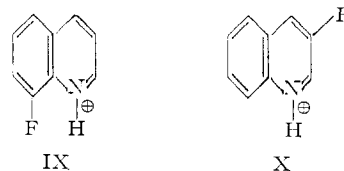


respective of ρ for the over-all reactions). The effect of *o*-substituents will be larger than expected on the basis of acid ionization constants because the reactive centers involved in the rate-determining steps are one carbon atom along the chains closer to the ring and $\cos \theta$ for a group like *o*-Cl will have a value of about -0.1 as compared to about -0.2 for the acid ionizations. It is possible that part of the proximity effect discussed by Hammett⁸ for *o*-substituents may be regarded as the result of changing balances between field and inductive effects.

A comparable influence of field and inductive effects can be employed to explain reactivities in some other systems. Thus the conjugate acid of 8-fluoroquinoline (IX, $pK_a = 3.08$) is a stronger acid than the conjugate acid of quinoline ($pK_a = 4.69$) but substantially weaker than the conjugate acid of 3-fluoroquinoline (X, $pK_a = 2.36$).¹¹ The value of $\cos \theta$ for IX should be almost 0 and about $+0.8$ for X.

(11) W. K. Miller, S. B. Knight and A. Roe, *ibid.*, **72**, 4763 (1950).



Studies of the reactivities of some other "horse-shoe"-type compounds are in progress.

ADDED IN PROOF.—In a recent paper, D. H. McDaniel and H. C. Brown, *THIS JOURNAL*, **77**, 3756 (1955), approach the effect of *o*-substituents in aromatic systems by an attempted calibration of *o*-electrical effects from studies of basicities of 2-substituted pyridines. The procedure would seem invalid because of (1) the large difference in θ in the change from a 2-substituted pyridine to an *o*-substituted benzoic acid and (2) the concomitant attenuation of the short-range inductive effect which appears to operate strongly only at the position immediately adjacent to the substituent; cf. also G. E. Hall, R. Piccolini and J. D. Roberts, *ibid.*, **77**, 4540 (1955).

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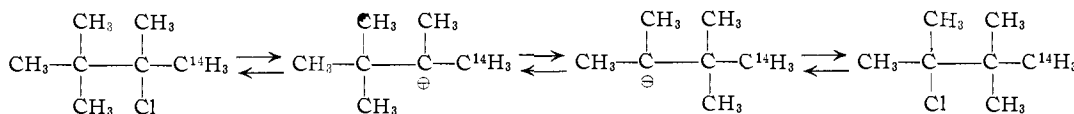
[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY AND LABORATORY FOR NUCLEAR SCIENCE AND ENGINEERING, MASSACHUSETTS INSTITUTE OF TECHNOLOGY]

Rearrangements in Carbonium-ion Type Reactions of C¹⁴-Labeled Pentamethylethanol (2,3,3-Trimethyl-2-butanol-1-C¹⁴)¹

BY JOHN D. ROBERTS² AND JOEL A. YANCEY

RECEIVED MAY 9, 1955

Treatment of 2,3,3-trimethyl-2-butanol-1-C¹⁴ with concentrated hydrochloric acid and zinc chloride (Lucas reagent) yielded 2-chloro-2,3,3-trimethylbutane with the C¹⁴ distributed essentially equally among the five methyl groups. Under the conditions used, the aliphatic chloride equilibrated completely with Lucas reagent containing radioactive chloride ion. The rearrangement and chloride exchange may be accounted for by the following equilibria involving solvated carbonium ions.



Treatment of 2,3,3-trimethyl-2-butanol-1-C¹⁴ with concentrated hydrochloric acid at 25° for 20 minutes and 0° for one minute gave 36% and 12–16% of methyl group rearrangement, respectively. At 0° and one minute, the reaction was essentially irreversible since chloride exchange between the aliphatic chloride and radioactive concentrated hydrochloric acid was negligible. Hydrolysis of 2-chloro-2,3,3-trimethyl-2-butane by shaking with water at room temperature gave no additional methyl group rearrangement. It is concluded that the non-classical cationic intermediate VIII is not an important intermediate in irreversible carbonium ion type reactions of pentamethylethyl derivatives in aqueous solution and that such an intermediate is unlikely to be as stable as the classical cations shown in the equations above.

