[CONTRIBUTION FROM THE CONVERSE MEMORIAL LABORATORY OF HARVARD UNIVERSITY]

Highly Branched Molecules. IV.[1] Solvolysis of the *p*-Nitrobenzoate of Tri-*t*-butylcarbinol and Some of its Homologs

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The *p*-nitrobenzoates of the highly branched alcohols from triisopropylcarbinol to tri-*t*-butylcarbinol react in aqueous dioxane solutions near neutrality at rates independent of the hydroxyl ion concentration to yield olefins as the sole products of the reaction. In the case of the tri-*t*-butylcarbinol ester the product has been shown to be 3,3,4,4-tetramethyl-2-*t*-butylpentene-1 (V) by degradation to *t*-butyl triptyl ketone and comparison with synthetically prepared material. A chemical and spectroscopic study suggests the structures shown in Table II for the olefins from other members of the series. The effect of high branching, which tends to spread the C–C–C bond angle, and of small or strained ring formation, which forces a contraction of this angle, upon the infrared stretching frequency of the carbonyl group and of the methylene group is observed and interpreted. The rates and activation parameters of reaction of these *p*-nitrobenzoates in aqueous dioxane are reported in Tables IV and V. Although the ester with the most crowded molecular structure reacts the fastest, there is not a simple or regular variation in rate with degree of branching.

Introduction.—In Part II of this series, it was shown that the highly branched carbinols from triisopropylcarbinol to tri-*t*-butylcarbinol were converted by concentrated hydrochloric acid into mixtures of various numbers of chlorides, all of which reacted in aqueous acetone solutions at first-order rates from 5 to 50,000 times that of *t*-butyl chloride. It was not possible to establish the structures of any of these chlorides because of the prevalence of molecular rearrangements in the series and because no chloride could be converted into a derivative which revealed its structure. In Part III it was shown that the *p*-nitrobenzoate of tri-*t*-butylcarbinol, which could be prepared from the carbinol by an unambiguous method, underwent solvolysis with the entire *p*-nitrobenzoate group coming off as an anion, and this provided a series of derivatives of the highly branched carbinols having known structures and directly observable rates of solvolysis. The present work is divided into two parts: first, the identification of the reaction product of tri-*t*-butylcarbinyl *p*-nitrobenzoate in a hydroxylic solvent, and second, the establishment of the comparative reaction rates of the *p*-nitrobenzoates of the alcohols from triisopropylcarbinol to tri-*t*-butylcarbinol.

The *p*-Nitrobenzoates.—The four *p*-nitrobenzoates of tertiary carbinols in Table I were prepared as described in Part III. The lithium alkyls were prepared in ethyl ether at −40 to −50° and allowed to react with the appropriate ketone at −60 to −70°. The resulting lithium alkoxide was brought directly into reaction with *p*-nitrobenzoyl chloride, affording the esters in 25 to 40% yield, based on ketone. A small amount of secondary alcohol ester, which was difficult to separate from the desired product, was obtained in some cases. In purifying the products, the small amounts of *p*-nitrobenzoic acid were removed by stirring a warm petroleum ether solution of the ester with alumina, then separating and recrystallizing several times. It was possible also to effect purification by chromatography on alumina.

TABLE I

MELTING BEHAVIOR OF *p*-NITROBENZOATES OF HIGHLY BRANCHED ALCOHOLS, $R_1R_2R_3COOCC_6H_4NO_2$-*p*

R_1	R_2	R_3	Temperature, °C. M.p.	Dec.	Remelt
t-Bu	*t*-Bu	*t*-Bu	105–106	108	238–240
i-Pr	*t*-Bu	*t*-Bu	103–104	119	241–242
t-Bu	*i*-Pr	*i*-Pr	94–95	121	241–242
i-Pr	*i*-Pr	*i*-Pr	77–78	127	241–242

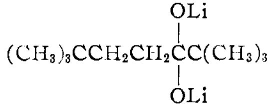
The four compounds had in common a characteristic behavior on melting. Each ester melts sharply to a clear liquid, then crystallizes very rapidly with the formation of long sharp needles at a characteristic temperature (T_{dec}) and finally remelts at 240 ± 2°. Apparently the decomposition yields *p*-nitrobenzoic acid, m.p. 242°, and hydrocarbon products which distil from the capillary below 240° to leave behind the relatively pure acid. Table I shows the melting properties of the four *p*-nitrobenzoates based upon a constant heating rate of approximately 2° per minute.

Hexamethylacetone used as a starting point for the preparation of tri-*t*-butylcarbinol was prepared for the most part by the direct carbonation of *t*-butyllithium at temperatures of −35 to −40°. Even at these temperatures the solvent ether is attacked, yielding 14 to 21% of *t*-butyl neohexyl ketone. This product results from the sequence of reactions[3]

$$(CH_3)_3CLi + (C_2H_5)_2O \longrightarrow (CH_3)_3CH + C_2H_5OLi + CH_2{=}CH_2$$

$$(CH_3)_3CLi + CH_2{=}CH_2 \longrightarrow (CH_3)_3CCH_2CH_2Li$$

$$(CH_3)_3CCH_2CH_2Li + (CH_3)_3CLi + CO_2 \longrightarrow$$



$$(CH_3)_3CCH_2CH_2\underset{\displaystyle OLi}{\overset{\displaystyle OLi}{C}}C(CH_3)_3$$

An attempt to diminish the formation of this by-product by increasing the rate of carbon dioxide addition resulted in an increased yield of acid and a decreased yield of hexamethylacetone. Even with yields of the latter around 30%, the procedure proved advantageous because of its simplicity and the relatively short time required from *t*-butyl chloride to hexamethylacetone.

The proof of structure of the *t*-butyl neohexyl ketone provides a further example of a known type of abnormal Beckmann rearrangement. The treatment of 6 g. of the oxime of this ketone with phos-

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[1] Part III of this series, P. D. Bartlett and E. B. Lefferts, THIS JOURNAL, **77**, 2804 (1955).

[2] From the Ph.D. thesis of Martin Stiles, Harvard University, 1953.

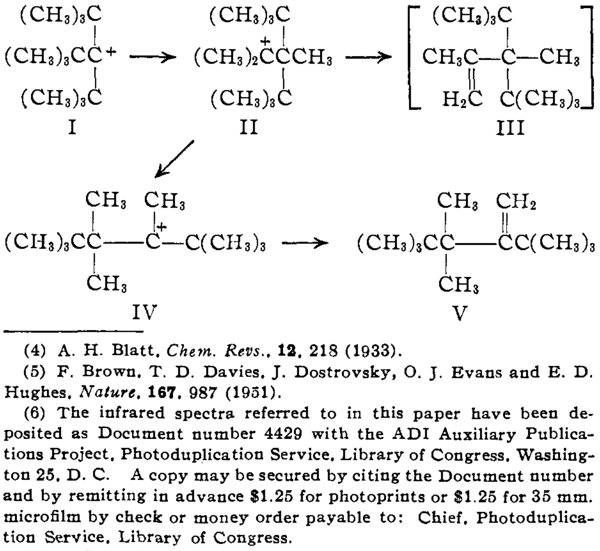
[3] P. D. Bartlett, S. Friedman and M. Stiles, THIS JOURNAL, **75**, 1771 (1953).

