **5**-Z and the crowded compounds is the largest at the methoxy substituent and it becomes smaller with the decreasing electron-supplying ability of substituent. On the other hand, when the electron-withdrawing ability of the para substituent increases to an extreme, the inductive effect of the aryl ring will become important and the resonance effect will be no longer major. The relief of steric strain in the transition state will become an increasingly important factor for the reactivity. This increasing importance with the introduction of an electronegative substituent was explained in the previous paper[5] using an energy diagram.[19] Table I shows that **7**-CF_3 and **8**-CF_3 solvolyze 4.0 and 1.4 times, respectively, faster than **5**-CF_3 at 100°. It is, however, noted that **5**-CF_3 has a $\Delta S^{\ddagger}$ of -6.89 eu and **6**-CF_3, **7**-CF_3, and **8**-CF_3 have $\Delta S^{\ddagger}$ of $+1.50$, $+4.52$, and $+1.50$, respectively. These differences in $\Delta S^{\ddagger}$ correspond to rate accelerations of 68, 311, and 68, respectively, for **6**-CF_3, **7**-CF_3, and **8**-CF_3 relative to **5**-CF_3. The fast rates of **7**-CF_3 and **8**-CF_3 relative to **5**-CF_3 are not due to low $\Delta H^{\ddagger}$. The activation enthalpy $\Delta H^{\ddagger}$ is lower for **5**-CF_3 (28.05 kcal) than **6**-CF_3 (31.75), **7**-CF_3 (31.27), and **8**-CF_3 (30.94). So, if one calculates rates at 25° from the activation parameters, one finds the order, **7**-CF_3 ($k_1 = 6.95 \times 10^{-10}$) > **5**-$CF_3$ (5.13×10^{-10}) > **8**-CF_3 (2.69×10^{-10}) > **6**-CF_3 (6.76×10^{-11} sec^{-1}). At far lower temperatures **5**-CF_3 will be the most reactive compound because its $\Delta H^{\ddagger}$ is the lowest. In addition, $\Delta H^{\ddagger}$ for the crowded CF_3 compounds suggest the reactivity order of **8**-CF_3 > **7**-CF_3 > **6**-CF_3. We consider that the lower $\Delta H^{\ddagger}$ of **5**-CF_3 relative to those of the crowded CF_3 compounds is mainly due to the still-existing resonance stabilization effect by the trifluoromethylphenyl ring on **5**-CF_3 and no effect (or, if any, negligibly small) on the crowded compounds. In an ideal case where the resonance is perfectly eliminated, we expect that the reactivity of **5**-Z is far below those of the crowded systems because the relief of strain is minimum in **5**-Z. When the straight lines in Figure 1 are extrapolated very far to high σ^+ values (an approach to complete elimination of the resonance effect by introduction of a sufficiently strong electron-withdrawing substituent), the reactivity order seen is **8**-Z > **7**-Z > **6**-Z > **5**-Z.

The relative importance of the two major factors governing the solvolytic reactivity of the highly crowded α-aryldialkylcarbinyl *p*-nitrobenzoates, the rate-retarding steric hindrance to resonance stabilization of the aryl group and the rate-enhancing relief of strain, varies with the substituents. In fact, the reactivity of **8**-Z is the lowest at CH_3O, but is ranked as the second at CF_3.

Experimental Section

Melting points were taken by capillary and are corrected. Boiling points are uncorrected. Vpc analyses were performed on a Hitachi Perkin-Elmer Model F-6D with a 1 m × 4 mm XE60 5% column and a 2 m × 3 mm Carbowax 1% glass column using helium as a carrier gas. Nmr spectra were determined on a Varian A-60 spectrometer using tetramethylsilane as internal standard. Uv spectra were measured on a Hitachi EPS-032 spectrometer. Infrared spectra were measured on a JASCO Model IR-S. Properties and analyses of the *p*-nitrobenzoates prepared in this study are summarized in Table III.

Dineopentyl ketone (2), *tert*-butylneopentyl ketone (3), and di-*tert*-butyl ketone (4) were prepared by methods described in the literature.[20]

Phenyl-,[21] *p*-methoxyphenyl-,[22] *p*-methylphenyl-,[23] and *p*-chlorophenyldimethylcarbinols[24] were synthesized in accordance with methods described in the literature and acylated with *p*-nitrobenzoyl chloride in pyridine to give phenyldimethylcarbinyl *p*-nitrobenzoate (**5**-H) in 75% yield, and its derivatives **5**-OMe in 43%, **5**-Me in 83%, and **5**-Cl in 68%.