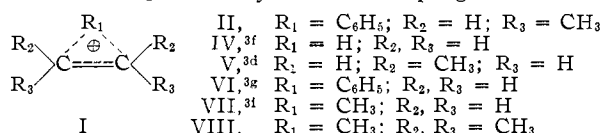
A large part of our program of research³ on carbonium-ion type reactions has been devoted to elucidation of the structural and environmental factors which are important for the occurrence of non-

(1) Supported in part by the joint program of research of the Office of Naval Research and the U. S. Atomic Energy Commission. Presented at the Symposium on Reaction Mechanisms at the 75th Anniversary of the American Chemical Society, September 13, 1951.

(2) Gates and Crellin Laboratories, California Institute of Technology, Pasadena 4, Calif.

(3) (a) J. D. Roberts, R. E. McMahon and J. S. Hine, *THIS JOURNAL*, **72**, 4237 (1950); (b) J. D. Roberts and R. H. Mazur, *ibid.*, **73**, 2509, 3542 (1951); (c) J. D. Roberts and C. C. Lee, *ibid.*, **73**, 5009 (1951); (d) J. D. Roberts, W. Bennett, R. E. McMahon and E. W. Holroyd, Jr., *ibid.*, **74**, 4283 (1952); (e) J. D. Roberts and G. R. Coraor, *ibid.*, **74**, 3586 (1952); (f) J. D. Roberts and J. A. Yancey, *ibid.*, **74**, 5943 (1952); (g) J. D. Roberts and C. M. Regan, *ibid.*, **75**, 2069 (1953); (h) J. D. Roberts and J. A. Yancey, *ibid.*, **75**, 3165 (1953); (i) J. D. Roberts and M. Halmann, *ibid.*, **75**, 5759 (1953); (j) J. D. Roberts, C. C. Lee and W. H. Saunders, Jr., *ibid.*, **76**, 4501 (1954); **77**, 3034 (1955).

classical cationic intermediates of the "ethyleneonium" variety I. Very substantial progress toward



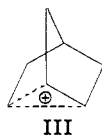
similar objectives has been made, principally by Winstein,⁴ Cram,⁵ Collins⁶ and their co-workers, using reaction rate and stereochemical techniques. Non-classical cationic intermediates of one variety

(4) (a) As a leading reference to a number of papers see S. Winstein, C. R. Lindgren, H. Marshall and L. L. Ingraham, *ibid.*, **75**, 147 (1953); (b) S. Winstein and D. Trifan, *ibid.*, **71**, 2953 (1950); **74**, 1147, 1154 (1952).

(5) Cf. D. J. Cram, *ibid.*, **71**, 3863 (1949); **74**, 2129, 2159 (1952); and later papers.

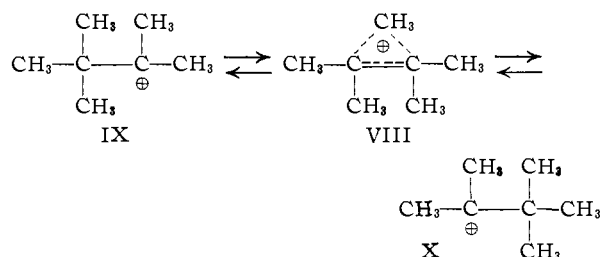
(6) C. J. Collins and W. Bonner, *ibid.*, **75**, 5372 (1953); **77**, 72, 99 (1955).

or the other have been decisively demonstrated by these methods, notably "phenonium" (II)^{4a,5} and "norbornonium" (III)^{4b} cations.



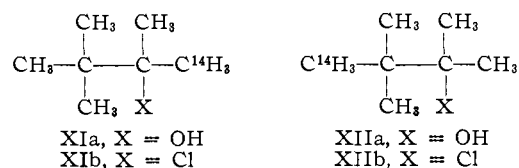
With many substances, the stereochemical and reaction rate procedures are not readily applicable and the isotopic tracer technique³ can yield information of value.⁷ By this means, intermediates such as I have been shown to be of relatively minor importance in carbonium ion type processes where R₁ = H (IV, V)^{3d,f} but possibly of more significance where R₁ = C₆H₅ (VI).^{3g} The state of affairs for *symmetrical* cations such as I, with R₁ = alkyl, is as yet unsettled. Although there is strong evidence for "methylene participation" in the strained norbornyl system (*i.e.*, to give III)^{3c,j,4b} the tendency to form VII is relatively smaller.³ⁱ

