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Strained Homomorphs.[1] 14. General Summary.

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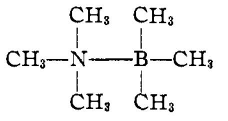
It is proposed that molecules having the same or closely similar molecular dimensions be termed "homomorphs." By consideration of the strains present in representative molecular addition compounds, an estimate is reached of the strains present in related homomorphic molecules. It is concluded that strains of 5.4 kcal./mole are present in homomorphs of di-*t*-butylmethane, strains of 17 kcal./mole in homomorphs of 2,6-dimethyl-*t*-butylbenzene, and strains of at least 25 kcal./mole in homomorphs of *o*-di-*t*-butylbenzene. The strains in homomorphs of hemimellitene (1-2 kcal.) and *o*-*t*-butyltoluene (4-6 kcal.) are somewhat smaller. In all of these cases it is possible to follow the effect of the strain upon the chemical properties of a wide variety of homomorphic derivatives. The concept of homomorphs permits a useful correlation between the chemical properties of molecules of widely different functions, but of similar sizes and shapes.

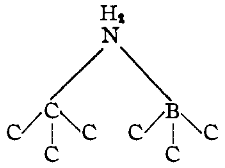
Ten years ago, in the first paper of this series,[8] it was proposed that the study of molecular addition compounds should furnish a convenient tool for the estimation of steric strains in related carbon compounds. The dimensions and geometry of the boron-nitrogen bond are almost identical with those of the carbon-carbon bond. Any strains present in the addition compounds, trimethylamine-trimethylboron (I) and *t*-butylamine-trimethylboron (II) should also be present in the hydrocarbons hexamethylethane (III) and di-*t*-butylmethane (IV), respectively.

It is apparent that the concept need not be restricted to hydrocarbons. Replacement of one or more atoms or groups in the hydrocarbon by other atoms or groups of closely similar dimensions should result in the formation of molecules with widely different functional groups, but with closely related strains. Examples of such structural changes in the case of di-*t*-butylmethane are illustrated in Fig. 1.

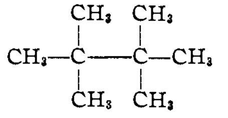


$$\begin{array}{cccc} & \mathrm{CH_3} & \mathrm{CH_3} & \\ & | & | & \\ \mathrm{CH_3}- & \mathrm{N}- & -\mathrm{B} & -\mathrm{CH_3} \\ & | & | & \\ & \mathrm{CH_3} & \mathrm{CH_3} & \end{array}$$

I

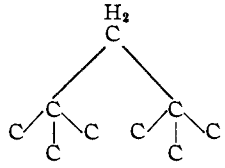


II



$$\begin{array}{cccc} & \mathrm{CH_3} & \mathrm{CH_3} & \\ & | & | & \\ \mathrm{CH_3}- & \mathrm{C}- & -\mathrm{C} & -\mathrm{CH_3} \\ & | & | & \\ & \mathrm{CH_3} & \mathrm{CH_3} & \end{array}$$

III



IV

It is, of course, well known that molecules having the same general size and shape are frequently quite similar in their physical properties. The similarity in melting point, volatility and odor of hexamethylethane and triptyl chloride is a typical example.[9] Evidence is here advanced to support the original thesis that strains, estimated from the stability of addition compounds, persist in related organic molecules of similar sizes and shapes and profoundly modify the chemical behavior of these substances.

Although experimental examination of the utility of the concept was undertaken at the time of the original publication, a number of circumstances made it impossible to pursue the investigation as rapidly as desired. Accordingly discussion was

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[1] Studies in Stereochemistry. XIX. Based upon theses submitted to the faculties of the University of Chicago, Wayne University, and Purdue University in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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[7] A.E.C. Fellow at Purdue University (1950-1952).

[8] H. C. Brown, H. I. Schlesinger and S. Z. Cardon, THIS JOURNAL, **64**, 325 (1942).

[9] G. Calingaert, H. Soroos, V. Hnizda and H. Shapiro, *ibid.*, **66**, 1389 (1944).

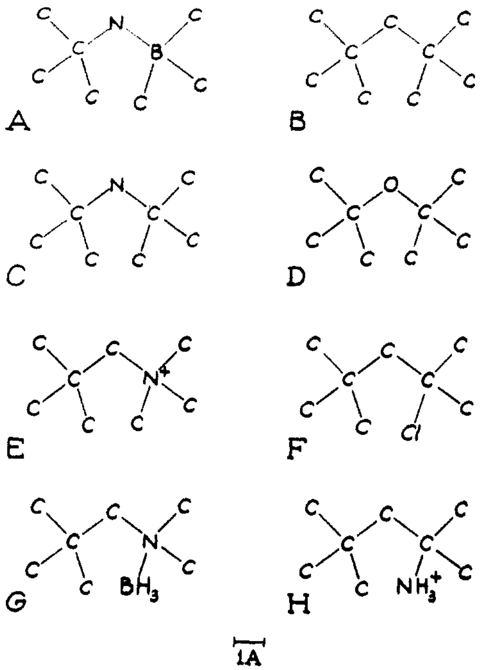

Fig. 1.—Homomorphs of di-*t*-butylmethane.

deferred until additional data were available. Such data are now reported in the accompanying series of papers. In the meantime, however, Spitzer and Pitzer have discussed this relationship between strains in addition compounds and strains in hydrocarbons.[10] Consequently, the present paper will be restricted largely to a discussion of the effects of related strains on the chemistry of other types of organic compounds.