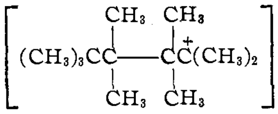
phorus pentachloride in ether yielded 3.3 g. of a liquid nitrile in a vigorous reaction. The nitrile could be hydrolyzed to ammonia and neopentylacetic acid (anilide m.p. 139–140°, mixed m.p. undepressed) in 78% yield. The infrared spectrum of the nitrile showed no trace of an amide function. Since the analysis of the oxime indicated the ketone to be definitely a $C_{11}H_{22}O$ compound, a *t*-butyl group must have been lost, probably as isobutylene or perhaps as *t*-butyl chloride. This course for the Beckmann rearrangement is analogous to that observed in camphor oxime.[4]

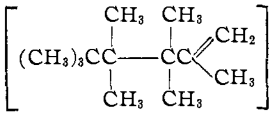
The Olefin from Tri-*t*-butylcarbinyl *p*-Nitrobenzoate.—The *p*-nitrobenzoate of tri-*t*-butylcarbinol was dissolved in 2:1 dioxane–water at 40° and the solution kept neutral by periodic additions of sodium hydroxide solution over a period of 48 hours as was done in the measurements of the solvolysis rate. From such runs both at 40 and 80–90° a solid hydrocarbon, $C_{13}H_{26}$(olefin A), m.p. 135–138° (sealed tube), was isolated in 80–85% yields. No other product was obtained and it seems reasonable to assume that the 15–20% unaccounted for represents loss by evaporation of this quite volatile product during the evaporation of the large amounts of solvent. Alternatively there may have been fragmentation of the alkyl residue to the extent of 15–20%.[5]

Olefin A was a volatile wax-like solid with well-defined infrared absorption bands at 6.17 and at 11.18 μ, characteristic of a terminal double bond.[6,7,8]

The formation of an olefin from tri-*t*-butylcarbinyl *p*-nitrobenzoate obviously requires at least one molecular rearrangement. The only possible rearrangement of conventional type involves the migration of one of the nine methyl groups from the β-carbon atom to the α in the tri-*t*-butylcarbonium ion (I), yielding a new carbonium ion (II) which can lead to an olefin of structure III. As soon as this first shift has taken place, the way is open for migration of a *t*-butyl group from the β- to the α-position in the new carbonium ion resulting in IV which opens the way to an olefin of structure V. Still a further shift of the methyl group might lead through VI to the olefin of structure VII. The following evidence indicates that olefin A has structure V.




VI


VII

Four methods of fractionation all failed to separate olefin A into fractions having significantly different properties. The methods tried included a fractional distillation through a 40-cm. glass-packed column, (b) fractional sublimation at 1 mm. pressure at 40°, (c) repeated recrystallization from methanol at low temperatures, and (d) chromatography on alumina in petroleum ether solution. In each case the material in all fractions possessed identical infrared spectra and melting points.

Olefin A was recovered unchanged in 90% yield after 14 hours of refluxing with strong aqueous alkaline permanganate; no manganese dioxide was detected.

Olefin A decolorized a solution of bromine in carbon tetrachloride at 0° with evolution of hydrogen bromide. The product was a dark lachrymatory oil which did not crystallize. The olefin was hydrogenated in acetic acid over Adams catalyst to a paraffin, m.p. 116–118° (sealed tube), which showed no bands in the infrared spectrum assignable to unsaturation.

Perbenzoic acid at 0° in three days gave a 65% yield of a solid epoxide, m.p. 166–168° (sealed tube), which could not be hydrated to a diol, but which was converted by sulfuric or periodic acid in dioxane–water solution into a compound yielding a positive Schiff test and a carbonyl peak in the infrared. In this respect the epoxide resembles that of 1,1-dineopentylethylene which is also strongly resistant to permanganate.[9] The ozonization of olefin A in dry ethyl acetate at −20° gave a mixture which upon chromatography yielded the same epoxide in about 50% yield. The crude ozonization product did not absorb hydrogen over a palladium catalyst. The direct production of an epoxide in ozonization also has been observed before in highly hindered compounds. Backer[10] obtained an epoxide, $C_{12}H_{24}O$, from the ozonization of an olefin obtained by partially hydrogenating 2,3-di-*t*-butylbutadiene.

In another hindered terminal olefin, camphene, it has been shown recently by Hickinbottom and Wood[11] that an epoxide is the initial product of attack of chromic acid and that this epoxide rearranges under the reaction conditions to camphenilane aldehyde, the usual product of the chromic acid oxidation of camphene.[12]

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[4] A. H. Blatt, *Chem. Revs.*, **12**, 218 (1933).

[5] F. Brown, T. D. Davies, J. Dostrovsky, O. J. Evans and E. D. Hughes, *Nature*, **167**, 987 (1951).

[6] The infrared spectra referred to in this paper have been deposited as Document number 4429 with the ADI Auxiliary Publications Project, Photoduplication Service, Library of Congress, Washington 25, D. C. A copy may be secured by citing the Document number and by remitting in advance $1.25 for photoprints or $1.25 for 35 mm. microfilm by check or money order payable to: Chief, Photoduplication Service, Library of Congress.

[7] H. L. McMurry and V. Thornton, *Anal. Chem.*, **24**, 318 (1952).

[8] R. S. Rasmussen and R. R. Brattain, *J. Chem. Phys.*, **15**, 120, 131 (1947); R. S Rasmussen, R. R. Brattain and P. S. Zucko, *ibid.*, **15**, 135 (1947); N. Sheppard and G. B. B. M. Sutherland, *Proc. Roy. Soc.* (*London*), **A196**, 195 (1949).

[9] P. D. Bartlett, G. L. Fraser and R. B. Woodward, THIS JOURNAL, **63**, 495 (1941).

[10] J. J. Backer, *Chem. Weekblad*, **36**, 214 (1939).

[11] W. J. Hickinbottom and D. G. M. Wood, *J. Chem. Soc.*, 1906 (1953).

[12] W. Hückel and K. Hartmann, *Ber.*, **70**, 969 (1937).

Olefin A reacted with osmium tetroxide in ether solution over a period of four weeks to produce an approximately 5% yield of a glycol. This glycol was non-crystalline and was identified by its infrared spectrum, by its formation of a solid compound with osmium tetroxide, and by the fact that it reacted with periodic acid to yield *t*-butyl triptyl ketone.[5] Accompanying the glycol was a smaller amount of another hydroxyl compound which also reacted with periodic acid. This substance was obtained in insufficient quantity for further investigation. After four more weeks a similar yield of glycol was produced, this time with no contamination by the second hydroxylic substance. Upon removing osmium compounds from the mother liquors, there was recovered 86% of the starting material with unchanged melting point. The infrared spectrum of the recovered material was not significantly different from that of olefin A.

The synthesis of *t*-butyl triptyl ketone and the identity of the infrared spectrum of the synthetic material with that of the substance obtained by degradation of olefin A completed the establishment of the structure of olefin A as 3,3,4,4-tetramethyl-2-*t*-butyl-1-pentene (V).

Subsequent attempts to prepare larger amounts of the glycol failed altogether. The significant difference between these and the earlier successful preparations was apparently the difference between an old sample of osmium tetroxide obtained from Merck at Darmstadt many years ago and the newer material with which the later experiments were tried. Suspecting that the older osmium tetroxide might have been active by virtue of some other material accompanying it, we tried a reaction between ruthenium tetroxide and olefin A.[13] This reaction led only to a liquid whose infrared spectrum showed neither hydroxyl nor carbonyl absorption. The examination of this compound was postponed until later.

Despite the low yields in which the glycol has been obtained from olefin A it would be difficult to support the conclusion that the glycol was the reaction product of only a minor component of the olefin. The identity of the infrared spectra before and after formation and removal of the glycol and the identity of the melting point of olefin A before and after argues strongly against such a view. The molal freezing point lowering constant of tri-*t*-butylcarbinol is 74° per mole per 1000 g.,[1] but the molal freezing point depression constant of olefin A would have to be not over 5° per mole per 1000 g. in order to account for the observed constancy of the melting point on removal of 10 mole % of an impurity.