In the present investigation, the stability of the methyl-bridged cation VIII with respect to its classic isomers IX and X has been studied. This



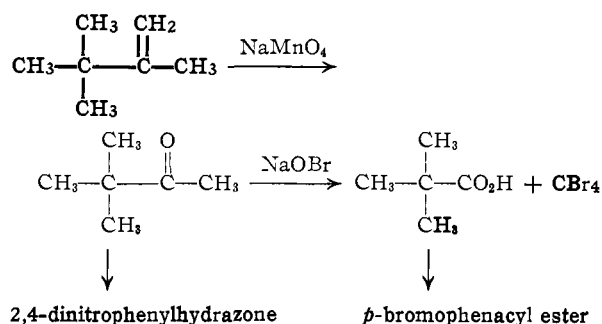
system is particularly interesting since it provides an unusual opportunity to distinguish experimentally between the non-classical cation VIII and an equilibrium mixture of the classical cations IX and X. Thus, if one carries out a cationic reaction with a 2,3,3-trimethyl-2-butyl-1-C¹⁴ derivative (XI) and the intermediate were the symmetrical non-classical cation VIII, with equivalent carbon atoms at positions 2 and 3, it should be clear that a 50-50 mixture of the two possible C¹⁴-labeled products (corresponding to XI and XII) would be expected. On the other hand, if an equilibrium mixture of the classical cations IX and X is involved, one would expect a product mixture corresponding to statistical mixing of methyl groups, *i.e.*, 60% of the C¹⁴-label at position 4 and 40% at position 1. The argument is only valid for irreversible carbonium reactions, *i.e.*, where the intermediate is formed irreversibly from the starting material and is converted irreversibly to the final product. If the initial formation of the intermediate is reversible, we could have an isotope-position rearrangement of the starting material and if the product-forming reaction is reversible, we might have a rearrangement of the first-formed product. In either case, a reversible reaction involving intermediate VIII would lead to the same products as from an equilibrium mixture of ions IX and X.

(7) A relatively complete discussion (for which no great originality is claimed) has been given earlier.^{3d}



Synthetic and Degradative Methods

2,3,3-Trimethyl-2-butanol-1-C¹⁴ was synthesized through the reaction of pinacolone with methyl-C¹⁴-magnesium iodide.⁸ The method of locating the C¹⁴ in the methyl groups of pentamethylethyl derivatives depended on their conversion to 2,3,3-trimethyl-1-butene. With alcohol XIa, this was achieved reasonably satisfactorily by dehydration with phenyl isocyanate. With the chlorides, the most satisfactory procedure involved dehydrohalogenation with dimethylaniline. The subsequent degradation of the alkene is shown in the equation



The substances whose formulas are printed in bold-faced type were analyzed for C¹⁴. The C¹⁴-analyses on the degradation products obtained by dehydration of alcohol XIa with phenyl isocyanate are given in Table I. Clearly, the rearrangement in the preparation of XIa and its degradation was relatively small (3-6%).

Results and Discussion

The extent of rearrangement in the carbonium ion type reactions of 2,3,3-trimethylbutyl-1-C¹⁴ derivatives (XI) was found to depend markedly on the degree of reversibility of the processes as defined by the reaction conditions. For example, treatment of the alcohol XIa with Lucas reagent (concentrated hydrochloric acid-zinc chloride solution) for three hours at room temperature gave a chloride in which the methyl groups were completely equilibrated, *i.e.*, a 60:40 mixture of XIb and XIIb (Table I). The experiment gives no real information regarding the role of the non-classical ion VIII since the reaction was completely reversible as shown by the fact that, under the same conditions, the chloride was completely equilibrated with Lucas reagent containing radioactive chloride ion (Table II). In circumstances where the reaction was less reversible, less rearrangement was observed. Thus, with concentrated hydrochloric acid at room temperature in 20 minutes, 36% of the rearranged chloride XIIb was detected and the extent of exchange with radioactive hydrochloric acid

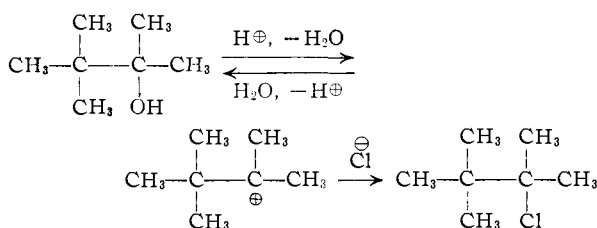
(8) The methyl iodide used in the preparation of the Grignard reagent was obtained from Tracerlab, Inc., on allocation from the U. S. Atomic Energy Commission.

