hol is due to a combination of three factors: decreased ability of *t*-butyl alcohol to serve as a nucleophilic solvating agent for the incipient carbonium ion, decreased ability of the tertiary hydroxyl group to solvate the incipient chloride ion, and reduced dielectric constant of the solvent. However, considerable additional work would be required to establish the relative importance of each of these factors.

The Influence of the Water Content of Aqueous Ethanol on the Solvolysis Rates.—The solvolysis of neopentyldimethyl- and dineopentylmethylcarbinyl chlorides in 70, 80, 90 and 100% ethanol was observed. The data are reported in Table VI and Fig. 3.

Using these data and the expression $\log k = mY + \log k_0$ proposed by Grunwald and Winstein[19] it is possible to calculate the values of the parameter m for the two highly branched chlorides under investigation. The following data for m are of interest: *t*-butyl chloride, 1.000; *t*-amyl chloride, 0.873; neopentyldimethylcarbinyl chloride, 0.858; dineopentylmethylcarbinyl chloride, 0.698. It appears that m may measure the relative importance of the contribution by the solvent, with a low value of m indicating that the halide under consideration requires a relatively small contribution from the solvent in the ionization stage.

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[19] E. Grunwald and S. Winstein, THIS JOURNAL, **70**, 846 (1948).

LAFAYETTE, INDIANA

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY OF PURDUE UNIVERSITY]

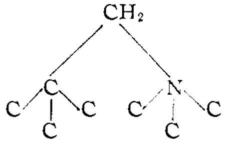
Neopentyltrimethylammonium Ion as a Strained Homomorph; the Rates of Reaction of Neopentyldimethylamine with Alkyl Iodides[1,2]

BY HERBERT C. BROWN AND W. HALLAM BONNER[3]

RECEIVED FEBRUARY 28, 1952

Neopentyltrimethylammonium ion is a homomorph of the strained molecules, *t*-butylamine-trimethylboron and di-*t*-butylmethane. The predicted slow rate of reaction of neopentyldimethylamine with methyl and ethyl iodides is observed—the rate constants are less than $^1/_{100}$ those of the corresponding reactions of *n*-butyldimethylamine and the energies of activation are 2.2–2.7 kcal. greater. The increase in steric strain in the reaction neopentyldimethylamine→neopentyltrimethylammonium ion was estimated from heats of formation data for homomorphic hydrocarbons. The result, 2.0–2.5 kcal., is considered to be in satisfactory agreement with the observed increase in activation energy.

Neopentyltrimethylammonium ion (I) is a homomorph of the strained molecules, *t*-butylamine-trimethylboron (II) and di-*t*-butylmethane. The addition compound, *t*-butylamine-trimethylboron, is some 5.4 kcal. less stable than estimated.[4] It is proposed that such strains, measured by the stability of molecular addition compounds, exist in homomorphs of the parent molecule and should markedly affect their properties. It follows that neopentyldimethylamine (III) should behave as a highly hindered amine in its reaction with methyl iodide and other alkyl halides, as contrasted with the behavior of an aliphatic amine without the unusual features of the neopentyl derivative.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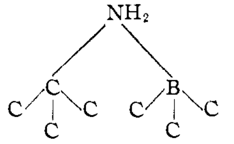
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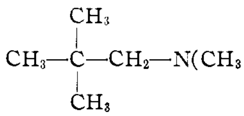
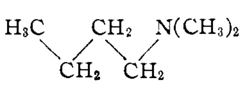


$$CH_3-\overset{\displaystyle CH_3}{\underset{\displaystyle CH_3}{\overset{|}{\underset{|}{C}}}}-CH_2-N(CH_3)_2$$

III



IV

In neopentyldimethylamine the branch is two atoms from the reaction center. Classically, this is not a molecule which would be expected to exhibit steric hindrance in a great degree. Actually, neopentyltrimethylammonium iodide was prepared some time ago by Ingold and Patel[5] by the reaction of neopentyldimethylamine and methyl iodide in the absence of a solvent. However, they did not report that the reaction displayed any unusual characteristics.