The infrared spectrum of olefin A and that of the paraffin obtained from its hydrogenation support a generalization of McMurry and Thornton that an absorption peak at 7.10 to 7.13 μ is to be correlated with the presence of the triptyl group. Triptane, ethyltriptane, isopropyltriptane and *n*-propyltriptane[14] have peaks at 7.14, 7.13, 7.11 and 7.13, respectively. Olefin A, its saturation product and olefin B (see below) all have small but distinct peaks at 7.11. Methyl triptyl ketone absorbs at 7.11, *t*-butyl triptyl ketone at 7.13, and the epoxide from olefin A has a peak at 7.12. Such a peak is not found in any of numerous compounds not possessing the triptyl group. Among the known compounds possessing the triptyl group, only 2,2,3,3-tetramethylbutane fails to show the peak at 7.11 to 7.14 and the disappearance of bands from the infrared spectrum is not surprising in highly symmetrical compounds.

Synthesis of *t*-Butyl Triptyl Ketone.—Hexamethyl-3-hexanone (*t*-butyl triptyl ketone) was synthesized by the series of reactions outlined on the flow sheet. The key starting material, dimethyl-*t*-butylacetic acid, was prepared in less than 10% yield by the carbonation of triptylmagnesium chloride. A better method was based upon the interesting rearrangement of hexamethylacetone described by Barton, Morton and Porter.[15] We found that by omitting the benzene and simply dissolving hexamethylacetone in concentrated sulfuric acid, the product after eight hours contained at least 60% methyl triptyl ketone. The slow reaction of this ketone with sodium hypochlorite could be made to produce 75–80% yields of dimethyl-*t*-butylacetic acid by making the mixture strongly alkaline toward the end of the reaction, since the cleavage of trichloromethyl triptyl ketone is the slow and hindered step in the process. In order to rule out the possibility of rearrangement during the oxidation of *t*-butyltriptylcarbinol to *t*-butyl triptyl ketone, the ketone was reconverted to the carbinol with lithium aluminum hydride in nearly quantitative yields. A comparison of the infrared spectra of the ketones from synthesis and from degradation of olefin A indicates the identity of the samples.

t-Butyl triptyl ketone was reported previously by Favorskiĭ and Nazarov.[16] They described its isolation from the reaction of pinacolone with metallic sodium followed by pinacol rearrangement. When this work was repeated, the only ketone obtained[17] from this reaction was an isomeric one, 2,2,5,6,6-pentamethylheptane-3-one, resulting from reductive aldolization.

Olefin B from Di-*t*-butylisopropylcarbinyl *p*-Nitrobenzoate.—From the solvolysis of this ester there was obtained after distillation from a 20-cm. glass-packed column an 83% yield of a hydrocarbon, olefin B, b.p. 101–103° at 40 mm., $n^{27}\text{D}$ 1.4570. Three fractions into which the distillate was arbitrarily divided all exhibited the same infrared spectrum. Olefin B, like olefin A, did not decolorize potassium permanganate in acetone solution. It reacted slowly with perbenzoic acid in benzene solution. After 86 hours at 0°, a liquid epoxide was obtained in 81% yield. The action of ozone in ethyl acetate at 0° gave a mixture consisting chiefly of the epoxide, but containing an appreciable amount of a carbonyl compound with

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(13) C. Djerassi and R. E. Engle, THIS JOURNAL, **75**, 3838 (1953).

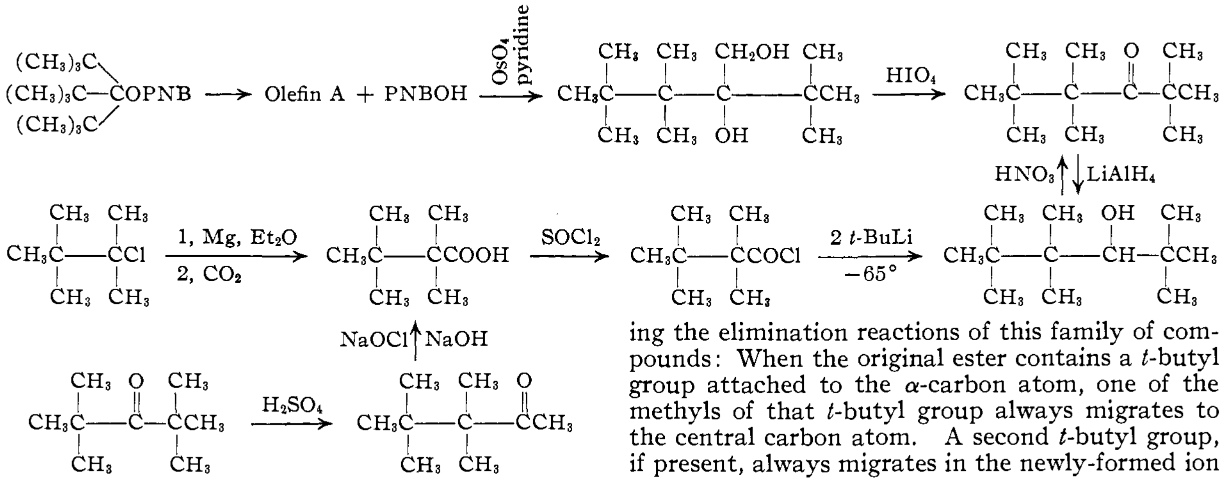
(14) American Petroleum Institute Research Project 44, National Bureau of Standards "Catalog of Infrared Spectra," Vols. 1-5.

(15) S. Barton, F. Morton and C. R. Porter, *Nature*, **169**, 373 (1952).

(16) A. E. Favorskiĭ and I. N. Nazarov, *Bull. soc. chim.*, [5] **1**, 46 (1934); *Compt. rend.*, **196**, 1229 (1933); *Bull. acad. sci. URSS, Classe sci. math. nat.*, 1309 (1933); *C. A.*, **28**, 2674 (1934); I. N. Nazarov, *Ann. Leningrad. State Univ. Chem. Ser.*, **1**, 123 (1935); *C. A.*, **31**, 6617 (1937).

(17) P. D. Bartlett, M. Roha and M. Stiles, THIS JOURNAL, **76**, 2349 (1954).

FLOW SHEET



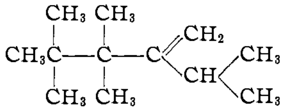
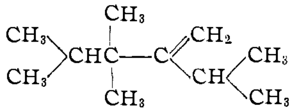
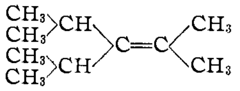
its infrared absorption peak at 5.92 μ. These compounds could not be separated by chromatography. Olefin B was recovered unchanged after treatment with osmium tetroxide and pyridine in ether at room temperature for three weeks.

Similar olefins, C and D, were obtained from the *p*-nitrobenzoates of *t*-butyldiisopropylcarbinol and triisopropylcarbinol, respectively. They were not purified further.

Infrared absorption spectra of olefins A, B, C and D allow certain conclusions to be drawn concerning the probable structures of the last three. In each case elimination of *p*-nitrobenzoic acid was possible without molecular rearrangement. Such elimination would, however, lead to tetrasubstituted ethylenes, a type of structure in which the double bond usually is not detectable from the infrared spectrum. In general, however, a 1,1-disubstituted ethylene is recognized easily by the characteristic bands in the 6.1 and 11.2 μ regions.[7,8] Such structures can arise from the esters used here only by molecular rearrangement. Olefins A, B, C and D all exhibit absorption in the regions characteristic of a 1,1-disubstituted ethylene. In olefin D, however, the intensity of each absorption is substantially reduced, that at 11.2 μ being only one-fifth as intense as in olefins B and C. This would be expected if a large part of the elimination product from the triisopropylcarbinyl ester is unrearranged. Roberts and Young[18] found that the dehydration product of triisopropylcarbinol over copper sulfate was a mixture which gave diisopropyl ketone and acetone upon ozonization as well as some formaldehyde, and accordingly contained unrearranged as well as rearranged olefins. The comparison of our four olefins suggests that elimination without molecular rearrangement does not become important in any of our esters except that of triisopropylcarbinol.