***p*-Trifluoromethylphenyldimethylcarbinyl *p*-Nitrobenzoate (5-CF_3).** A solution of *p*-trifluoromethylphenyl bromide (6.0 g, 26.7 mmol) in 10 ml of anhydrous ether was added to a stirred solution of *n*-butyllithium (27.3 mmol) in 20 ml of hexane under a nitrogen atmosphere at −50°. A solution of an excess amount of acetone in ether was added to the above alkyllithium solution at −40°. After 10 min of stirring at the same temperature, the reaction mixture was poured into ice-cooled aqueous ammonium chloride and extracted with ether. After evaporation of the solvent, the residue (4.9 g) was acylated by *p*-nitrobenzoyl chloride (4.82 g, 26 mmol) and pyridine in the usual way. Recrystallization from ether gave 5.0 g (60.3%) of crystals.

General Comments on the Preparation of Aryldineopentylcarbinyl, -*tert*-butylneopentylcarbinyl, and -di-*tert*-butylcarbinyl *p*-Nitrobenzoates (6-Z, 7-Z, and 8-Z). Phenyllithium and *p*-tolyllithium were prepared from solutions of the corresponding aryl bromides in ether and lithium metal in the usual way. Since the reactions of *p*-methoxy- *p*-chloro-, and *p*-trifluoromethylphenyl bromides with lithium metal were very slow, *n*-butyllithium was used in these cases. The aryllithium was added to a stirred solution of the appropriate ketone (**2**, **3**, and **4**) in ether under nitrogen at −30 to *ca.* −20°. A solution of *p*-nitrobenzoyl chloride in ether was then added at −20 to *ca.* −10°, and the mixture was allowed to stand

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(19) Figure 2 in ref 5.

(20) Footnotes 25–27 in ref 8.

(21) H. Kwart, *J. Amer. Chem. Soc.*, 77, 4907 (1955).

(22) M. Oki and H. Iwamura, *Bull. Chem. Soc. Jap.*, **35**, 1552 (1962).

(23) H. C. Brown, *J. Amer. Chem. Soc.*, **79**, 1897 (1957).

(24) M. Oki and H. Iwamura, *Bull. Chem. Soc. Jap.*, **35**, 1552 (1962).

Table III. Analyses and Properties of *p*-Nitrobenzoates

Compd	Mp, °C	Ir($CHCl_3$), cm^{-1}[a] OCOPh	Calcd, % C	H	N	Found, % C	H	N
5-OCH_3	83–84	1710	84.75	5.43	4.44	64.97	5.52	4.64
5-CH_3	108–109	1725	68.21	5.73	4.68	68.27	5.80	4.83
5-H	99–101	1725	67.36	5.30	4.91	67.61	5.27	5.07
5-Cl	132–134	1725	60.10	4.41	4.38	60.33	4.39	4.57
5-CF_3	110–111	1725	57.79	3.99	3.97	57.76	3.82	3.94
6-OCH_3	100–101	1717	70.23	7.78	3.28	70.37	7.91	3.43
6-CH_3	120–121	1716	72.96	8.08	3.40	73.14	8.14	3.25
6-H	126–127	1718	72.51	7.86	3.52	76.62	7.83	3.38
6-Cl	167	1719	66.73	7.00	3.24	66.77	7.00	3.45
6-CF_3	139–140	1721	64.50	6.50	3.01	64.62	6.72	2.92
7-OCH_3	115–116	1718	69.15	7.32	3.51	69.18	7.55	3.67
7-CH_3	131–132	1717	72.51	7.86	3.52	72.38	7.90	3.41
7-H	154–155	1719	72.03	7.62	3.65	72.13	7.64	3.65
7-Cl	147–148	1720	66.10	6.75	3.35	66.15	6.79	3.45
7-CF_3	134	1722	63.84	6.25	3.10	64.07	6.42	3.00
8-OCH_3	165–166	1723	69.15	7.32	3.51	69.18	7.55	3.67
8-CH_3	173–174	1723	72.03	7.62	3.65	72.07	7.46	3.95
8-H	163–164	1724	71.52	7.37	3.79	71.69	7.35	3.92
8-Cl	184–185	1723	65.42	6.49	3.47	65.31	6.61	3.49
8-CF_3	192–193	1725	63.15	5.99	3.20	62.94	6.28	3.16
9	116–117	1713	68.03	8.71	4.18	67.91	8.82	4.26
10	119–120	1716	67.26	8.47	4.36	67.36	8.50	4.44
11	101–102	1715	66.42	8.20	4.56	66.49	8.19	4.63

[a] Taken with a Hitachi DS-403-G spectrometer using 0.25-mm cell.

overnight at room temperature. The reaction mixture was poured into ice–water and extracted with ether. The ether layer was washed with dilute aqueous potassium bicarbonate, dried, and evaporated.