TABLE I
 REARRANGEMENT IN REACTIONS OF 2,3,3-TRIMETHYL-2-BUTYL-1-C¹⁴ DERIVATIVES

Reaction	2,3,3-Trimethyl-1-butene ^a	Pinacolone DNP ^{a,b}	CBr ₄ ^c	BrPA ^d trimethyl acetate ^e	Rearr., %		
					A ^d	B ^e	Av.
2,3,3-Trimethyl-2-butanol-1-C ¹⁴ dehydrated with C ₆ H ₅ NCO	3510 ± 16	1748 ± 21	1327 ± 9	109 ± 12	3.1	3.5	3
2,3,3-Trimethyl-2-butanol-1-C ¹⁴ with Lucas reagent, room temp., 3 hr.	2918 ± 14	1468 ± 17	1283 ± 14	174 ± 9	6.0	6.3	6
	2172 ± 15	1817 ± 25	412 ± 4	1291 ± 15	59.4	57.9	59
2,3,3-Trimethyl-2-butanol-1-C ¹⁴ with concd. HCl, 25°, 20 min.	3340 ± 36	2122 ± 24	928 ± 6	1136 ± 5	34.0	37.3	36
2,3,3-Trimethyl-2-butanol-1-C ¹⁴ with concd. HCl, 0°, 1 min.	2404 ± 18	1294 ± 2	1023 ± 21	273 ± 5	11.4	11.7	12
 ^f	0.1256 ^g	0.0905 ^g	0.0344 ^g	..	15.9	(16) ⁱ
2,3,3-Trimethyl-2-butyl-1-C ¹⁴ chloride ^h with water, room temp. ^f	0.1080 ^g	0.0767 ^g	0.0265 ^g	..	14.4	(14) ⁱ

^a Corrected C¹⁴-activities with standard deviations in c./min./labeled carbon atom calculated as described earlier^{3a} from activities (corrected for background) of "infinitely-thick" barium carbonate precipitates prepared as described by J. D. Roberts, W. Bennett, E. W. Holroyd, Jr., and C. H. Fugitt, *Anal. Chem.*, **20**, 904 (1948), and measured in a window-less methane-filled proportional counter ("Nucleometer," Radiation Counter Laboratories). ^b DNP = 2,4-dinitrophenylhydrazone. ^c BrPA = *p*-bromophenacyl. ^d A = activity of bromophenacyl ester/activity of alkene × 100. ^e B = activity of bromophenacyl ester/(activity of dinitrophenylhydrazone plus carbon tetrabromide) × 100. ^f The alkene gave erratic results in the Van Slyke oxidation. ^g C¹⁴-Activity in μc./millimole determined with vibrating-reed electrometer (Applied Physics Corp.) as described by O. K. Neville, *THIS JOURNAL*, **70**, 3499 (1948). ^h The chloride was part of the product which showed 15.9% rearrangement on degradation *via* dehydrohalogenation with dimethylaniline. ⁱ Single value.

was 17%.⁹ Treatment of the alcohol XIa with concentrated hydrochloric acid at 0° for one minute gave still less rearrangement (12–16%) and about 2% of exchange with radioactive hydrochloric acid (see Tables I and II).⁹ The system is clearly labile, but the tendency for rearrangement can be greatly reduced by working under mild conditions.¹⁰ The small extent of rearrangement under mild conditions obviously indicates that the symmetrical non-classical cation VIII is not the principal cationic intermediate in the irreversible reactions of the alcohol XIa with hydrochloric acid. At *most*, only one of about four alcohol molecules could be converted to the cation VIII in reaction with concentrated hydrochloric acid. This is obviously an *upper* limit since, although conditions were found where the chloride-forming step appeared to be essentially irreversible, there is a good possibility of reversibility (and rearrangement) in carbonium ion formation from the starting alcohol as shown in the equations



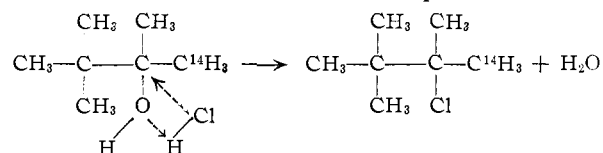
Thus, when the cation is formed from the alcohol in hydrochloric acid solution, it may return to alcohol

(9) The extents of exchange in these experiments may be low because the reactions were heterogeneous. As a result, it does not seem desirable to attach more than qualitative significance to the ratios of exchange and isomerization reaction rates.