The spectra of olefins A and B show the "triptyl" peak at 7.11 μ as a nick on the side of a more intense absorption band. Olefins C and D lack this peak. If the presence of the peak indeed indicates the triptyl grouping in the compound, then we can formulate a simple general rule governing the elimination reactions of this family of compounds: When the original ester contains a *t*-butyl group attached to the α-carbon atom, one of the methyls of that *t*-butyl group always migrates to the central carbon atom. A second *t*-butyl group, if present, always migrates in the newly-formed ion to produce a triptyl compound. Thus we arrive at the following most probable structures for the elimination products of the highly branched esters.

TABLE II

Carbinol	Olefin	Probable structure
Tri-*t*-butyl-	A	V
Di-*t*-butyl-isopropyl-	B	
t-Butyldi-isopropyl-	C	
Triisopropyl-	D	

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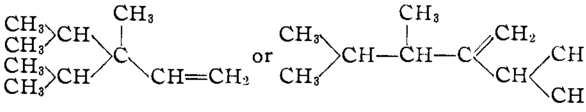

The Infrared Spectra of Branched Ketones.—The carbonyl stretching band in the infrared spectra of hexamethylacetone and *t*-butyl triptyl ketone occurs at a higher wave length than in previously reported saturated ketones. Table III notes the wave lengths of the carbonyl stretching frequencies observed in these and certain other branched and bicyclic ketones. These spectra were observed on 2.5% carbon tetrachloride solutions of the compounds, using the Baird model B infrared spectrometer. All the observations were made during a single two-hour period and the instrument was calibrated with a polystyrene standard film. The

TABLE III

WAVE LENGTH OF ABSORPTION PEAK DUE TO C=O STRETCHING (μ)

Cyclobutanone	5.63	Cyclohexanone	5.84
Cyclopentanone	5.74	Pinacolone	5.86
Camphor	5.78	Hexamethylacetone	5.93
Fenchone	5.78	*t*-Butyl triptyl ketone	5.97
"Normal acyclic ketones"	5.81–5.84		

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[18] W. G. Young and J. D. Roberts, THIS JOURNAL, **66**, 1444 (1944).

wave length values obtained in this manner are accurate to 0.01 μ. For comparison the values for cyclobutanone, cyclopentanone and cyclohexanone are included from a recently published summary.[19]

In general the carbon–oxygen stretching frequency is increased in those cyclic ketones in which the C–C–C angle is forced to be less than the 120° required for complete sp^2 hybridization and decreased in branched acyclic ketones where mutual repulsion between the hydrocarbon groups tends to spread the C–C–C bond angle. The results are consistent with the general view that an increase in the p character of the C–C bonds should be attended by an increase in s character and hence in force constant of the C–O bond.

The methylene stretching frequency in hydrocarbons A, B, C and D appears at 6.17, 6.12, 6.10 and 6.08 μ, respectively. This is consistent with the assigned structures in which the double bond is in a position sensitive to the bulk of the saturated groups attached to one end of the double bond and this bulk decreases from olefin A to olefin D.

Kinetics of Reaction of the *p*-Nitrobenzoates.— The rates of reaction of the four esters were measured in 60% dioxane–40% water by weight, the ionic strength being maintained at 0.10 *M* by the addition of sodium perchlorate. The method of Peters and Walker[20] was used for some runs, but was abandoned in favor of an aliquot method in which the end-points were easier to observe. The two methods agreed when applied to the same compound under the same conditions. In the aliquot method, 25-ml. portions of reacting solution were pipetted at intervals into 60 ml. of cold water to precipitate the ester. The acid was then titrated with standard base to a phenolphthalein end-point. Rate measurements were made at 40 and 60° for all four esters and at 28.1° for all but the triisopropylcarbinyl ester which solvolyzed too slowly for convenient measurement at the lower temperature. In general the values of the rate constants agreed to within 2% for duplicate runs. The rate constants were determined graphically from a plot of $\log (V_\infty - V)$ *vs.* time, where V is the volume of base required at time t, and V_∞ the volume required after at least ten half-lives. The values of V_∞ obtained experimentally agreed satisfactorily with those calculated from the weight of ester used. Table IV summarizes the rate constants.

TABLE IV

RATE CONSTANTS OF FIRST ORDER SOLVOLYSIS IN 60 WEIGHT PER CENT. DIOXANE

p-Nitrobenzoate of	k_1, sec.$^{-1}$ × 10^6 28.1°	40.0°	50.0°
Tri-*t*-butylcarbinol	21.5	90.5	317
Di-*t*-butylisopropylcarbinol	4.92	24.2	84.2
t-Butyldiisopropylcarbinol	5.67	25	86.5
Triisopropylcarbinol		2.93	9.73

In one run in which the sodium perchlorate was omitted, the ester of tri-*t*-butylcarbinol showed a rate constant 8.17×10^{-5} sec.$^{-1}$, approximately 10% less than for runs with added salt, showing a small positive salt effect.

Table V lists the parameters of the equation $\log (k/T) = A/T + B$ calculated from these data as well as the enthalpy and entropy of activation calculated from the Eyring equation.[21]

TABLE V

ACTIVATION PARAMETERS OF *p*-NITROBENZOATES IN 60 WEIGHT PER CENT. DIOXANE

p-Nitrobenzoate of	A	B	$\Delta H\ddagger$, kcal.	$\Delta S\ddagger$, e.u.
Tri-*t*-butylcarbinol	−5115	9.81	23.4	−2.3
Di-*t*-butylisopropylcarbinol	−5320	9.88	24.4	−2.0
t-Butyldiisopropylcarbinol	−5169	9.39	23.6	−4.2
Triisopropylcarbinol	−5132	8.36	23.5	−9.0

Under the experimental conditions of the rate runs a gram of tri-*t*-butylcarbinol was allowed to stand in solution along with 0.1 g. of *p*-nitrobenzoic acid in dioxane and water at 45–50° for 40 hours, after which the carbinol was recovered unchanged to the extent of 93%. This confirms the other evidence at hand that the reaction product does not arise even in part from normal ester hydrolysis of the *p*-nitrobenzoate. The descending order of solvolysis rate constants from the *p*-nitrobenzoate of tri-*t*-butylcarbinol to that of triisopropylcarbinol is in general accord with expectations based upon the view that steric strains in starting material are being relieved in the transition state (whether through the formation of a planar classical carbonium ion or through bridging by a methyl group). However, the near equality in rate between di-*t*-butylisopropylcarbinyl *p*-nitrobenzoate and *t*-butyldiisopropylcarbinyl *p*-nitrobenzoate is somewhat puzzling. In view of the alacrity with which these compounds undergo double molecular rearrangement, we must consider the possibility of their undergoing an exceedingly rapid internal molecular rearrangement on being dissolved in a part aqueous medium (an extreme case of "internal return"[22]) and that the rates which we are observing are in each case the solvolysis and rearrangement rates of dimethylalkylcarbinyl *p*-nitrobenzoates where the successive changes in the large alkyl group do not seem as directly important as they do in the original tertiary compounds. Although one might thus plausibly shift the problem back into the unknown, no such completely internal ionic rearrangements have yet been observed and hence the suggestion lacks attractiveness. If we note that the decrease in rate from the first member of this ester series to the second is referable to a change in the activation energy, but that the decrease from the third to the fourth member of this series is referable entirely to an increased negative entropy of activation, we may realize that we are not dealing with a simple one-dimensional property of these highly branched compounds. The rates in the isopropyl compounds may well be dominated by the exact extent

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[19] F. A. Miller in Gilman, "Organic Chemistry, An Advanced Treatise," Vol. 3, John Wiley and Sons, Inc., New York, N. Y., 1953, p. 132.

[20] R. A. Peters and E. Walker, *Biochem. J.*, **17**, 260 (1923); Part 11, ref.

[21] S. Glasstone, K. J. Laidler and H. Eyring, "Theory of Rate Processes," McGraw-Hill Book Co., Inc., New York, N. Y., 1940, p. 196.

