

sistent with the moments of the chloro and methyl derivatives,  $117 \pm 3^\circ$ , indicates that if tautomerism exists, the keto form is present in the tautomeric mixture to a very small extent.

If dioxane were to break the OH---N bonds in these anils, forming O---HO bonds, the solvated salicylideneaniline molecules should have a configuration similar to that of the methyl ether, with a moment of about 3.6. The calculated moments of salicylidene-*p*-toluidine and salicylidene-*p*-chloroaniline with this configuration in dioxane are 3.3 and 4.6. Assuming no rupture of the OH---N bonds, the moments of these anils should be about 0.15 unit higher in dioxane than in benzene, a portion of this increase being due to the interaction of dioxane with the H—C=N hydrogen atoms. The addition of this increment gives values of 2.55, 2.78 and 2.42, respectively, for the calculated moments of salicylideneaniline, salicyl-

idene-*p*-toluidine and salicylidene-*p*-chloroaniline. The moments obtained for these three compounds in dioxane are 2.57, 2.74 and 2.49, indicating that dioxane does not break the OH---N bonds in the anils.

### Summary

Electric moments reveal that about 83% of salicylonitrile molecules have a *cis* configuration in carbon tetrachloride, indicating a weak OH---N bond. Very many of these bonds are broken when this compound is dissolved in benzene, and almost all are broken in dioxane.

An analysis of the moments of several anils indicates the presence of an O—H---N bridge in salicylideneaniline which is not broken in dioxane. The keto form is present to a very small extent, if at all, in this compound.

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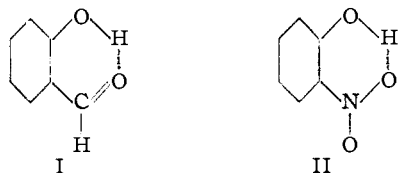
[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY OF WAYNE UNIVERSITY AND THE GEORGE HERBERT JONES LABORATORY OF THE UNIVERSITY OF CHICAGO]

## Dissociation of the Compounds of Trimethylboron with Pyridine and the Picolines; Evidence for the Steric Nature of the Ortho Effect<sup>1</sup>

BY HERBERT C. BROWN AND GERALDINE K. BARBARAS

*Ortho* benzene derivatives often exhibit markedly different properties than the corresponding *meta* and *para* compounds. Numerous such observations by Victor Meyer and his collaborators led to the concept of steric hindrance.<sup>2</sup> According to this interpretation, the unusual effects of groups in the *ortho* positions of benzene derivatives are due to their steric requirements which hinder the near approach of other groups or molecules to the reactive centers.

In recent years, other explanations have been advanced to explain certain cases of unusual behavior in *ortho*-substituted compounds. Thus Sidgwick and Callow<sup>3</sup> attribute the high volatility and non-polar character of such compounds as salicylaldehyde (I) and *ortho*-nitrophenol (II) to the formation of a six-membered "chelate" ring



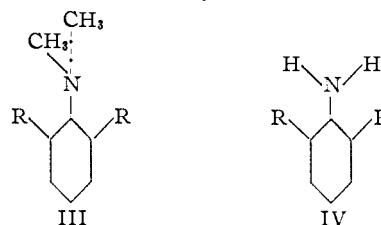
(1) Acid-Base Studies in Gaseous Systems. III. Paper no. X in the series Studies in Stereochemistry. For preceding paper, see *Science*, **103**, 385 (1946).

(2) Meyer, *Ber.*, **27**, 510 (1894); Meyer and Sudborough, *ibid.*, **27**, 1580 (1894). The literature on *ortho* effects and steric hindrance is too voluminous to be cited here. For an introduction to the literature on the subject, see Stewart, "Stereochemistry," Longmans, Green and Co., New York, 1907, pp. 314-443; Cohen, "Organic Chemistry," Edward Arnold and Co., London, 1928, 5th Ed., Vol. 1, Chapt. V; Anschütz, *Z. anorg. Chem.*, **41**, 691 (1928).

(3) Sidgwick and Callow, *J. Chem. Soc.*, **125**, 527 (1924).

involving hydrogen bonding of the hydroxyl group with the *ortho* substituent.

More recently, certain marked differences in the properties of *ortho* substituted dimethylaniline derivatives (III) as compared with those of the corresponding *ortho* substituted aniline compounds (IV), have been ascribed to inhibition of resonance in the dimethylaniline derivative.