It is convenient to have a term to designate molecules which have similar molecular dimensions. The term "homomorph" is proposed for molecules related in this manner.[11]

Homomorphs of Di-*t*-butylmethane.—Typical homomorphs of di-*t*-butylmethane are indicated in Fig. 1. The molecules are drawn to scale[12] in such a way as to indicate the steric relationships. If we consider the value of the van der Waals radii for methyl, chlorine, borine and the $^+NH_3$ group, it is apparent that there must be considerable crowding and steric strain in these homomorphic molecules.

An estimate of this strain is provided by the dissociation data for *t*-butylamine-trimethylboron (Fig. 1A). The heat of dissociation of this compound is 13.0 kcal.[13] as compared to the 18.4 kcal. for the corresponding *n*-butylamine derivative.[14] Since the two amines do not differ significantly in base strength,[15] the difference in the heats of dissociation, 5.4 kcal., may be attributed to steric strain in the *t*-butylamine derivative. It follows from the thesis proposed that steric strain of this magnitude should be present in the homomorphs of di-*t*-butylmethane and should profoundly affect the ease with which they may be prepared, their stabilities, and their reactions.

It is probably significant that the preparation of di-*t*-butyl ether (Fig. 1D) was first reported in 1941 by the relatively unusual reaction of silver carbonate with *t*-butyl chloride.[16] Moreover, the compound is highly unstable to acids. In addition, the preparation of di-*t*-butylamine (Fig. 1C) has been reported but once in a yield of 12% in 70% purity[17] and attempts to repeat this preparation in at least two other laboratories have been unsuccessful.

Combustion data permit an estimation of the strain energy in di-*t*-butylmethane (Fig. 1B). These measurements lead to a value for the heat of isomerization of *n*-nonane (g) to di-*t*-butylmethane (g) of −3.97 kcal.[18] However, from the estimate by Spitzer and Pitzer,[10] each neo grouping should stabilize a molecule over its straight-chain isomer by 4.6 kcal. It follows that di-*t*-butylmethane is 5.2 kcal. less stable than predicted on this basis, leading to an estimated strain of this magnitude. Considering the approximations that are necessarily made in estimating the strains in the hydrocarbon as well as in the addition compound, the agreement between the two values, 5.2 and 5.4, may be considered satisfactory.

From the similar dimensions of the chlorine atom and the methyl group, one may predict that strains of this magnitude (*i.e.*, 5.2–5.4 kcal.) should be present in neopentyldimethylcarbinyl chloride (Fig. 1F). It was pointed out some time ago that if steric strain is relieved in the course of attaining the transition state, the reaction will be strongly assisted.[19]

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[10] R. Spitzer and K. S. Pitzer, THIS JOURNAL, **70**, 1261 (1948).

[11] The term "isostere" is restricted to compounds containing the same total number of electrons. Some, but not all, homomorphs are also isosteres. H. Erlenmeyer and H. P. Furger [*Helv. Chim. Acta*, **26**, 366 (1943)] have utilized the term "structure-similar" with a somewhat different connotation. The term "homomorph" should be particularly useful in biological and pharmaceutical chemistry to designate such related molecules as sulfanilamide and *p*-aminobenzoic acid.

[12] L. Pauling, "The Nature of the Chemical Bond," Cornell University Press, Ithaca, N. Y., 1939.

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

[14] H. C. Brown, M. D. Taylor and Sei Sujishi, *ibid.*, **73**, 2464 (1951).

[15] *n*-Butylamine, pK_a 10.61 (25°); *t*-butylamine, pK_a 10.82 (16°). N. F. Hall and N. R. Sprinkle, THIS JOURNAL, **54**, 3473 (1932); G. Vexlearschi, *Compt. rend.*, **228**, 1655 (1949).

[16] J. L. E. Erickson and W. H. Ashton, THIS JOURNAL, **63**, 1769 (1941).

[17] F. Klages, G. Nober, F. Kircher and M. Bock, *Ann.*, **547**, 1 (1941).

[18] The heats of combustion of *n*-nonane and di-*t*-butylmethane [W. H. Johnson, E. J. Prosen and F. D. Rossini, *J. Research Natl. Bur. Standards*, **38**, 419 (1947)] lead to the equation:

(1) *n*-nonane (1,25°) = di-*t*-butylmethane (1,25°) $\Delta H = -1.11$ kcal.