[22] W. G. Young, S. Winstein and H. L. Goering, THIS JOURNAL, **73**, 1958 (1951); W. Winstein and D. Trifan, *ibid.*, **74**, 1154 (1952); S. Winstein and K. C. Schreiber, *ibid.*, **74**, 2171 (1952).

to which rotations prohibited in the crowded ester are recovered in the first transition state for the series of reactions observed.

Drifts in the unimolecular rate constant by which internal return has been detected in a number of cases[22] were carefully sought for and found to be absent in the reactions of these compounds.

If we accept the observed reactivity series of these esters as belonging inherently to this series of highly branched molecules, then it is impossible with its aid to assign structures to the chlorides analyzed kinetically in Part II of this series. We plan to continue the investigation of structures possibly involved in the molecular rearrangements observed in this series of compounds. When such examination is complete, it may be possible to determine whether any of the chlorides prepared from these carbinols have the unrearranged structure or not.

Experimental

The *t*-butyl chloride used was dried carefully and distilled at 51.5–52.0°. The isopropyl chloride was distilled at 34.5°.

Pinacolone.—Crude pinacolone, prepared by students and kindly made available by Dr. J. Kochi, was washed with sodium bicarbonate solution, dried and distilled from a 40-cm. glass-packed column. The purified material distilled at 105°.

Pivalic Acid.—Pinacolone was oxidized with sodium hypochlorite; yield 79%, b.p. 161–162°, m.p. above 25°.

Pivalyl Chloride.—Pivalic acid (37 g., 0.36 mole) was refluxed two hours with 69 g. (0.58 mole) of thionyl chloride. After removal of the excess thionyl chloride, the product was carefully fractionated. The material used in subsequent syntheses, 27.5 g., 63%, distilled at 104–105°.

***p*-Nitrobenzoyl Chloride.**—Eastman Kodak Co. White Label material was recrystallized from carbon tetrachloride and had m.p. 72°.

Diisopropyl Ketone.—Redistilled diisopropyl ketone, Eastman Kodak practical grade, was furnished by Dr. Sidney Friedman, b.p. 123–124°.

Dioxane (tech.) was purified as described by Fieser[23]; the pure material, b.p. 101°, $n^{25}\text{D}$ 1.4201, was stored under nitrogen.

Hexamethylacetone.—Ninety-four grams (1.0 mole) of *t*-butyl chloride in 200 ml. of dry ether was added to 17 g. (2.47 moles) of lithium sand, average diameter 1–2 mm., in 500 ml. of ether, with rapid stirring at −40 to −50° over a 2-hour period. Stirring at this temperature was continued for one hour after addition was complete. Then 25 g. (0.57 mole) of carbon dioxide was added in a stream of nitrogen over an 8-hour period at −35° with rapid stirring of the solution. An additional 5 g. of carbon dioxide was allowed to enter while stirring overnight at −40 to −60°. A large excess of Dry Ice was then added and the low temperature bath was removed. The mixture was hydrolyzed with ice, neutralized with dilute sulfuric acid and the layers separated. The aqueous layer was washed twice with ether, the ether solutions combined and washed several times with sodium carbonate solution, then with water, dried over Drierite and the solvent removed. The product was distilled through a 40-cm. column packed with glass helices, the following fractions being taken

Fraction	Wt., g.	$n^{22}\text{D}$	B.p., °C.
1	4.0	1.4140	140–152
2	23.5 (33.1%)	1.4180	152–153
3	1.0	1.4220	153–160
Residue	10.0		

The alkaline extracts were acidified, extracted with ether, dried and distilled. Twenty grams (0.20 mole) of pivalic acid, b.p. 161°, was obtained. The yield of hexamethylacetone in several preparations averaged from 30–35% by this procedure. The residue was largely *t*-butyl neohexyl ketone and yielded a 2,4-dinitrophenylhydrazone melting at 130–131°.

Oxime of *t*-Butyl Neohexyl Ketone.—Ten grams of ketone was treated with 25 g. of hydroxylamine hydrochloride and 10 g. of potassium hydroxide in methanol–water on the steam-bath for 30 minutes. Upon standing overnight, 9.0 g., 83%, of white needles, m.p. 113–114°, were obtained. A recrystallization from methanol–water was essentially quantitative, m.p. 113.5–114.5°.

Anal. Calcd. for $C_{11}H_{23}ON$: C, 71.35; H, 12.54; N, 7.57. Found: C, 71.67; H, 12.54; N, 7.51.

Treatment of the Oxime with Phosphorus Pentachloride. Six grams of oxime, m.p. 113.5–114.5°, was dissolved in about 50 ml. of ether and 10 g. of phosphorus pentachloride was added in portions. After the immediate vigorous reaction, the mixture was refluxed on the steam-bath for 2 hours, ice-water was added and the layers separated. The ether solution was washed with sodium bicarbonate, then with water, dried over anhydrous sodium sulfate, and the solvent removed. There remained 3.3 g. of nearly colorless liquid whose infrared spectrum showed no absorption in the 6 μ region, but possessed a strong sharp peak at 4.5 μ characteristic of the nitrile group.

Hydrolysis of the Nitrile.—The crude nitrile, 2.3 g., was refluxed for 5 hours with 20 ml. of 50% aqueous sulfuric acid containing 0.5 g. of sodium chloride. The crude mixture was made alkaline with potassium hydroxide, the oily layer dissolved completely, and the odor of ammonia was detected. No organic material was obtained from an ether extraction of the alkaline solution. After filtering off a small amount of potassium sulfate, the aqueous solution was acidified with hydrochloric acid and extracted twice with ether. The ether solution was dried over anhydrous sodium sulfate, the solvent removed, and the residue distilled from a small distilling flask at reduced pressure. There was obtained 2.1 g. of colorless product, b.p. approximately 112° at 13 mm. with a neutral equivalent of 132 (0.0458 g. of acid required 3.56 ml. of 0.0971 *N* sodium hydroxide solution; calculated for $C_7H_{14}O_2$, neutral equivalent, 130); S-benzylthiuronium salt, m.p. 150–151°.

Anal. Calcd. for $C_{15}H_{24}O_2N_2S$: C, 60.81; H, 8.18; N, 9.46. Found: C, 60.79; H, 8.23; N, 9.66.

The amide melted at 135–136° after recrystallization from water. The literature[24] records 140–141° as the melting point of the amide of neopentylacetic acid. The anilide, after recrystallization from chloroform–petroleum ether, melted at 139–140° (literature 138–139°[25]) and a mixed melting point with a sample of neopentylacetanilide, furnished by Dr. Sidney Friedman, was undepressed. The latter sample was prepared by the reaction of neohexylmagnesium chloride with phenyl isocyanate.

Tri-*t*-butylcarbinyl *p*-nitrobenzoate was prepared as described in Part III from *t*-butyllithium, hexamethylacetone and *p*-nitrobenzoyl chloride. After recrystallization from 30–60° petroleum ether to remove the *p*-nitrobenzoate of di-*t*-butylcarbinol, the purified material melted at 105–106°, resolidified at 108° and remelted at 238–240°.

Anal. Calcd. for $C_{20}H_{31}O_4N$: C, 68.73; H, 8.96; N, 4.01. Found: C, 68.78; H, 9.04; N, 4.01.

From the crude ester before recrystallization it was possible to isolate the *p*-nitrobenzoate of di-*t*-butylcarbinol by a selective solvolysis of the tertiary ester. Thirty grams of the crude material was dissolved in 800 ml. of 80% aqueous dioxane containing 15 drops of sodium alizarin sulfonate–methylene blue indicator solution and heating under reflux while adding aqueous sodium hydroxide solution to keep the *p*H near the end-point. After three hours of refluxing, the solution was saturated with sodium chloride and the dioxane layer separated. The aqueous layer was extracted twice with 30–60° petroleum ether. The organic layers were combined and the solvent removed. The residue was taken up in petroleum ether and adsorbed on alumina. After elution of the olefin resulting from solvolysis of the tertiary ester, there was obtained 3.05 g., 10%, of the crude ester, m.p. 114–115°.