It appeared desirable, therefore, to examine the rate of reaction of neopentyldimethylamine with methyl and ethyl iodides and to compare these rates with those for a related amine without the unique structural features of the neopentyl derivative. *n*-Butyldimethylamine (IV) was selected for comparison.

The two tertiary amines were made by the sequence of reactions

$$\mathrm{RCOOH} \xrightarrow{\mathrm{C_6H_5COCl}} \mathrm{RCOCl} \xrightarrow{\mathrm{Me_2NH}} \mathrm{RCONMe_2} \xrightarrow{\mathrm{LiAlH_4}} \mathrm{RCH_2NMe_2}$$

The reactions with methyl and ethyl iodides were studied in nitrobenzene solution. The rate data are summarized in Table I and Fig. 1.

At 40° the reaction of methyl iodide with *n*-butyldimethylamine proceeds at a rate 120 times greater than that of the corresponding reaction with neopentyldimethylamine. Similarly, in the reaction with ethyl iodide there is a factor of 132 in the relative rates. This is certainly a very large difference which cannot be accounted for in terms of the minor differences in the polar effects of the neopentyl and *n*-butyl groups.

The differences in the energies of activation of the two amines with methyl iodide is 2.7 kcal. In the case of ethyl iodide, the difference is 2.2 kcal. Because of the lower precision of the kinetic data for the reaction of *n*-butyldimethylamine with methyl iodide, the smaller value is considered to be the better estimate of the difference in strains in the transition states for the neopentyl and *n*-butyl derivatives.

According to the concepts discussed in this series

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[1] Chemical Effects of Steric Strains. VII. Strained Homomorphs. IV.

[2] Based upon a thesis submitted by W. Hallam Bonner to the Faculty of Purdue University in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

[3] Purdue Research Foundation Fellow (1949–1951).

[4] H. C. Brown and G. K. Barbaras, THIS JOURNAL, **75**, 6 (1953).

[5] C. K. Ingold and C. S. Patel, *J. Chem. Soc.*, 67 (1933).

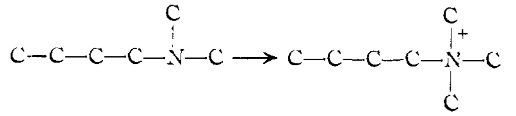
TABLE I

RATE CONSTANTS FOR THE REACTIONS OF *n*-BUTYL- AND NEOPENTYLDIMETHYLAMINES WITH METHYL AND ETHYL IODIDES[a]

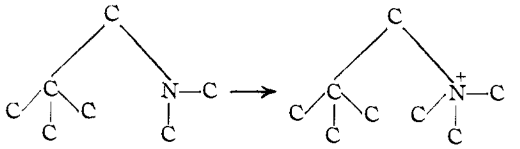
Amine	Iodide	Rate constants, k_2 (l. mole^{-1}sec.$^{-1}$)[b] 10°	25°	40°	60°	80°	E_{act}, kcal./mole	log PZ
n-Butyldimethyl-	Methyl	0.0665	0.144	0.310			9.1	5.84
Neopentyldimethyl-	Methyl		0.962×10^{-3}	2.58×10^{-3}	7.83×10^{-3}		11.8	5.63
n-Butyldimethyl-	Ethyl		1.59×10^{-3}	4.17×10^{-3}	13.9×10^{-3}		12.2	6.18
Neopentyldimethyl-	Ethyl			3.16×10^{-5}	12.9×10^{-5}	43.3×10^{-5}	14.4	5.55

[a] Solvent: nitrobenzene. [b] Precision of the rate constants ±2% except for *n*-butyldimethylamine and methyl iodide (±4%) where the rapidity of the reaction reduced the accuracy of the rate measurements.

of papers, the observed increase of 2.2–2.7 kcal. in the energy of activation should be related to the difference in steric strain resulting from the two structural changes.



$$\mathrm{C{-}C{-}C{-}C{-}\overset{C}{N}{-}C \longrightarrow C{-}C{-}C{-}C{-}\overset{C}{\underset{C}{\overset{|+}{N}}}{-}C} \quad (1)$$



(2)

That is, steric strain (2) − steric strain (1) should be approximately equal to 2.2–2.7 kcal.