To obtain the heat of isomerization for the gaseous hydrocarbons, it was necessary to estimate the heat of vaporization of di-*t*-butylmethane. This quantity was estimated in two ways. A comparison of data for the heats of formation at 25° for the gaseous and liquid hydrocarbons [E. J. Prosen and F. D. Rossini, *ibid.*, **34**, 267 (1945)] yielded values for the heats of vaporization at 25° of a number of isomeric hydrocarbons from the butanes through the octanes. The data reveal that the average decrease in the heat of vaporization from the normal isomer is 0.43 kcal. for an iso grouping and 1.00 kcal. for a neo grouping. The effect appears to be additive. Thus, the heat of vaporization of 2,5-dimethylhexane with two iso groupings is 0.86 kcal./mole less than for *n*-octane and the value for 2,2,4-trimethylpentane with one iso and one neo grouping is 1.51 kcal. less. Therefore, the heat of vaporization at 25° of di-*t*-butylmethane with two neo groupings is estimated to be 8.1 kcal., or 2.0 kcal. less than for *n*-nonane. Application of the method of W. Heukelom [*Rec. trav. chim.*, **68**, 661 (1949)] leads to a value of 8.38 kcal. at the b.p. The average of these two estimates, 8.24 kcal., was adopted.

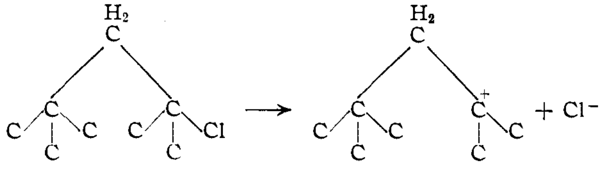
(2) *n*-nonane (g,25°) = *n*-nonane (1,25°) $\Delta H = -11.10$ kcal.

(3) di-*t*-butylmethane (1, 25°) = di-*t*-butylmethane (g, 25°) $\Delta H = +8.24$ kcal.

Combining equations 1–3, we obtain: *n*-nonane (g, 25°) = di-*t*-butylmethane (g, 25°)$\Delta H = -3.97$ kcal.

[19] H. C. Brown, *Science*, **103**, 385 (1946). We believe that this paper contains the first proposal that relief of steric strain should assist the solvolysis of tertiary chlorides, as well as other reactions of highly branched carbon compounds which proceed with a decrease in steric strain in the transition state. E. D. Hughes, *et al.* [*Nature*, **167**, 987 (1951)] have recently provided another discussion of this principle, apparently overlooking our original discussion. In this connection we also wish to point out the early suggestion by G. Baddeley [*ibid.*, **144**, 444 (1939)] that bulky ortho groups in aromatic compounds may sterically promote aromatic substitution by a combination of steric and electrical effects.

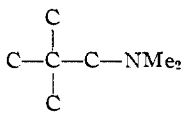
The ionization of the tertiary chloride should lead to a carbonium ion with considerably less strain (V).


V

In conformity with this prediction, rate studies revealed that neopentyldimethylcarbinyl chloride[20] solvolyzes in 80% ethanol at a rate some 16 times that of *n*-butyldimethylcarbinyl chloride.[21]

Additional support for the importance of steric strains in these compounds is the observation that the tertiary chloride with two neopentyl groups, dineopentylmethylcarbinyl chloride, could be prepared from the olefin only at low temperatures. At room temperature this chloride dissociates spontaneously into hydrogen chloride and olefin; moreover, it solvolyzes at a rate some 400 times that of less strained tertiary chlorides.[20]

In further support of the principle that reactions which involve a decrease in steric strain in the transition state are assisted, while reactions which involve an increase are hindered,[22] is the contrasting behavior of neopentyldimethylamine (VI) and *n*-butyldimethylamine (VII) toward alkyl halides. At first glance it would appear that neopentyldimethylamine, with the branch in the chain two atoms removed from the reaction center, should react quite normally. However, the product of the reaction with methyl iodide, neopentyltrimethylammonium ion, is a homomorph of di-*t*-butylmethane (Fig. 1E). It was observed that the reactions of *n*-butyldimethylamine with methyl and ethyl iodides proceeded more than 100-fold faster than did the corresponding reactions of neopentyldimethylamine.[23] Moreover, the observed increase in the energy of activation for the hindered amine, 2.2–2.7 kcal., is similar to the increase in steric strain in hydrocarbons of related structure.[23]



$$\mathrm{C{-}\overset{\displaystyle C}{\underset{\displaystyle C}{C}}{-}C{-}NMe_2}$$

VI

$\mathrm{C{-}C{-}C{-}C{-}NMe_2}$

VII

Finally we observed that neopentyldimethylamine forms a highly unstable addition compound with trimethylboron, far less stable than the corresponding derivative with *n*-butyldimethylamine.[24]

It follows from this presentation that the results do indeed point to the presence in the homomorphs of di-*t*-butylmethane of strains which profoundly affect the reactions of these substances.