Anal. Calcd. for $C_{16}H_{23}O_4N$: C, 65.49; H, 7.90; N, 4.77. Found: C, 65.54; H, 8.01; N, 4.89.

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[23] L. F. Fieser, *Experiments in Organic Chemistry*, D. C. Heath & Co., Boston, 1941.

[24] R. S. Spindt and D. R. Stevens, U. S. Patent 2,470,876; *C. A.*, **43**, 7501 (1949); L. Cavalieri, C. B Pattison and M. Carmack, THIS JOURNAL, **67**, 1783 (1945).

[25] L. Schmerling, *ibid.*, **67**, 1152 (1945).

Hydrolysis of 1.5 g. of ester, m.p. 114–115°, with potassium hydroxide in diethylene glycol, yielded 0.5 g. of di-*t*-butylcarbinol, m.p. 46–48°; phenylurethan, m.p. 119–121°.

Triisopropylcarbinyl *p*-nitrobenzoate was prepared in a manner similar to that described for tri-*t*-butylcarbinyl *p*-nitrobenzoate. The yield was 25 g. (27%, based on ketone) of the ester, m.p. 77–78°.

Anal. Calcd. for $C_{17}H_{25}O_4N$: C, 66.54; H, 8.20; N, 4.56. Found: C, 66.47; H, 8.34; N, 4.37.

Isopropyl-di-*t*-butylcarbinyl *p*-nitrobenzoate was prepared in a yield of 31 g. (31%, based on ketone), m.p. 103–104°.

Anal. Calcd. for $C_{19}H_{29}O_4N$: C, 68.04; H, 8.72; N, 4.18. Found: C, 68.08; H, 8.83; N, 4.01.

Diisopropyl-*t*-butylcarbinyl *p*-nitrobenzoate was obtained in a yield of 30 g. (27%, based on ketone) with m.p. 94–95°.

Anal. Calcd. for $C_{18}H_{27}O_4N$: C, 67.27; H, 8.46; N, 4.35. Found: C, 67.12; H, 8.44; N, 4.24.

Solvolysis of Tri-*t*-butylcarbinyl *p*-Nitrobenzoate.—The ester (3.00 g., 0.00859 mole) was dissolved in 300 ml. of dioxane and 150 ml. of water to which 10 drops of the mixed indicator had been added. The solution was maintained at 40° for 48 hours with intermittent addition of just sufficient aqueous sodium hydroxide solution to keep the *p*H near the end-point, but never enough to make the solution alkaline. After cooling, the solution was extracted five times with 70-ml. portions of 20–40° petroleum ether. The extracts then were washed continuously with water until the dioxane was completely removed. After drying over anhydrous sodium sulfate and concentrating to a volume of 100 ml., the petroleum ether solution was passed through a column containing 50 g. of alumina and the material was eluted with more of the same solvent. There was obtained as the only product isolated 1.30 g. (83.2%) of a solid hydrocarbon, m.p. 135–138° (sealed tube).

Anal. Calcd. for $C_{13}H_{26}$: C, 85.63; H, 14.37. Found: C, 86.21, 85.58; H, 13.69, 14.38.

This material, olefin A, was identical with that obtained along with di-*t*-butylcarbinyl *p*-nitrobenzoate in the solvolysis of the impure ester.

Tri-*t*-butylcarbinol under Solvolytic Conditions.—One gram of tri-*t*-butylcarbinol prepared by Dr. E. B. Lefferts and 0.10 g. of *p*-nitrobenzoic acid were dissolved in 100 ml. of dioxane and 50 ml. of water was added. The solution was stored at 45–50° for 40 hours, cooled, made alkaline with sodium hydroxide and extracted four times with petroleum ether. The extracts were washed five times with water, dried over Drierite and the solvent removed. On cooling, 0.930 g. of unchanged tri-*t*-butylcarbinol, m.p. 116–118°, was recovered.

Hydrogenation of Olefin A.—Two hundred milligrams of olefin A was dissolved in 10 ml. of acetic acid (distilled from potassium permanganate) and added to a suspension of prereduced platinum oxide catalyst (50 mg.) in the same volume of solvent. After stirring in an atmosphere of hydrogen for 24 hours (hydrogen uptake 25 ml., 92%), the catalyst was removed by filtration and the solution was diluted with water and extracted with ether. The ether solution was washed with sodium bicarbonate, dried and the solvent removed. The residue, 150 mg. of waxy solid, was sublimed at 35–40° under 2 mm. pressure. The paraffin, 73 mg., melted at 116–118° (sealed tube) and its infrared spectrum showed no absorption in the 6.0–6.3 μ region.

Perbenzoic acid was prepared in a concentration of 0.465 *M* in benzene and standardized iodometrically. The iodine liberated by 1 ml. of the solution required 9.30 ml. of 0.100 *M* sodium thiosulfate for its neutralization.

Peracid Oxidation of Olefin A.—Two grams (0.0110 mole) of olefin A was treated with 0.0139 mole of perbenzoic acid in benzene solution (total volume 45 ml.) at 0–5°. After 72 hours a 1-ml. aliquot, titrated as before, required 2.02 ml. of 0.100 *N* sodium thiosulfate (85% reaction). The benzene solution was extracted with aqueous sodium bicarbonate, washed with water, dried over Drierite, and the solvent removed. The residue was dissolved in 30–60° petroleum ether and chromatographed on alumina, using more of the same solvent as eluant. The first fraction, 0.220 g., contained roughly half olefin and half epoxide as indicated by its infrared spectrum. From the subsequent fractions there was obtained 1.21 g. (55.5%) of solid material, m.p. 165–169° in a sealed tube.

Anal. Calcd. for $C_{13}H_{26}O$: C, 78.7; H, 13.1. Found: C, 77.8, 80.4; H, 13.3, 13.4.

Ozonization of Olefin A.—Ozone was bubbled through a solution of 2.00 g. of olefin in 30 ml. of reagent ethyl acetate for one hour at −15 to −20°. The solution was then transferred to an ice-bath at 0° and an attempt was made to hydrogenate the mixture at atmospheric pressure in the presence of palladium-on-strontium carbonate. No hydrogen was absorbed. The catalyst was filtered and the solvent removed under reduced pressure, leaving 1.85 g. of white solid residue. A small sample, 0.12 g., of this material was unaffected by boiling with zinc dust in water containing a small crystal of silver nitrate and about 1 mg. of hydroquinone. The remainder of the material was chromatographed on a 40-cm. alumina column using 30–60° petroleum ether as solvent and eluant. There was obtained 1.36 g. of solid material with an infrared spectrum the same as that of the epoxide. Recrystallization from methanol at low temperature yielded 0.554 g. of crystalline epoxide, m.p. 162–165° in a sealed tube, which melted at 166–169° after a second recrystallization. No other pure compound was obtained from the chromatogram upon further elution with benzene and benzene–methanol.