(10) In a recent paper, H. C. Brown and R. B. Kornblum, *THIS JOURNAL*, **76**, 4510 (1954), report substantially less rearrangement in the reactions of 2,2,3-trimethyl-3-pentanol and 2,3,3-trimethyl-2-pentanol with hydrogen chloride than we observed with 2,3,3-trimethyl-2-butanol-1-C¹⁴ under similar conditions. One possible difference between the two systems is that interconversion of the *t*-amyldimethylcarbinyl and *t*-butylethylmethylcarbinyl cations through methyl migration necessitates eclipsing an ethyl and three methyl groups in two pairs which would be sterically less favorable than eclipsing four methyls in two pairs as in VIII.

or pick up chloride ion (irreversibly) to yield organic chloride. If water competes favorably (as it should) with chloride ion for the carbonium ion, then each molecule of alcohol might be converted many times to cation (each time with slight rearrangement) before being converted to chloride. This interpretation is favored by the lack of rearrangement in neutral hydrolysis of the chloride (see below) where all of the reaction steps are likely to be irreversible.

We infer from the foregoing that the non-classical ion VIII is less stable than its classical isomers IX and X *provided* that reversibility of the reaction in question is adequately indicated by the exchange experiments and the mechanism involves a carbonium ion intermediate rather than a S_Ni-type process between the alcohol and undissociated hydrogen chloride molecules as shown in the equation



Although there is not much direct evidence for the participation of carbonium ion intermediates in the reaction of tertiary alcohols with hydrochloric acid, the general character of such processes is in harmony with a carbonium ion mechanism. Ample evidence is available for the carbonium-ion character of hydrolyses of tertiary chlorides¹¹ and we have used the hydrolysis reaction as a test of whether the alcohol-hydrochloric acid reaction behaves differently from a *bona fide* carbonium ion process. This experiment was carried out in the following way. 2,3,3-Trimethyl-2-butanol-1-C¹⁴ (XIa) was converted to the chloride with hydrochloric acid at 0° (one minute) and the chloride divided into two portions. One part was dehydrohalogenated with dimethylaniline and the isotope position C¹⁴-distribution of the resulting alkene compared with that of material obtained by hydrol-

(11) C. K. Ingold, "Structure and Mechanism in Organic Chemistry," Cornell University Press, Ithaca, N. Y., 1953, Chap. VII.

TABLE II
 EXCHANGE BETWEEN HCl³⁶ AND 2,3,3-TRIMETHYL-2-BUTYL CHLORIDE

Reagent	Millimoles of chloride ion	Millimoles of organic chloride	CH ₂ Cl ₂ , ml.	Time, min.	Temp., °C.	AgCl ³⁶ activities ^a		Exch., %
						Starting HCl solution	Organic chloride after reaction	
Concd. HCl ^b	98	7.4	2.0	1.0	0	1310 ± 44	15 ± 10	~1
Concd. HCl ^b	97	8.3	1.5	20	Room	978 ± 32	156 ± 15	17
Lucas reagent ^c	215	9.0	1.5	180	Room	1601 ± 54	1674 ± 56	110

^a Measured activities corrected for background (~45 c./min.). For procedure see Experimental part. ^b 12.1 M hydrochloric acid. ^c Made from 9.60 g. of anhyd. zinc chloride and 6.0 ml. of concd. (12.1 N) hydrochloric acid.

ysis of another portion of the chloride with water at room temperature and treatment of the product with phenyl isocyanate (to convert the resulting mixture of alkene and alcohol to alkene). No significant difference in the amount of rearrangement by the two separate paths was observed and this fact provides another link in the chain of evidence that the *symmetrical* non-classical cation VIII is a relatively unimportant intermediate in the irreversible carbonium type reactions of pentamethylethyl derivatives in aqueous solution.¹² For all practical purposes, it seems valid to consider that VIII is less stable than the classical cations IX and X. Indeed, VIII may only be a transition state through which the latter ions are interconverted. From the accumulated evidence,³ we may expect that similar situations will be encountered generally with aliphatic compounds, except where stereochemical, solvent or steric factors tend to make the non-classical cations more stable relative to their classical isomers.