Homomorphs of 2,6-Dimethyl-*t*-butylbenzene.—Trimethylboron forms a stable compound with pyridine with a heat of dissociation of 17.0 kcal.[25] With 2,6-lutidine, a stronger base (in aqueous solution), trimethylboron does not react (Fig. 2A). Indeed, a determination of the solubility of gaseous trimethylboron in 2,6-lutidine not only does not indicate any tendency toward combination, but the gas is even less soluble than is calculated for an ideal solution.[24] It follows that homomorphs of 2,6-dimethyl-*t*-butylbenzene (Fig. 2) should be strained by at least 17 kcal.

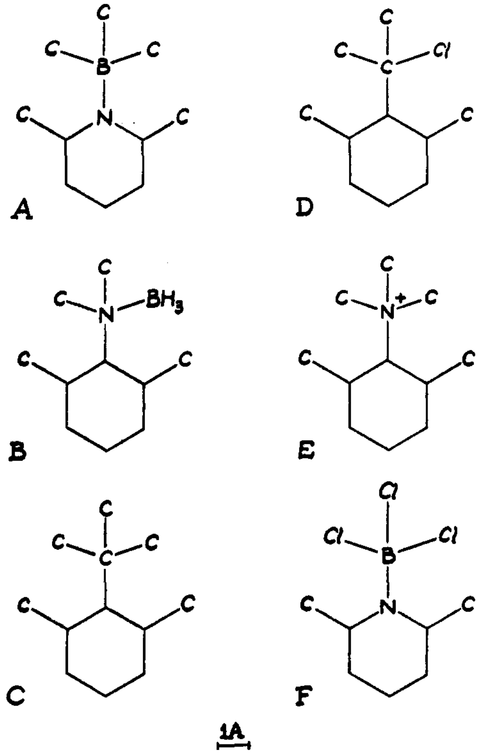


Fig. 2.—Homomorphs of 2,6-dimethyl-*t*-butylbenzene.

The parent hydrocarbon (Fig. 2C) is not known. An attempt was made to introduce a *t*-butyl group between two methyl groups by a Friedel–Crafts reaction on mesitylene. However, under conditions which gave an excellent yield of 1,3-dimethyl-5-*t*-butylbenzene with *m*-xylene, no *t*-butylation of mesitylene occurred.[26]

Similarly, over a period of several months, no significant reaction of 2,6-N,N-tetramethylaniline with methyl iodide (Fig. 2E) was observed.[26] The reaction with boron trifluoride is also pertinent. Whereas the heat of reaction of boron trifluoride with trimethylamine may be estimated as 28 kcal.[27] and that observed for the corresponding reaction with pyridine is 25.0 kcal.,[28] 2,6,N,N-tetramethylaniline adds boron trifluoride with difficulty.[24] The compound is unstable and readily loses boron trifluoride. By comparison with other similar unstable addition compounds, the heat of reaction of the amine with boron trifluoride must be less than 10 kcal./mole.[29] From these data it follows that the addition of the BF_3 group is accompanied by an increase in strain of approximately 15 kcal. In view of the magnitude

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(20) H. C. Brown and H. L. Berneis, THIS JOURNAL, **75**, 10 (1953).

(21) H. C. Brown and R. S. Fletcher, *ibid.*, **71**, 1845 (1949).

(22) E. D. Hughes, *et al.* (ref. 19), propose to replace the commonly used term "steric hindrance" by the new term "steric retardation" and propose the corollary term "steric acceleration." However, we see no advantage in the proposed change and will continue to use the terms steric hindrance and steric assistance to designate the two opposite effects of steric strains on reaction rates and equilibria.

(23) H. C. Brown and W. H. Bonner, THIS JOURNAL, **75**, 14 (1953).

(24) H. C. Brown and R. B. Johannesen, *ibid.*, **75**, 16 (1953).

(25) H. C. Brown and G. K. Barbaras, *ibid.*, **69**, 1137 (1947).

(26) H. C. Brown and M. Grayson, *ibid.*, **75**, 20 (1953).

(27) A. B. Burg and Sister A. A. Green, *ibid.*, **65**, 1838 (1943).

(28) Unpublished work with R. M. Horowitz.

(29) Strictly speaking the boron trifluoride group is somewhat too large to convert 2,6,N,N-tetramethylaniline into a satisfactory homomorph of 2,6-dimethyl-*t*-butylbenzene. The borine addition compound (Fig. 2B) would be much more satisfactory. However, the use of diborane in these studies has offered difficulties which we are only now overcoming. Thermochemical measurements of the heats of reactions of diborane with representative tertiary amines are under investigation.

of the strains involved, the observed failure of the amine to react with methyl iodide is not surprising.