Although thermodynamic data for the amines and quaternary salts shown in equations (1) and (2) are not available, data for the homomorphic hydrocarbons are available (Table II).

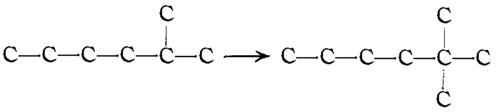
TABLE II

THERMODYNAMIC DATA[a] FOR ISOMERIC HYDROCARBONS (25°, GAS PHASE)

Hydrocarbon	ΔH_f, kcal.	Obsd.[b] ΔH_i, kcal.	Calcd.[c] ΔH_i, kcal.	Steric strain, kcal.
2-Methylbutane	−36.9	−1.9	−1.7	−0.2
2-Methylpentane	−41.7	−1.7	−1.7	.0
2-Methylhexane	−46.6	−1.7	−1.7	.0
2,2-Dimethylbutane	−44.6	−4.4	−4.6	+ .2
2,2-Dimethylpentane	−49.3	−4.4	−4.6	+ .2
2,2-Dimethylhexane	−53.7	−3.9	−4.6	+ .7
2,2,4-Trimethylpentane	−53.57	−3.75	−6.3	2.55
2,2,4,4-Tetramethylpentane	−58.71[d]	−3.97[d]	−9.2	5.2

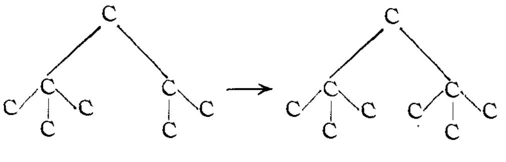
[a] E. J. Prosen and F. D. Rossini, *J. Research Natl. Bur. Standards*, **34**, 267 (1945). [b] Heat of isomerization of normal to branched-chain hydrocarbon. [c] R. Spitzer and K. S. Pitzer, THIS JOURNAL, **70**, 1263 (1948). [d] Calcd. from data for the liquid hydrocarbons. See note 18 [H. C. Brown, *et al.*, THIS JOURNAL, **75**, 1 (1953)].

From the data in Table II we see that the change



$$\mathrm{C{-}C{-}C{-}C{-}\overset{C}{\overset{|}{C}}{-}C \longrightarrow C{-}C{-}C{-}C{-}\overset{C}{\underset{C}{\overset{|}{C}}}{-}C} \quad (1')$$

involves an increase in steric strain of 0.2–0.7 kcal., while the related change



(2′)

is accompanied by an increase in steric strain of 2.7 kcal.

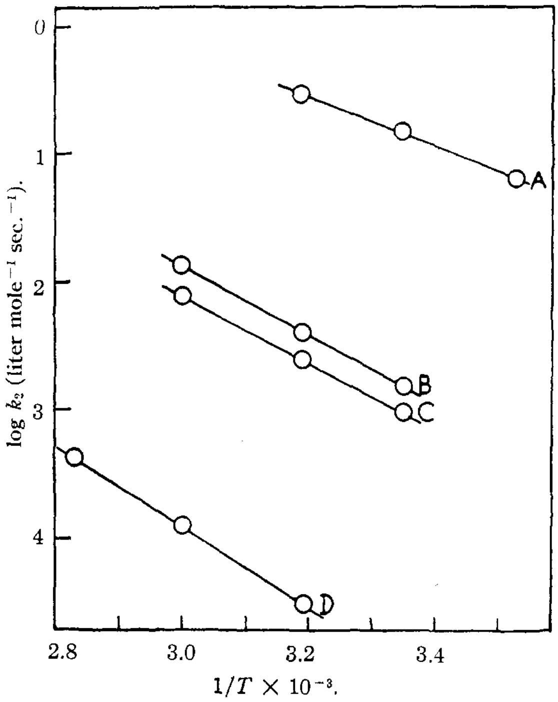


Fig. 1.—Energies of activation: A, *n*-butyldimethylamine + methyl iodide; B, neopentyldimethylamine + methyl iodide; C, *n*-butyldimethylamine + ethyl iodide; D, neopentyldimethylamine + ethyl iodide.