Acknowledgment.—We are indebted to Mrs. Clare Regan and Mr. E. C. Stivers for the C¹⁴ analyses.

Experimental

2,3,3-Trimethyl-2-butanol-1-C¹⁴.—Pinacolone (24 g.) dissolved in 70 ml. of anhydrous ether was added dropwise over 3 hours to a solution of methyl-C¹⁴-magnesium iodide prepared under a nitrogen atmosphere by the reaction of 40 g. of methyl-C¹⁴ iodide (containing about 0.3 mc. of C¹⁴) with 7 g. of magnesium in 160 ml. of anhydrous ether. The mixture was refluxed for an hour after the addition was complete and the complexes were decomposed by shaking with saturated ammonium chloride solution and ice in a separatory funnel. The ether layer was separated and the aqueous solution extracted four times with 20-ml. portions of ether. The combined extracts were dried with magnesium sulfate, 70 ml. of anhydrous benzene was added and the ether removed by distillation. Barium oxide (45 g.) was added to the benzene solution, the mixture refluxed for three hours, and then distilled at 5–10 mm. Inactive alcohol (14.2 g.) was added to the distillate and the mixture distilled through a carefully-dried 60 × 1-cm. helix-packed column. The yield of 2,3,3-trimethyl-2-butanol-1-C¹⁴ was 88.5 g., b.p. 129–131°. The yield was 74% when account was taken of the carrier carbinol. The product must be carefully protected from moisture since it very readily forms the crystalline hydrate, m.p. 80.9–81.2°.

2-Chloro-2,3,3-trimethylbutane-x-C¹⁴.—The following experiment is typical and illustrates the isolation procedure. 2,3,3-Trimethyl-2-butanol-1-C¹⁴ (4.1 g.) was stirred vigorously for 20 minutes at room temperature with 10 ml. of methylene chloride and 50 ml. of concentrated hydrochloric acid. The aqueous layer was separated and extracted with fresh methylene chloride. The combined methylene chloride extracts were dried over magnesium sulfate and the solvent distilled, the latter part under reduced pressure. The residue was sublimed under reduced pressure and yielded 4.5 g. (94%) of chloride, m.p. 130.2–132.6° (sealed tube).

(12) A similar situation has been noted by D. J. Cram and J. D. Knight, *THIS JOURNAL*, **74**, 5839 (1952), with regard to formation of cations like VIII in solvolysis reactions of 3,4-dimethyl-3-phenylhexyl derivatives.

2,3,3-Trimethyl-1-butene-x-C¹⁴. A. From 2,3,3-Trimethyl-2-butanol-1-C¹⁴.—A mixture of 4.8 g. of the C¹⁴-labeled alcohol, 14 g. of phenyl isocyanate and 2–4 drops of pyridine was refluxed for four hours in an oil-bath at 150°. The material then was distilled and the fraction boiling below 90° collected. The distillate was washed three times with 10-ml. portions of cold water and dried over calcium chloride. Distillation from barium oxide through a semi-micro column¹³ yielded 2.6 g. (62%) of alkene, b.p. 78°. A sample of this material absorbed 99.2% of the calculated amount of hydrogen over platinum oxide.

B. From 2-Chloro-2,3,3-trimethylbutane-x-C¹⁴.—2-Chloro-2,3,3-trimethylbutane-x-C¹⁴ (5 g.) was refluxed with 40 ml. of dimethylaniline for 1.75 hours. The mixture was distilled through a semi-micro column¹⁰ and gave 3.2 g. (88%) of 2,3,3-trimethyl-1-butene-x-C¹⁴, b.p. 78°.

The infrared spectra of samples of the alkene prepared from the alcohol and chloride were identical except for faint carbonyl absorption in the material prepared by the phenyl isocyanate dehydration.