Finally we synthesized 2,6-dimethylphenyldimethylcarbinol and mesityldimethylcarbinol[30] and attempted to convert these tertiary alcohols into the corresponding tertiary chlorides.[26] However, under conditions which readily convert phenyldimethylcarbinol into its chloride, the di-ortho-substituted carbinols are merely converted into the corresponding olefins. The olefins neither add bromine nor decolorize cold permanganate solutions. At temperatures of −30 to −80°, the olefins appear to absorb considerable hydrogen chloride and are converted into red solids, perhaps carbonium ion salts. However, upon warming to room temperature or upon solution in cold alcohol, the hydrogen chloride is given off and no evidence for the formation of the tertiary chloride can be obtained.

From published values of bond energies[12] it may be calculated that the addition of hydrogen chloride to an olefin is normally exothermic to the extent of 9.7 kcal./mole. However, in the case of 2,6-dimethylphenyldimethylcarbinyl chloride (Fig. 2D) there will be present strains of at least 17 kcal. This is sufficient to reverse the normal mode of reaction and render the loss of hydrogen chloride from this molecule quite exothermic.

With the sole exception of the unstable addition compound of 2,6,N,N-tetramethylaniline and boron trifluoride, no homomorph of 2,6-dimethyl-*t*-butylbenzene could be prepared, in excellent support of the conclusion that homomorphs of this compound should carry strains of at least 17 kcal.

Homomorphs of *o*-Di-*t*-butylbenzene.—As was pointed out previously, the heat of reaction of boron trifluoride is estimated to be approximately 25 kcal. and the observation that boron trifluoride fails to add to *o*-*t*-butyl-N,N-dimethylaniline at 0 or −80° points to a minimum strain in the homomorphs of *o*-di-*t*-butylbenzene (Fig. 3) of this magnitude.[24] It follows that such homomorphs should be exceedingly difficult, if not impossible, to prepare. For example 25 kcal. is an appreciable fraction of the normal strength of a carbon-carbon bond[12] and calculation reveals that on this basis the loss of isobutylene from *o*-di-*t*-butylbenzene should proceed as an exothermic process at 25°. It follows that the synthesis of *o*-di-*t*-butylbenzene (Fig. 3C) or related hydrocarbons through the Friedel–Crafts reaction is not feasible, although alternative, indirect syntheses may prove possible.

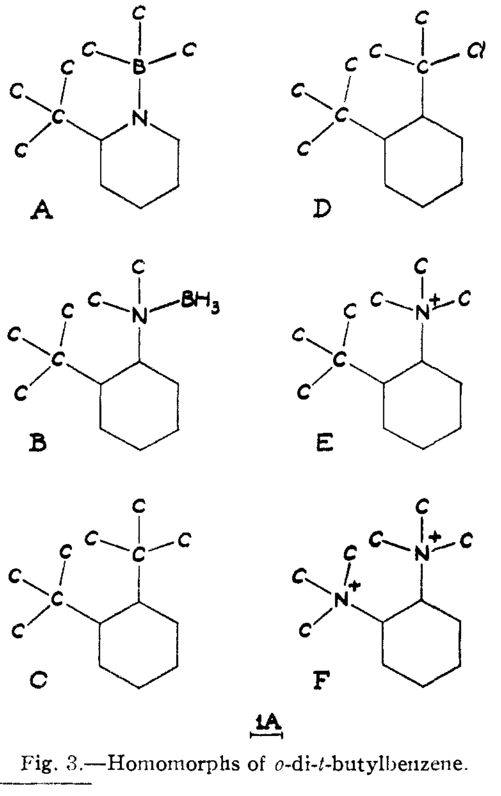
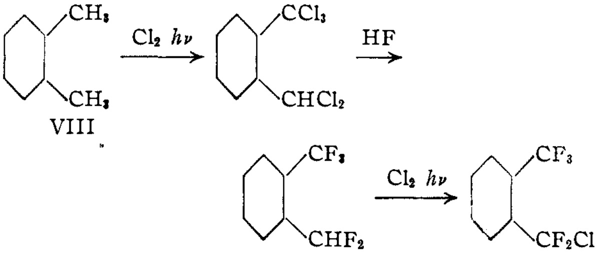


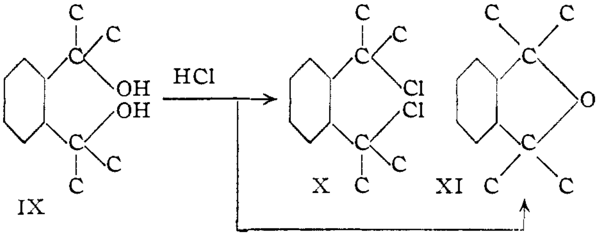
Fig. 3.—Homomorphs of *o*-di-*t*-butylbenzene.