It follows that steric strain (2′) − steric strain (1′) is 2.0–2.5 kcal., in excellent agreement with the observed increase of 2.2–2.7 kcal. in the activation energies for the reactions of the two amines.

While this agreement may be only fortuitous in this particular case,[6] it does suggest the interesting possibility that we may be able to estimate with considerable precision strains in activated complexes from the strains in related hydrocarbons or in homomorphic addition compounds. A research program with this objective has been underway at Purdue University for several years. The results have been highly encouraging and will be reported shortly.[7]

(6) The energy of activation for the reaction of 2,6-lutidine with methyl iodide is 1.0 kcal. greater than for the corresponding reaction of pyridine. This is also in good agreement with the strain of 1.2 kcal. estimated in the product from heat of formation data for hemimellitene and isomeric hydrocarbons; see H. C. Brown, *et al.*, THIS JOURNAL, **75**, 1 (1953).

(7) Unpublished work with A. Cahn, M. Solomon and R. M. Horowitz. This investigation has been made possible by the financial support of the Office of Naval Research.

Experimental Part

***n*-Butyldimethylamine.**—N,N-Dimethylbutyramide b.p. 185–189°, was prepared in 84% yield by adding an excess of gaseous dimethylamine to a solution of 134 g. of butyryl chloride[8] in 200 cc. of ether. A solution of 117 g. of this amide in an equal volume of ether was added during two hours to a stirred solution of 38 g. of lithium aluminum hydride.[9] After standing overnight, an excess of acetone was slowly added to destroy excess lithium aluminum hydride, followed by 100 ml. of water. The reaction mixture was then placed in a 1-l. distilling flask, 200 ml. of water added, and the ether removed by distillation. Sodium hydroxide, 80 g., was added and a mixture of water and amine was collected until the distillate no longer reacted basic. The distillate was neutralized with hydrochloric acid and evaporated to a sirupy consistency. The concentrated solution of the amine hydrochloride was dropped onto solid pellets of potassium hydroxide and the free amine collected over pellets of potassium hydroxide. The amine was separated and distilled through a Todd micro column from phosphorus pentoxide. The pure amine, b.p. 94.7–95.2° at 749 mm., $n^{20}D$ 1.3970, was obtained in yields of 50%.

Neopentyldimethylamine.—Pivalic acid was converted into the acid chloride[8] in yield of 88%. The acid chloride was transformed into N,N-dimethylpivalamide, b.p. 180–183°, in 76% yield by the procedure described above. The amide was reduced[9] to dimethylneopentylamine, b.p. 97.5–97.8° at 754 mm., $n^{20}D$ 1.3972, in 50% yield.

Procedure for Kinetic Studies.—Technical nitrobenzene (du Pont) was used as the solvent. Standard solutions of the amine and alkyl iodide in this solvent were made by weighing. The concentrations were verified by analyzing the amine solutions by acid-base titration and the halide solution by the Volhard procedure, after converting the halogen into ionic form with an excess of piperidine. The change of concentration with change in temperature was corrected by applying a factor for the change in density of nitrobenzene with temperature. Equal volumes of equimolar (approximately 0.2 *N* each) solutions were mixed in a flask and 8 samples (10 ml.) were pipetted into small thin-walled ampules. These were sealed and placed in a constant temperature bath. At appropriate intervals an ampule was removed, rinsed with acetone, and smashed in a flask containing 10 ml. of 0.15 *N* hydrochloric acid in 40 ml. of water. The free base was determined by titration of the excess acid with standard (0.1 *N*) barium hydroxide solution, using methyl red as the indicator.

The reaction of methyl iodide with *n*-butyldimethylamine was too rapid to permit utilization of this procedure. In this case the concentration of the iodide and of the amine in the reacting mixture was reduced by a factor of five. Standardized solutions of the two reagents were brought to the reaction temperature, rapidly mixed and 25-ml. aliquots removed by pipet at suitable intervals. The extent of reaction was then determined as in the case of the sealed ampules.

The data for each determination were corrected by the method of least squares to give the best straight line through the points. The energies of activation were calculated from the reaction constants at three temperatures, again using the method of least squares in the calculation.