Purification by thin layer chromatography on Kieselgel GF_{254} nach Stahl (Merck) using a 1:1 solvent mixture of chloroform and carbon tetrachloride followed by recrystallization gave **6**-OCH_3 in 33% yield (recrystallized from petroleum ether–ether), **6**-CH_3 in 36% (90% acetone), **6**-H in 54% (petroleum ether–ether), **6**-Cl in 27% (ether), **6**-CF_3 in 13% (*n*-pentane), **7**-OCH_3 in 28% (petroleum ether–ether), **7**-CH_3 in 48% (90% acetone), **7**-H in 43% (petroleum ether–ether), **7**-Cl in 40% (petroleum ether–ether), **7**-CF_3 in 25% (petroleum ether–ether), **8**-OCH_3 in 50% (petroleum ether–ether), **8**-CH_3 in 56% (petroleum ether–ether), **8**-H in 60% (peteroleum ether–ether), **8**-Cl in 45% (ethylene dichloride–ethanol), and **8**-CF_3 in 39% (ethylene dichloride–ethanol).

General Comments on the Preparation of Dineopentyl-, *tert*-Butylneopentyl- and Di-*tert*-butylmethylcarbinyl *p*-Nitrobenzoates (9, 10, and 11). A solution of methyllithium (12.3 mmol) in 10 ml of ether was added to a stirred solution of the corresponding ketone (12.3 mmol) in 10 ml of ether under nitrogen atmosphere at −20°. After 10 min of stirring at the same temperature, a solution of *p*-nitrobenzoyl chloride (12.3 mmol) in 20 ml of ether was added to the alkoxide solution, and the mixture was allowed to stand overnight at room temperature. The ether layer was washed with dilute aqueous potassium bicarbonate and evaporated. Recrystallization from *n*-pentane–ether gave **9** (51% yield), **10** (66%), and **11** (46%).

Olefinic Products. Thermolysis was found to produce the same kinds of hydrocarbons as those obtained from the solvolyses and to be more convenient for the preparation of authentic samples. Thus, the *p*-nitrobenzoates (**6**-H, **7**-H, and **8**-H) were decomposed by heating at about 200° under nitrogen in a sealed tube. The oily material obtained was extracted with petroleum ether and the organic solution was washed with dilute aqueous sodium hydroxide, dried, and evaporated. Vpc separation gave the olefins and the cyclopropane derivative.

2-*tert*-Butyl-1-neopentylstyrene (vinyl hydrogen cis to phenyl) (12) was found to have mp 34–35°; uv max (95% C_2H_5OH) 237 mμ (ϵ 12,000); nmr (CCl_4) δ 0.73 (s, 9, *t*-Bu), 1.20 (s, 9, *t*-Bu), 2.62 (broad s, 2, CH_2), 5.37 (broad s, 1, vinyl), and 7.12 (almost s, 5, aromatic); mass spectrum (70 eV) *m/e* 230.

Anal. Calcd for $C_{17}H_{26}$: C, 88.62; H, 11.38. Found: C, 88.53; H, 11.19

2-*tert*-Butyl-1-neopentylstyrene (vinyl hydrogen trans to phenyl) (13) was obtained as an oil: n^{24}D 1.4901; uv max (95% C_2H_5OH) 230 mμ (ϵ 7000); nmr (CCl_4) δ 0.77 (s, 9, *t*-Bu), 0.87 (s, 9, *t*-Bu), 2.22 (d, 2, $J \simeq$ 1 Hz, CH_2), 5.37 (t, 1, $J \simeq$ 1 Hz, vinyl), and 7.12 (5, aromatic); mass spectrum (70 eV) *m/e* 230.

Anal. Calcd for $C_{17}H_{26}$: C, 88.62; H, 11.38. Found: C, 88.35; H, 11.42.

1,2-Di-*tert*-butylstyrene (15) was found to have mp 41–42°; uv max (95% C_2H_5OH) 242 mμ (ϵ 203), 253.5 (229), 259 (253), and 265.5 (189); nmr (CCl_4) δ 0.75 (s, 9, *t*-Bu), 1.02 (s, 9, *t*-Bu), 5.48 (s, 1, vinyl), and 7.3–6.8 (5, aromatic); mass spectrum (70 eV) *m/e* 216.

Anal. Calcd for $C_{16}H_{24}$: C, 88.82; H, 11.18. Found: C, 88.92; H, 11.28.