In view of the magnitude of the strain involved, it is not surprising that no homomorphs of *o*-di-*t*-butylbenzene are known. Trimethylboron does not add to 2-*t*-butylpyridine (Fig. 3A).[24] *o*-Phenylenediamine reacts with a total of five moles of methyl iodide (Fig. 3F) to form 2-(dimethylamino)-N,N,N-trimethylanilinium iodide,[31] whereas *m*- and *p*-phenylenediamine readily react with six moles of methyl iodide to form the bis-quaternary ammonium salts.[32] Similarly, over a period of several months, no reaction was observed between *o*-*t*-butyl-N,N-dimethylaniline and methyl iodide (Fig. 3E).[31]

Finally, it is interesting to note that in the chlorination of *o*-xylene, five but not six chlorine atoms could be introduced on the side chains, whereas in the meta and para compounds a total of six chlorine atoms could be so introduced. If the five chlorines (van der Waals radius 1.80 Å.) of the ortho isomer are replaced by five fluorine atoms (van der Waals radius 1.35 Å.), the remaining hydrogen can then be substituted by photochlorination (VIII).[33]



One further case may be cited in support of the thesis. Treatment of the bis-tertiary glycol[34a] (IX) with hydrogen chloride[31] does not yield the bis-tertiary chloride (X); instead the stable ether[34b] (XI) is obtained.



In the two cases just discussed of *o*-di-*t*-butylbenzene and of 2,6-dimethyl-*t*-butylbenzene the strains are so great (17–25 kcal.) as effectively to prohibit the ready formation of homomorphs of these structures. The strains in the homomorphs of di-*t*-butylmethane are considerably less (5.4 kcal.) so that no difficulty was encountered in synthesizing a number of the homomorphs and in following the effect of the strain on the chemical behavior of these substances. It is of interest to examine homomorphs of hemimellitene and *o*-*t*-butyltoluene, substances in which the strains

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[30] E. P. Kohler and L. W. Blanchard, Jr., THIS JOURNAL, **57**, 367 (1935); M. S. Newman and N. C. Deno, *ibid.*, **73**, 3644 (1951).

[31] H. C. Brown and K. L. Nelson, *ibid.*, **75**, 24 (1953).

[32] A. W. Hofmann, *Compt. rend.*, **56**, 994 (1863).

[33] I. G. Farbenindustrie Aktiengesellschaft, British Patent, 465,885 (May 18, 1937).

[34] (a) E. Ott and F. Schurmann, *Ber.*, **61**, 2119 (1928); (b) G. M. Bennett and R. L. Wain, *J. Chem. Soc.*, 1114 (1936).

would be expected to be even smaller than that present in di-*t*-butylmethane, in order to observe whether the smaller strain plays any important role in the reactions of these homomorphs.

Homomorphs of Hemimellitene.—Representative homomorphs of hemimellitene are shown in Fig. 4. From the heats of combustion of the trimethylbenzenes,[35] hemimellitene (Fig. 4D) appears to be approximately 1.2 kcal./mole less stable than its isomers. 2,6-Lutidine-borine (Fig. 4A) is less stable than pyridine-borine,[36] but quantitative data are not now available. The rates of reaction of pyridine and 2,6-lutidine with methyl iodide (Fig. 4E) in nitrobenzene solution at 60° are 39.0×10^{-4} and 2.35×10^{-4} l. mole^{-1} sec.$^{-1}$, respectively. The corresponding energies of activation are 13.9 and 14.9 kcal./mole.[37]

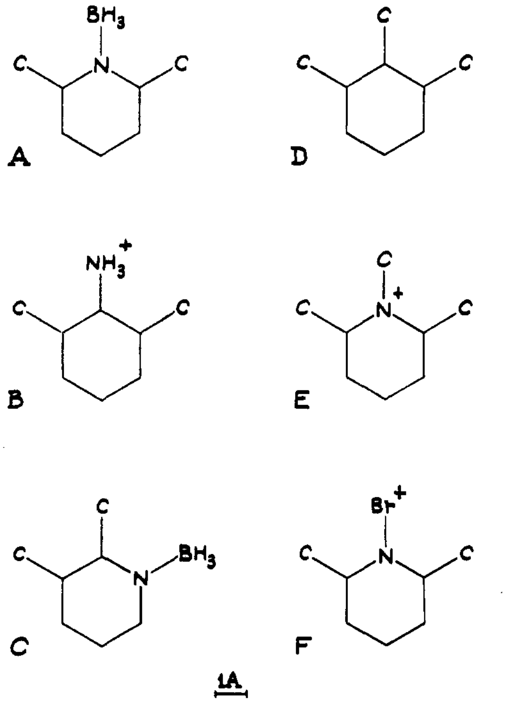

Fig. 4.—Homomorphs of hemimellitene.