LAFAYETTE, INDIANA

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[8] H. C. Brown, THIS JOURNAL, **60**, 1325 (1938).

[9] A. Uffer and E. Schlittler, *Helv. Chim. Acta*, **31**, 1397 (1948).

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY OF PURDUE UNIVERSITY]

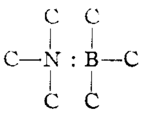
Dissociation of the Addition Compounds of Trimethylboron with *n*-Butyl- and Neopentyldimethylamines; Interaction of Trimethylboron and Boron Trifluoride with Highly Hindered Bases[1,2]

BY HERBERT C. BROWN AND ROLF B. JOHANNESEN[3]

RECEIVED FEBRUARY 28, 1952

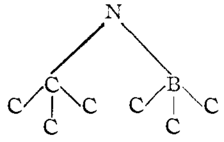
The conclusion that neopentyldimethylamine is a highly hindered base is verified by a study of the relative stabilities of the addition compounds of this base and of *n*-butyldimethylamine with trimethylboron. Whereas the latter base forms a stable addition compound with ΔH 15.3 kcal., ΔF°_{100} − 1720 cal. and ΔS° 45.6 e.u., the compound with neopentyldimethylamine is at least 98.5% dissociated at 50° and is too unstable to allow thermodynamic constants for its dissociation to be obtained. Neither 2-*t*-butylpyridine nor 2,6-lutidine add trimethylboron at temperatures as low as −80°. The Henry's law constants at 0°, 3060 and 4100 mm., respectively, are much larger than the value for an ideal solution, 1546 mm., indicating the absence of any attractive forces between the two bases and trimethylboron. From these observations, strains in the homomorphs of *o*-di-*t*-butylbenzene and 2,6-dimethyl-*t*-butylbenzene of at least 17 kcal. are estimated. Boron trifluoride does not add to *o*-*t*-butyl-N,N-dimethylaniline, leading to an increased estimate of 25 kcal. for the strains in homomorphs of *o*-di-*t*-butylbenzene. Boron trifluoride adds to 2,6,N,N-tetramethylaniline to form an unstable addition compound with a high dissociation pressure at room temperature.

Introduction



$$\begin{array}{ccccc} & C & & C & \\ & | & & | & \\ C{-} & N & : & B & {-}C \\ & | & & | & \\ & C & & C & \end{array}$$

I



II

The estimated heat of dissociation for the addition compound, trimethylamine-trimethylboron (I) is 25.4 kcal.; the experimental value is 17.6 kcal.[4] The discrepancy of 8 kcal. is attributed to steric strain.[4,5] It has long been recognized that the accumulation of alkyl groups about a reaction center may markedly decrease the reactivity of the molecule.[6] There is, therefore, no great surprise in the observation that the attachment of six

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[1] Acid-Base Studies in Gaseous Systems. X. Strained Homomorphs. V.

[2] Based upon a thesis submitted by Rolf B. Johannesen to the Faculty of Purdue University in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

[3] A.E.C. Fellow at Purdue University (1949–1951).

[4] H. C. Brown, H. Bartholomay and M. D. Taylor, THIS JOURNAL, **66**, 435 (1944).

[5] The strain is considered to be of two types: F-strain, which is dependent upon the steric requirements of the reference acid (*e.g.*, trimethylboron), and B-strain, which is independent of the reference acid. R. Spitzer and K. S. Pitzer [*ibid.*, **70**, 1261 (1948)] have carried out a calculation of B-strain from spectroscopic data and concluded that it is too small to be considered significant in trimethylamine itself. We have recently completed a number of similar calculations, using methods that in our opinion represent a less approximate approach, and have by these methods obtained values for B-strain that are some 10 times greater than that previously calculated by Spitzer and Pitzer. Moreover, we now have considerable new experimental data which strongly point to the presence of considerable strain in trimethylamine and related molecules. This work with E. A. Fletcher, E. Lawton and S. Sujishi will be reported shortly.

[6] For a review of the older literature dealing with steric hindrance see J. Cohen, "Organic Chemistry," Vol. 1, Edward Arnold and Co., London, 1928, 5th Ed., Chapt. V.