Osmium Tetroxide Oxidation of Olefin A.—Olefin A (1.40 g., 0.00768 mole) and 1.20 g. (0.015 mole) of pyridine were dissolved in 25 ml. of dry ether and to the colorless solution was added 2.0 g. (0.008 mole) of osmium tetroxide obtained from the firm of E. Merck, Darmstadt. The orange-yellow solution was transferred to a Pyrex tube, sealed, and allowed to stand at room temperature in the dark for three weeks. After the opening of the tube a brown solid was separated from the dark solution by centrifuging and washing several times with ether. The solid was dissolved in methylene chloride in which it is sparingly soluble and shaken with about 50 ml. of a solution containing 1 g. of potassium hydroxide and 1 g. of mannitol,[26] until the organic layer was colorless. The aqueous solution became deep red. The organic layer was separated, washed several times with water, dried over Drierite, and the solvent removed. The liquid residue, 0.2 g., was dissolved in petroleum ether and chromatographed on a 30-cm. column containing 25 g. of alumina. Elution with further quantities of petroleum ether yielded 0.104 g. of pure olefin A. A 20% solution of ethyl ether in petroleum ether eluted 0.060 g. of a viscous liquid, glycol A, with strong OH absorption in the infrared spectrum. Changing the eluant to pure ethyl ether yielded about 0.020 g. of another liquid, probably also a glycol since it gave a white precipitate when added to an ether solution of periodic acid. The mother liquors and washings from the first work-up were combined and allowed to stand in a stoppered bottle at room temperature in the dark for 5 weeks longer, during which time an additional quantity of brown solid was deposited. When this material was worked up as described above, there was obtained a small quantity of unreacted olefin, about 10 mg., and 0.085 g. of glycol A as the only other product. The total yield of glycol A based on a $C_{13}H_{28}O_2$ formula was 9%. The mother liquors and washings from the second work-up were combined, evaporated to a volume of 2 ml. and dissolved in 40 ml. of 95% ethanol. A solution of 10 g. of sodium sulfite in water was added and the mixture was refluxed overnight. The dark solution was filtered and washed thoroughly with ethanol. The filtrate and washings were combined, an equal volume of water was added and the mixture was extracted several times with ether. The ether extracts were washed with water, then with dilute hydrochloric acid, and finally with water until most of the ethanol was removed. After drying over Drierite, removal of solvent left 1.10 g. of olefin A, m.p. 135–138°. The total recovery of olefin was 1.21 g., 86%.

Treatment of the recovered olefin with osmium tetroxide (purchased from Merck & Co., Rahway, N. J.) as described above yielded no oxidized product. The olefin was recovered unchanged.

Treatment of Glycol A with Periodic Acid.—The glycol, 0.028 g., was dissolved in 15 ml. of dry ether and 0.045 g. of crystalline periodic acid dihydrate was added. A fine precipitate was deposited as the crystals dissolved. The flask was swirled to effect solution of periodic acid and allowed to stand. After one hour the precipitation of iodic

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(26) R. Criegee, B. Marchand and H. Wannowius, *Ann.*, **550**, 99 (1942).

acid appeared complete. The solution was allowed to stand two additional hours and the clear ether solution was decanted from the solid. The solution was washed with sodium bicarbonate solution, then with water, dried over Drierite, and the solvent removed. There remained 0.20 g. of oil with a camphor-like odor. The infrared spectrum of this material was identical with that of *t*-butyl triptyl ketone (see below).

Reaction of Olefin A with Ruthenium Tetroxide.—A carbon tetrachloride solution of ruthenium tetroxide was prepared by heating an aqueous solution of ruthenium sulfate with periodic acid as described by Martin.[27] The volatile tetroxide was condensed in cold carbon tetrachloride in which it formed a yellow solution. When a drop of 95% ethanol was added to a small sample of this solution, a fine black precipitate appeared instantly.

Ten milliliters of the solution of ruthenium tetroxide was added dropwise with swirling to a solution of 0.110 g. (0.6 millimole) of olefin A in 2 ml. of carbon tetrachloride solution at 0°. During the addition the solution became orange-red and a small amount of a very dark layer, probably containing some water, settled to the bottom. After standing at 0° for approximately 2 hours, the solution was centrifuged and the clear yellow solution decanted from the heavier dark material which was water soluble. The carbon tetrachloride layer was shaken with an alkaline mannitol solution in the same manner as described earlier for hydrolyzing osmium complexes. In this case the alkaline layer turned green and the organic phase became colorless. The carbon tetrachloride solution was separated, washed with water, dried over Drierite, and the solvent was removed. The liquid residue, 0.080 g., had an infrared spectrum which exhibited no absorption due to hydroxyl or carbonyl groups, but appeared to be an unsaturated hydrocarbon different from olefin A.

3,3,4,4-Tetramethylpentan-2-one (Methyl Triptyl Ketone).—One hundred milliliters of concentrated sulfuric acid was cooled to 0° and 13.5 g. (0.095 mole) of hexamethylacetone was added slowly with stirring. The clear solution was then allowed to stand at room temperature for eight hours, at which time the color was yellow-orange with a slight turbidity. After pouring the mixture on 600 g. of ice, the organic layer was separated and the aqueous phase extracted with petroleum ether. The organic layers were combined and washed with sodium bicarbonate, then with water, and dried over Drierite. Removal of solvent left 12 g. of liquid ketone, the infrared spectrum of which showed no bands due to hexamethylacetone. By distillation at atmospheric pressure (b.p. 171–175°) and crystallization at low temperature, there was obtained 7.0 g. of methyl triptyl ketone, m.p. 58–60° (literature 63°[28]). Since the compound crystallizes with some difficulty, the crude ketone was in most cases oxidized directly without purification.

Dimethyl-*t*-butylacetic Acid from Oxidation of the Methyl Ketone.—To 150 ml. of a 5.25% solution of sodium hypochlorite (commercial bleach) was added 5.0 g. (0.034 mole) of methyl triptyl ketone and 5 g. of sodium hydroxide. The mixture was stirred at 65–75° for 1.5 hours, then at approximately 90° for 20 hours. An additional 10 g. of sodium hydroxide was then added and the mixture refluxed for six hours. After cooling and extracting the neutral material with petroleum ether, the aqueous solution was acidified. The precipitated acid was collected on a filter, dried, and recrystallized from petroleum ether; yield 3.85 g. (76%) of dimethyl-*t*-butylacetic acid, m.p. 198–199°, identical with that obtained by carbonation of triptylmagnesium chloride.

When a sample of crude methyl triptyl ketone, prepared from 26.5 g. of hexamethylacetone by treating with 200 ml. of concentrated sulfuric acid, was oxidized with alkaline hypochlorite solution as described above, there was obtained 12 g. of acid, m.p. 197–198°. This is an over-all yield of 45%, based on hexamethylacetone.

Dimethyl-*t*-butylacetyl Chloride.—Dimethyl-*t*-butylacetic acid (6.8 g., 0.047 mole) was heated on the steam-bath for four hours with 7.0 g. of thionyl chloride. The excess thionyl chloride was then removed under vacuum and the crude acid chloride (7.0 g.) solidified on cooling. Because of the difficulty in crystallizing this compound without considerable loss (it can be crystallized from petroleum ether at Dry Ice temperatures), the crude acid chloride was used without further purification.

In one experiment the crude acid chloride, obtained by treating 14.0 g. of dimethyl-*t*-butylacetic acid with thionyl chloride as described above, was recrystallized from petroleum ether at −70°. There was obtained 9.5 g. of white wax-like solid, m.p. 74–76° (literature 78°[28]).

Hexamethylhexan-3-ol (*t*-Butyltriptylcarbinol).—A solution of *t*-butyllithium (0.15 mole) was prepared in 300 ml. of ether at −40 to −50°. After cooling to −60°, a solution of 7.0 g. of crude dimethyl-*t*-butylacetyl chloride (prepared from 6.8 g. of acid) in 100 ml. of ether was added over a one-hour period. The mixture was stirred at −55 to −65° for six hours and allowed to warm to room temperature overnight. Ice-water was added, the layers were separated, and the basic aqueous phase extracted twice with ether. The combined ether solutions were washed with water, dried over Drierite, and the solvent removed. The residue was distilled at reduced pressure from a small column packed with glass helices; yield 5.99 g. (74% based on acid chloride, 68% over-all yield from dimethyl-*t*-butylacetic acid), b.p. 130–135° at 70 mm., $n^{25}\text{D}$ 1.4547; phenylurethan, m.p. 101–102°.

Anal. Calcd. for $C_{19}H_{31}O_2N$: C, 74.71; H, 10.23; N, 4.59. Found: C, 74.74; H, 10.30; N, 4.57.