3-Phenyl-2,3,4,4-tetramethylpentene-1 (17) was obtained as an oil: uv max (95% C_2H_5OH) 243 mμ (ϵ 107), 248 (140), 253 (190), 258.5 (230), and 265 (168); nmr (CCl_4) δ 1.03 (s, 9, *t*-Bu), 1.47 (s, 3, CH_3), 1.48 (d, 3, $J \simeq$ 2 Hz, CH_3), 5.04 (quintet, 1, $J \simeq$ 2 Hz, vinyl), 5.22 (d, 1, $J \simeq$ 2 Hz, vinyl), and 7.0–7.2 (5, aromatic); mass spectrum (70 eV) *m/e* 202.

Anal. Calcd for $C_{15}H_{22}$: C, 89.04; H, 10.96. Found: C, 89.19; H, 10.90.

1-*tert*-Butyl-2,2-dimethyl-1-phenylcyclopropane (18) was obtained as an oil: uv max (95% C_2H_5OH) 250 mμ (ϵ 156), 255 (196), 260.5 (224), and 267 (160); nmr (CCl_4) δ 0.62 (d, 1, J = 5 Hz, cyclopropyl methylene), 0.99 (d, 1, J = 5 Hz, cyclopropyl methylene), 0.70 (s, 3, CH_3), 0.93 (s, 9, *t*-Bu), 1.43 (s, 3, CH_3), and 7.0–7.1 (5, aromatic); mass spectrum (70 eV) *m/e* 202.

Anal. Calcd for $C_{15}H_{22}$: C, 89.04; H, 10.96. Found: C, 89.17; H, 10.93.

Hydrogenation of the olefins was carried out with 5% Pd–C in ethanol to give the following hydrocarbons.

3-Phenyl-2,2,3,4-tetramethylpentane (19) was obtained as an oil: n^{24}D 1.5118; nmr (CCl_4) δ 0.83 (s, 9, *t*-Bu), 0.55 (d, 3, J = 6.5 Hz, CH_3), 1.15 (d, 3, J = 6.5 Hz, CH_3), 1.22 (s, 3, CH_3), 2.70 (quintet, 1, J = 6.5 Hz, CH), and 7.0–7.2 (5, aromatic).

Anal. Calcd for $C_{15}H_{24}$: C, 88.16; H, 11.84. Found: C, 87.96; H, 11.99.

4-Phenyl-2,2,6,6-tetramethylheptane was obtained from **12** and **13** as an oil: n^{24}D 1.4780; nmr (CCl_4) δ 0.75 (s, 18, two *t*-Bu), 1.2–1.9 (AA′BB′ part of AA′BB′X system, 4, two CH_2), 2.8 (m, 1, CH), and 7.10 (5, aromatic).

Anal. Calcd for $C_{17}H_{28}$: C, 87.86; H, 12.14. Found: C, 87.82; H, 12.04.

3-Phenyl-2,2,5,5-tetramethylhexane was obtained from **15** as an oil: n^{24}D 1.4825; nmr (CCl_4) δ 0.70 (s, 9, *t*-Bu), 0.83 (s, 9, *t*-Bu), 1.63–1.98 (AB part of ABC system, 2, CH_2), 2.15–2.67 (C part of ABC, 1, CH), 7.10 (5, aromatic).

Anal. Calcd for $C_{16}H_{26}$: C, 88.00; H, 12.00. Found: C, 87.84; H, 12.05.

Kinetic Experiments. A solution of the ester in 70% aqueous acetone ($6.5 \times 10^{-4} \sim 7.5 \times 10^{-4}$ *M*) was prepared at 25° and aliquots (5 ml) were distributed into tubes which were sealed under nitrogen after a degassing routine involving evacuation during three freeze–thaw cycles using Dry Ice–acetone. The tubes were placed in the bath and were successively withdrawn after appropriate intervals of time. The contents were cooled and diluted with 20 ml of acetone to stop the reaction and the rate of acid formation was determined by potentiometric titration of the aliquots with standard 0.003 *N* aqueous sodium hydroxide. The bath temperatures were controlled to ±0.03°.

Product Studies. The hydrolysis products of **6**-H, **7**-H, **8**-OCH_3, **8**-H, and **8**-CF_3 were examined by vpc. The ester (approximately 0.04 mmol) and a reference compound (*n*-tetradecane for **6**-H, *n*-tridecane for **7**-H, and *n*-octadecane for **8**-OCH_3, **8**-H, and **8**-CF_3) were dissolved in 14 ml of acetone, and 4 ml of 0.01 *N* aqueous sodium hydroxide and 2 ml of water were added, followed by enough 70% aqueous acetone to make the total volume 50 ml at 25°. The solution was heated in a glass bomb which was sealed under nitrogen after a degassing routine involving three freeze–thaw cycles using Dry Ice–acetone. After the specified time (10–12 half-lives), the contents were concentrated, made basic with dilute sodium bicarbonate solution and extracted with pentane. The combined pentane layers were washed with water. The pentane was distilled off and the residues were subjected directly to vpc analysis.