Degradation Procedure for 2,3,3-Trimethyl-1-butene-x-C¹⁴.—The alkene (2.6 g.) was shaken mechanically with a solution of 17 g. of sodium permanganate trihydrate in 170 ml. of water contained in a glass-stoppered bottle for 1.5 hours. During the reaction period, the mixture was maintained at 10–20°. The unreacted permanganate and manganese dioxide were destroyed by bubbling sulfur dioxide through the ice-cooled reaction mixture. The organic material was extracted with five 20-ml. portions of ethanol-free ether. The combined extracts were dried with anhydrous magnesium sulfate, the ether removed through a short column and the residue distilled through a semi-micro column.¹⁰ The yield of pinacolone was 0.84 g. (33%), b.p. 102–106°. The product was converted to the 2,4-dinitrophenylhydrazone, m.p. 127°, for C¹⁴-analysis.

Pinacolone-x-C¹⁴ (1.0 g.) was stirred for three hours with a mixture of 1.8 ml. of bromine, 12 g. of sodium hydroxide and 40 ml. of water at 0–10°. The resulting precipitate of carbon tetrabromide was steam distilled, collected by filtration, pressed between filter papers and sublimed twice. The yield was 1.5 g. (46%), m.p. 95°.

The residue from the steam distillation was cooled and then cautiously acidified by addition of concentrated sulfuric acid. Silver sulfate (13 g.) was added and the mixture again steam distilled. The distillate was neutralized and the water removed under reduced pressure. The residual sodium trimethylacetate was converted to the *p*-bromophenacyl ester (m.p. 77.0–77.4° after three recrystallizations from ethanol-water) for C¹⁴-analysis.

Exchange Reactions between HCl³⁶ and 2-Chloro-2,3,3-trimethylbutane.¹⁴—The following experiment is illustrative of the procedures used in the exchange reactions for which no great accuracy is claimed because of the heterogeneity of the reactions and difficulty of obtaining reproducible mixing.

An aliquot of a radioactive sodium chloride solution (containing Cl³⁶) was evaporated to dryness in a 50-ml. flask. The flask was evacuated and the residual salt (5.4 millimoles) was treated with 5 ml. of concentrated sulfuric acid. The resulting hydrogen chloride was condensed in a liquid air-cooled trap containing 9.0 ml. of ordinary concentrated hydrochloric acid. The trap was allowed to warm to room temperature, thoroughly mixed, and 8.2 ml. of the resulting radioactive hydrochloric acid was shaken vigorously with 1.00 g. of 2-chloro-2,3,3-trimethylbutane and 2.0 ml. of

(13) C. W. Gould, G. Holzman and C. Niemann, *Anal. Chem.*, **20**, 361 (1948).

(14) The Cl³⁶ used in these experiments was obtained from the Oak Ridge National Laboratory on allocation from the U. S. Atomic Energy Commission.

methylene chloride at 0° for 1.0 minute in a separatory funnel. The layers were separated, and the aqueous portion extracted several times with 5-ml. portions of methylene chloride. The combined methylene chloride extracts were washed with water, dried over magnesium sulfate and concentrated. The residual 2-chloro-2,3,3-trimethylbutane was purified by sublimation under reduced pressure. The recovery was 0.60 g.

The following procedures were used to convert the chloride samples to silver chloride for radioactive assay. A portion of the aqueous hydrochloric acid solution containing about 1–2 millimoles of chloride ion was diluted to 5 ml. with water containing 1 ml. of 6 *N* nitric acid. The solution was warmed to about 50° and 10 ml. of 10% silver nitrate solution added rapidly with stirring. The precipitate of silver chloride was collected on a sintered-glass funnel, rinsed several times with acetone and dried in an evacuated desiccator over phosphorus pentoxide. The organic chloride (about 0.1–0.2 g.) was dissolved in 5 ml. of ethanol, warmed to 50–60° and a warm solution of 10 ml. of 10% silver nitrate containing 1 ml. of 6 *N* nitric acid was added with stirring. The precipitated silver chloride was collected and dried as above.

The samples for counting were prepared by weighing out identical amounts of silver chloride on copper dishes previously checked for radioactive contamination. The samples were counted in a methane-filled proportional counter ("Nucleometer," Radiation Counter Laboratories). Trials indicated that the manner of spreading of the samples in the sample dish was not critical provided the samples were spread reasonably evenly. In the experiment described above, the measured activities for 29.0-mg. samples of silver chloride corrected for background with standard deviations were 1309 ± 44 and 15 ± 10 counts per minute for the silver chloride from the original aqueous solution and the organic chloride from the reaction mixture, respectively.