It may be significant that the 1.0 kcal. difference in energy of activation is in fair agreement with the strain predicted from combustion data. It was previously pointed out that the increase in energy of activation observed in the reaction of methyl iodide with neopentyldimethylamine also corresponds closely to the increase in steric strain observed in homomorphic hydrocarbons.[23] *m*-2-Xylidinium ion (Fig. 4B), the conjugate acid of *m*-2-xylidine, is also homomorphic with hemimellitene. The evidence for strain in this case lies in the weakness of *m*-2-xylidine as a base, pK_a being 3.42 *versus* 4.25 for aniline,[38] whereas the operation of both the inductive effect and steric inhibition of resonance should tend to increase the strength of the first base. The postulate that such strains are present in other related ortho substituted aromatic bases provides a simple reasonable explanation of hitherto unexplained peculiarities in the strengths of such bases.[39]

Homomorphs of *o*-*t*-Butyltoluene.—Of the three measurements which might give a satisfactory estimate of the strains in homomorphs of *o*-*t*-butyltoluene[40] (Fig. 5), the heat of combustion of the hydrocarbon (Fig. 5B), the heat of reaction of trimethylboron with 2-picoline (Fig. 5E), or the heat of reaction of borine with 2-*t*-butylpyridine (Fig. 5A), none are presently available.[41] From the observation that the heats of reaction of boron trifluoride with pyridine and 2-*t*-butylpyridine are 25.0 and 14.8 kcal., respectively, an upper limit to the strain of 10 kcal. can be placed.[23] However, the steric requirements of the borine group are considerably smaller than for boron trifluoride (Fig. 6), so that the actual strain must be considerably lower.

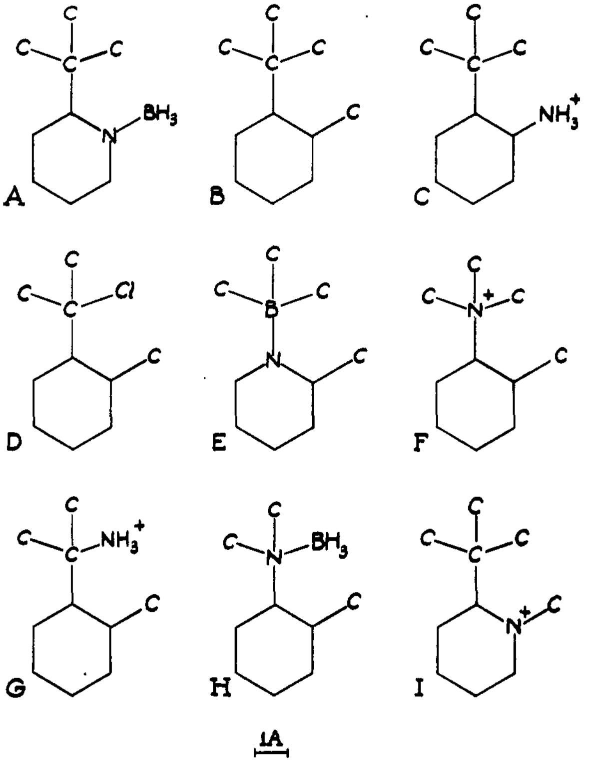

Fig. 5.—Homomorphs of *o*-*t*-butyltoluene.

The energies of activation for the reaction of methyl iodide with pyridine and 2-*t*-butylpyridine (Fig. 5I) in nitrobenzene solution are 13.9 and 17.5 kcal., respectively.[42] In view of the excellent agreement previously noted between the strains estimated from combustion data for homomorphic hydrocarbons and the observed increases in the energies of activation for the reactions of methyl iodide with neopentyldimethylamine and with 2,6-lutidine, the value 3.6 kcal. can be tentatively adopted as a lower limit for the strain present in homomorphs of *o*-*t*-butyltoluene. The energy of activation for the reaction of dimethyl-*o*-toluidine with methyl iodide to form the homomorph, *o*-

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(35) W. H. Johnson, E. J. Prosen and F. D. Rossini, *J. Research Natl. Bur. Standards*, **35**, 141 (1945).

(36) Unpublished work of H. C. Brown.

(37) Unpublished work with D. Gintis.

(38) G. Thomson, *J. Chem. Soc.*, 1113 (1946).

(39) H. C. Brown and A. Cahn, THIS JOURNAL, **72**, 2939 (1950).

(40) See K. T. Serijan, H. F. Hipsher and L. C. Gibbons, *ibid.*, **71**, 873 (1949), for a recent preparation of *o*-*t*-butyltoluene.

(41) We are currently studying the heats of reaction of trimethylboron and diborane with pyridine bases: work in progress with D. Gintis and L. Domash.

(42) Unpublished work with A. Cahn.