The results from **6**-H, **7**-H, and **8**-H are presented in Chart I. Yields of the oelfins and cyclopropane derivatives corresponding to **17** and **18** were 89 and 6% for **8**-OCH_3, and 78 and 17% for **8**-CF_3.

Mechanism of Hydrolysis of Benzoyl Glucose Acylals

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Abstract: The hydrolysis of 1-β-D-glucopyranosyl benzoate (I), 2,3-di-*O*-methyl-1-β-D-glucopyranosyl benzoate (II), and α- and β-2,3,4,6-tetra-*O*-methyl-D-glucopyranosyl benzoate (III) has been studied in aqueous solution. At low and intermediate pH all three esters hydrolyze *via* spontaneous and acid-catalyzed paths (78°). The acid-catalyzed reaction has been characterized as an A-1 process proceeding through a glycosyl oxocarbonium ion. The data available are consistent with an SN1 mechanism for the spontaneous hydrolysis. At high pH (30°) multiphasic kinetics were observed for the hydrolysis of I and II. The multiphasic kinetics were interpreted in terms of HO^- catalyzed O → O benzoyl migration in competition with HO^- catalyzed hydrolysis (Schemes III and IV). For I, O → O benzoyl migration may occur from C_1 to C_2–OH and C_6–OH while for II acyl migration may only occur to C_6–OH. In the hydrolysis of IIIa,b where O → O benzoyl migration is not possible, multiphasic kinetics are not observed and hydrolysis is first order in [HO^-]. Hydrazinolysis of II and III is both nucleophilic and self general-base catalyzed nucleophilic in nature. When hydrazine serves as a nucleophile, O → O benzoyl group migration cannot compete with the displacement of the benzoyl group and multiphasic kinetics are not observed.

A number of enzyme-catalyzed glycosyl transfer reactions have been suggested to involve glycosyl enzyme intermediates in which the anomeric carbon of the glycosyl moiety is covalently linked to a carboxyl group (a glycosyl acylal).[2] A case in point is *E. coli* β-galactosidase.[3,4] The magnitude of the secondary α-deuterium kinetic isotope effects for hydrolysis and methanolysis of the galactosyl enzyme has been interpreted[5] in terms of an acylal in equilibrium with a minor mole fraction of an ion pair of carboxyl anion and sugar oxocarbonium ion. In the Phillips[6] mechanism for lysozyme, the carboxyl group of Asp-52 has been suggested to electrostatically stabilize a glycosyl oxocarbonium ion intermediate. A more reasonable alternative would involve formation of an acylal with Asp-52 which is in spontaneous equilibrium with a steady-state concentration of oxocarbonium ion.[7] Voet and Abeles isolated, by protein modification and denaturation, a covalent β-glucose–enzyme intermediate from sucrose phosphorylase.[8] Though the mode of covalent linkage of the glucosyl moiety was not shown, an acylal was considered. In the hydrolysis of the denatured glucosyl enzyme multiphasic kinetics were observed for glucose release. It occurred to us that multiphasic kinetics would be unique to the hydrolysis of a glycosyl acylal intermediate since the acyl group can transfer not only to solvent, but intramolecularly to the 2- and possibly the 5-hydroxyl groups of the glucose ring. Outside the COOH group there are no enzyme functional groups which, when bonded to the C_1 of a sugar, could migrate to other positions. Facile O → O acyl shifts of this nature are known in the hydrolysis of glycerol β-monoacetate[9] and pose a problem in the identification of the position of acylation in amino acyl RNA.[10] These considerations suggest that identification of the mode of attachment of a glycosyl moiety of a (denatured) glycosyl enzyme might be made on the basis of the kinetics of its hydrolysis.

We report herein the results of our study of the mechanism of hydrolysis of 1-β-D-glucopyranosyl benzoate (I), 2,3-di-*O*-methyl-β-D-glucopyranosyl benzoate (II), and α- and β-2,3,4,6-tetra-*O*-methyl-D-glucopyranosyl benzoate (III). In previous studies, Fletcher and coworkers[11] prepared and examined the hydrolysis of several α-monosaccharide acylals. These studies were

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(2) See B. Capon, *Chem. Rev.*, **69**, 407 (1969), for a pertinent review of the literature.

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