In this experiment, the initial reaction mixture contained 98.5 millimoles of hydrochloric acid and 7.4 millimoles of organic chloride. If complete equilibration had occurred, the activity of the organic chloride would be $(98.5/106) \times 1310 \pm 44 = 1220 \pm 41$ counts per minute. The extent of exchange was thus $(15 \pm 10/1220) \times 100$ or $1.2 \pm 0.8\%$. Further experimental results regarding the exchanges are presented in Table II.

CAMBRIDGE 39, MASS.

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY OF THE UNIVERSITY OF CALIFORNIA AT LOS ANGELES]

Neighboring Carbon and Hydrogen. XIX. *t*-Butylcyclohexyl Derivatives. Quantitative Conformational Analysis

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The *cis*- and *trans*-4-*t*-butylcyclohexanols represent a pair of conformationally pure *equatorial* and *axial* cyclohexanols with no α - or β -substituents. The *t*-butyl group serves as a compelling but remote control of conformation. Thus the rates of reaction and other chemical behavior of the cyclohexanols and their derivatives supply information on the differences to be expected simply from the *equatorial* or *axial* disposition of the reactive group on the chair form of the cyclohexane ring. Also, the observed rates are useful as the basis of a quantitative conformational analysis of conformationally less homogeneous cyclohexyl derivatives. At 50°, the *axial*-4-*t*-butylcyclohexanol is oxidized by chromic anhydride in 75% acetic acid more rapidly, its acid phthalate is saponified more slowly in water and its toluenesulfonate solvolyzes more rapidly in acetic acid than the *equatorial*-4-*t*-butylcyclohexyl isomers by factors of 2.55, 9 and 3.24, respectively. The cyclohexyl derivatives display intermediate rates, closer to the *equatorial*-4-*t*-butylcyclohexyl derivatives. The data shed light on the conformational distribution of the cyclohexyl derivatives, and also other substituted cyclohexanols. Rough values of Δ , the free energy of preference for the equatorial position, have been derived for the OH, acid phthalate, OTs, *n*-Bu, *n*-Pr and Et groups. In solvolysis, the *equatorial*-4-*t*-butylcyclohexyl toluenesulfonate yielded 67–76% olefin and nearly completely inverted *axial*-4-*t*-butylcyclohexanol or its ester, in aqueous acetone, acetic acid or formic acid as solvents. The *axial*-4-*t*-butylcyclohexyl toluenesulfonate yielded 83–87% olefin and the rest alcohol, largely inverted *equatorial*-4-*t*-butylcyclohexanol in aqueous acetone, but containing increasing amounts of *axial*-4- and rearranged *axial*-3-*t*-butylcyclohexanols. The *axial*-4- and 3-alcohols are thought to arise from hydrogen-bridged cations, and the bearing of the results on the role, nature and behavior of carbonium ions in addition, solvolysis and rearrangement, is discussed.

In connection with investigations involving participation of neighboring groups in solvolysis of compounds containing cyclohexyl^{2,3} or steroidal^{4,5} ring systems, it was desirable to have available a pair of conformationally pure *equatorial* and *axial*^{6–9} simple cyclohexanols with no α - or β -substituents. The 4-*t*-butylcyclohexanols were anticipated as an ideal pair of such isomers, and the preparation and various reactions of these materials and some of their derivatives are described in the present article along with some comparable observations on the 3-

t-butylcyclohexanols which it became advisable to make during the course of the work.

The data collected on the *t*-butylcyclohexyl derivatives are helpful in understanding the rates of conformationally less homogeneous materials. In this paper the connection between rate and the distribution of a substance among conformational isomers is discussed. Also, a method of quantitative conformational analysis based on rate measurements is developed and applied.

Conformation and Reactivity.—For a better understanding of the relation of reactivity to structure and configuration we must explicitly recognize that both ground states and transition states may exist in more than one conformation. Such conformational heterogeneity is reduced^{8,10} in alicyclic systems, but one must pass over 3-, 4- and 5-rings^{10,11} to the cyclohexane ring to avoid angle strain and eclipsing strain as in acyclic materials.

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