Hexamethylhexan-3-one (*t*-Butyl Triptyl Ketone).—*t*-Butyltriptylcarbinol (4.35 g., 0.0234 mole) was added to 25 ml. of concentrated nitric acid and allowed to stand at room temperature. Within a few minutes the mixture became warm and nitrogen oxides were evolved. After six hours standing the mixture was refluxed for five minutes, cooled, and *ca.* 20 g. of ice added. The organic material was extracted with petroleum ether and the extracts were washed first with 10% sodium hydroxide solution, then with water until the washings were neutral. After drying over Drierite, the solvent was removed and the residue distilled at reduced pressure; yield 2.00 g. (46%), b.p. 75–80° at 14 mm. The infrared spectrum of this material was identical with that of the ketone obtained by oxidation of olefin A.

Reduction of *t*-Butyl Triptyl Ketone.—Lithium aluminum hydride (0.038 g., 0.001 mole) was dissolved in 25 ml. of dry ether, and 0.300 g. (0.00163 mole) of *t*-butyl triptyl ketone in 5 ml. ether was added. The solution was allowed to stand for three hours at room temperature, then refluxed for one hour, cooled, and hydrolyzed with 25 ml. of moist ether. After filtering off the insoluble material the ether solution was dried over Drierite and the solvent was removed. The crude product (0.260 g., 86%) had an infrared spectrum the same as that of *t*-butyltriptylcarbinol. Treatment of the material with phenyl isocyanate and chromatography of the product on alumina gave 0.330 g. (65%, based on ketone) of phenylurethan, m.p. 101–102°.

Methyltriptyl-*t*-butylcarbinol.—A solution of methyllithium was prepared by adding methyl iodide to 0.20 g. (0.029 mole) of lithium in 25 ml. of ether at gentle reflux until the metal was completely reacted. The solution was cooled and 0.50 g. (0.00272 mole) of *t*-butyl triptyl ketone in 25 ml. of ether was added. After standing at room temperature for two hours, the mixture was refluxed for four hours, cooled, and hydrolyzed with water. The ether layer was separated, washed with water, dried over Drierite, and the solvent removed. The infrared spectrum of the product indicated a mixture of ketone and alcohol. The material was dissolved in 30–60° petroleum ether and chromatographed on a column containing 40 g. of alumina. Elution with further quantities of petroleum ether yielded 160 mg. of unreacted ketone and 120 mg. of alcohol. Elution of the chromatogram with ethyl ether gave no more material. Attempts to induce crystallization of the alcohol and to prepare the *p*-nitrobenzoate were unsuccessful.

Solvolysis of Di-*t*-butylisopropylcarbinyl *p*-Nitrobenzoate.—The ester (12.0 g., 0.357 mole) was dissolved in 200 ml. of dioxane and 65 ml. of water, and stored at 50° for five days. Approximately 300 ml. of water was then added and the solution was made slightly alkaline with sodium hydroxide. The mixture was extracted twice with 100-ml. quantities of petroleum ether, and the extracts washed six times with 600-ml. portions of water. After drying over Drierite the solvent was removed, leaving 5.96 g. of liquid hydrocarbon. This product was distilled through a small column packed with glass helices.

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(27) F. S. Martin, *J. Chem. Soc.*, 2682 (1952).

(28) R. Locquin and W. Sung, *Bull. soc. chim.*, [4] **35**, 753 (1942); *Compt. rend.*, **178**, 1179 (1924).

Fraction	Weight, g.	B.p., °C.	Press., mm.	$n^{26}D$
1	0.50	101-102	44	1.4582
2	2.10	101-103	40	1.4570
3	2.40	101-103	40	1.4590
	5.00 (83.5%) olefin B.			

The infrared spectra of fractions 1, 2 and 3 were identical.

Solvolysis of *t*-Butyldiisopropylcarbinyl *p*-Nitrobenzoate and Triisopropylcarbinyl *p*-Nitrobenzoate.—These two esters were solvolyzed as described above except that the triisopropylcarbinol ester was allowed to stand at 50° for four weeks instead of five days. The crude products obtained (olefins C and D) after removal of solvent were not purified further.

Perbenzoic Acid Oxidation of Olefin B.—The olefin (1.0 g., 0.00595 mole) was dissolved in 25 ml. of benzene and treated with 15.0 ml. of 0.465 *M* solution of perbenzoic acid (0.00698 mole) at 0°. After 36 hours a 1-ml. aliquot was run into an acetic acid solution of potassium iodide and the liberated iodine titrated with 0.100 *N* sodium thiosulfate (1.02 ml. of thiosulfate required: 83% reaction). After 86 hours a 1-ml. aliquot required 0.78 ml. of the thiosulfate solution (91% reaction).

The benzene solution was shaken with a solution of potassium iodide in dilute acetic acid, then with dilute thiosulfate, and finally with sodium bicarbonate solution. After drying over Drierite and removing solvent, there remained 0.900 g. of a colorless liquid whose infrared spectrum was very similar to the epoxide obtained from olefin A. The compound did not crystallize.

Ozonization of Olefin B.—One gram of the olefin was dissolved in 25 ml. of dry ethyl acetate, and ozone was bubbled through the solution at −60 to −70° for two hours. At the end of this period the solution contained excess ozone as indicated by the deep blue color. The ozone was removed by bubbling dry nitrogen through the solution. Palladium-on-strontium carbonate (0.150 g.) was then added and the mixture was stirred in an atmosphere of hydrogen at room temperature for four hours; no hydrogen uptake was observed.

The catalyst was removed by filtration and the solvent evaporated from the filtrate. The residue (0.60 g.) was an oil whose infrared spectrum indicated it to be largely the epoxide, but to contain a considerable quantity of a carbonyl compound as well. Chromatography on alumina was not effective in separating the mixture. Attempts to crystallize the mixture also failed.

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[CONTRIBUTION FROM THE WARNER-CHILCOTT RESEARCH LABORATORIES]

The Decarboxylative Acylation of α-Substituted Acids

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It is shown that the decarboxylative acylation of carboxylic acids having a suitable electron-attracting group in the α-position is a base-catalyzed condensation of an anhydride with the carbonyl group of the acylating agent. The scope and stoichiometry of the reaction have been further defined. Probable reaction sequences for the various acids undergoing the reaction are discussed.

It has been shown that carboxylic acids having certain electron-withdrawing groups attached to the α-position to the carboxyl group can be made to undergo a decarboxylative acylation reaction in the presence of an acylating agent and a base to give a compound in which the original carboxyl group is replaced by an acyl group. The types of electron-withdrawing groups are varied and there are in all probability at least two major routes by which this type of reaction takes place. The purpose of this paper is to clarify the mechanistic picture of these reactions.

Acids which have been shown to undergo this reaction are those which have the following groups attached to the α-positions: $-NH_2$,[1] $-NHR$,[2] $-NR_2$,[3] an aryl group,[1c,4] a heterocyclic group[5] and an aryloxy group.[6] Notable examples of acids which have failed to undergo this reaction are: α-aminoisobutyric acid, α-phenylpropionic acid,[4] diphenylacetic acid,[4] proline[7] and 5-pyrolidone-2-carboxylic acid.[7] It should especially be noted at this point that the acids which undergo this reaction are all acids which, under the reaction conditions employed, do not decarboxylate in the absence of the acylating agent; we believe that the scope of this reaction must, by definition, be limited to such reactions since there are a number of examples of acids which do decarboxylate under these conditions in the absence of the acylating agents and which in the presence of a carbonyl group may[8] (quinaldinic acid) or may not (trichloroacetic acid, *vide infra*) react with the carbonyl group at the time of decarboxylation.

In the case of the primary amino acids it has been suggested[1d,9] that an oxazolone is the compound which reacts with the acylating agent and in certain cases[10] an acylated oxazolone has been isolated previous to decarboxylation. This proposed route is probably correct because most of these compounds undergo the reaction more readily than do other types of acids.

Stoichiometric studies were carried out by Ron-

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