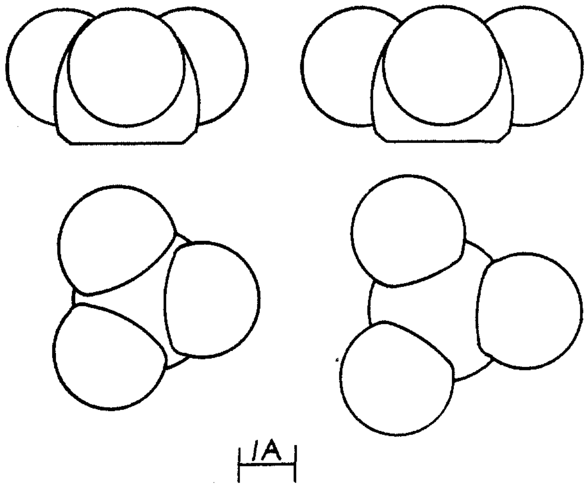

Fig. 6.—Molecular models: borine (left) and boron trifluoride (right).

tolyltrimethylammonium ion (Fig. 5F) is reported[43] to be 21.1 kcal., as compared with the value 15.2 for dimethylaniline. In view of our results, the difference 5.9 kcal. appears somewhat high. However, the aniline bases involve the possibility of an additional complication—steric inhibition of resonance. The precise relationships in these bases between strain in the transition state and increase in energy of activation must await further study.

Finally, it is significant that *o-t*-butylaniline is quite weak in water, pK_a being 3.78 *versus* 4.58 for aniline itself.[44] That is to say, the strained homomorph, *o-t*-butylanilinium ion (Fig. 5C) exhibits an enhanced tendency to transfer its proton to water.

Conclusions.—From this survey it appears that strains of the following magnitudes may be assigned to the model homomorphs:

Hemimellitene	1–2 kcal./mole
o-t-Butyltoluene	4–6
Di-*t*-butylmethane	5.4
2,6-Dimethyl-*t*-butylbenzene	≥ 17
o-Di-*t*-butylbenzene	≥ 25

Completion of present studies[42] on the heats of reaction of diborane and trimethylboron with pyridine bases will permit a more precise assignment of strains to the homomorphs of hemimellitene and *o-t*-butyltoluene. These strains have a pronounced effect on the homomorphs of these hydrocarbons. With the strains of lower magnitude, their effects are observed as decreased ease of formation of the compounds, decreased rates of reactions leading to the formation of the strained system, increased rates of reactions where the reaction leads to a decrease in strain, and decreased base strengths, both toward Lewis acids and hydrogen ion. The strains in the upper range appear sufficiently great as to prohibit practically all reactions which lead to the formation of the strained systems. Finally, it appears that the concept of homomorphs permits a useful correlation between the chemical properties of molecules of widely different functions, but of similar sizes and shapes.

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[43] D. P. Evans, H. B. Watson and R. Williams, *J. Chem. Soc.*, 1345, 1348 (1939).

[44] Private communication from Dr. B. M. Wepster of Delft Technical University, Delft, The Netherlands.

[CONTRIBUTION FROM THE GEORGE HERBERT JONES LABORATORY OF THE UNIVERSITY OF CHICAGO]

Dissociation of the Addition Compounds of Trimethylboron with Branched-Chain Primary Amines; the Effects of Chain-Branching[1,2]

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The addition compounds of trimethylboron with isopropyl-, *s*-butyl- and *t*-butylamines were prepared and characterized and their dissociation in the gas phase was examined. At 100° the dissociation constants for the reaction, $RNH_2{:}BMe_3 \rightleftharpoons RNH_2 + BMe_3$, are: R = H, 4.62 atm.; Me, 0.0360; Et, 0.0705; *i*-Pr, 0.368; *s*-Bu, 0.373; *t*-Bu, 9.46. The heats of dissociation show a marked decrease with chain-branching, the effect being especially pronounced in the case of the *t*-butylamine derivative: H, 13.75 kcal.; Me, 17.6; Et, 18.0; *i*-Pr, 17.4; *s*-Bu, 17.3; *t*-Bu, 13.0. Since the *n*-Bu compound has a heat of dissociation of 18.4 kcal., a strain of 5.4 kcal. is assigned to structures related to *t*-butylamine-trimethylboron (homomorphs of di-*t*-butylmethane).

Introduction

Previous qualitative experiments had shown that chain-branching in the alkyl group of the amine leads to a decrease in the stability of addition compounds with trimethylboron.[4] The decrease in stability was ascribed to steric strain arising from the larger steric requirements of the branched alkyl group. As part of our program to obtain quantitative data for the effect of structure on the stability of molecular addition compounds, it was decided to study the dissociation of the addition compounds of such branched-chain amines. Accordingly, the addition compounds of trimethylboron with isopropyl-, *s*-butyl- and *t*-butylamines were prepared and their dissociation in the gas phase studied by the techniques previously described.[5]

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[1] Acid–Base Studies in Gaseous Systems. IX. Strained Homomorphs. II. A preliminary communication of a portion of these results was published in *J. Chem. Phys.*, **14**, 114 (1946).

[2] Based upon a thesis submitted by Geraldine K. Barbaras to the Faculty of the University of Chicago in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

[3] Department of Chemistry, Purdue University.

[4] H. C. Brown, THIS JOURNAL, **67**, 1452 (1945); H. C. Brown and H. Pearsall, *ibid.*, **67**, 1765 (1945).

[5] H. C. Brown and M. Gerstein, *ibid.*, **72**, 2923 (1950).