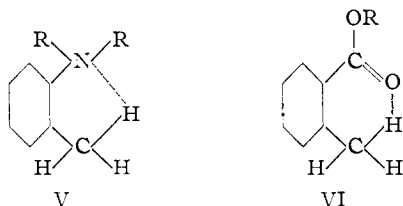
According to this interpretation, the *ortho* substituents prevent the dimethylamino group, but not the smaller amino group, from assuming the position coplanar with the benzene ring that is most favorable for resonance interaction.<sup>4</sup>

These interesting developments in the field of *ortho* effects have resulted in drawing attention away from Victor Meyer's original, purely steric, interpretation of such effects and have led to attempts to explain the observed phenomena in other than steric terms. Probably the most

(4) Ingham and Hampson, *ibid.*, 981 (1939); W. G. Brown, Widiger and Letang, *THIS JOURNAL*, **61**, 2597 (1939), and subsequent papers in *THIS JOURNAL*, by W. G. Brown and his collaborators. For a recent review of this field, see Wheland, "Resonance in Organic Chemistry," John Wiley and Sons, New York, N. Y., 1944, pp. 185-190, 272-279.

extensive such attempt is that of Watson, presented in a number of publications and summarized in his book.<sup>5</sup>

According to this interesting hypothesis, the peculiar behavior of *ortho* substituted dimethylanilines and benzoic acid esters are to ascribed not to the steric requirements of the *ortho* substituents as suggested by Victor Meyer, but to the possibilities for hydrogen bonding, either in the resting state of the molecule, as originally postulated by Sidgwick and Callow<sup>3</sup>, or in the transition state. In terms of this concept, the peculiarities observed in the reaction of methyl iodide with *ortho* substituted dimethylanilines,<sup>6</sup> and in the alkaline hydrolysis of *ortho* substituted ethyl benzoates<sup>7</sup> are explained by a redistribution of charge brought about by chelation in the transition complex. It is Watson's contention that the interaction of the unshared electrons of the trivalent nitrogen atom (V) or the carbonyl oxygen atom (VI) with a group in the *ortho* position of the benzene ring need not occur at any time except during the passage of the reacting system over the "energy pass."

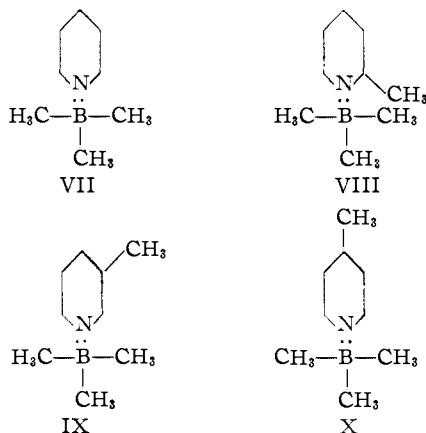


For that reason he does not consider it a critical point that no evidence of such hydrogen bonding has been obtained for many substances which in their reactions exhibit marked *ortho* effects.

Watson also points out that the strengths of most *ortho* substituted acids and bases appear to show no effects which are not found in the *para* isomerides, whereas the reactions of the same and similar compounds indicate a strong *ortho* effect. He suggests that this marked difference in the effect of *ortho* substituents on the ionization of acids and bases and the effect of such substituents upon the reactions of related compounds is due to the fact that "in reactions we are dealing with the highly energized transition complex, whereas equilibria are concerned with two resting states, and the factors which govern the former are quite different from those determining the latter."<sup>8</sup>

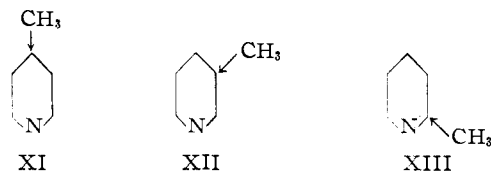
It seemed desirable to obtain experimental evidence on which to base a decision as to whether Victor Meyer's purely geometrical concept of the *ortho* effect or Watson's hypothesis of hydrogen bonding in the transition complex is better able to account for the peculiar behavior of most

*ortho* substituted derivatives.<sup>9</sup> Accordingly, a study was made of the dissociation in the gas phase of the addition compounds of trimethylboron with pyridine (VII), 2- (VIII), 3- (IX), and 4-picoline (X), since the geometry and properties of these molecules are such as to furnish a particularly favorable test of the two interpretations under consideration.

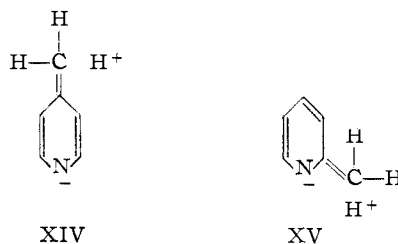


### Discussion

The introduction of a methyl group into the pyridine molecule should increase the availability of electrons at the nitrogen atom through operation of the inductive effect (+I) of alkyl groups. The magnitude of the effect should increase in the order, 4- < 3- < 2-, because of the decreasing distance of the methyl group from the nitrogen atom (XI, XII, XIII).



The hyperconjugative effect of the methyl group should also bring about an increase in the strength of the picoline as compared to the pyridine base, but the magnitude of this effect should change in the order, 2-, 4- > 3-, because of the contribution of structures such as XIV and XV and the impossibility of similar structures involving the 3-derivative.



(5) Watson, "Modern Theories of Organic Chemistry," Oxford University Press, New York, N. Y., 1941, pp. 241-254.

(6) Evans, Watson and Williams, *J. Chem. Soc.*, 1348 (1939).

(7) Evans, Gordon and Watson, *ibid.*, 1430 (1937).

(8) Ref. 5, p. 254.

(9) Such special instances of *ortho* effects as those which have been definitely demonstrated to be due to hydrogen bonding (ref. 3) or to the steric inhibition of resonance (ref. 4) are not here under consideration.

Either of two sequences of base strength may therefore be anticipated, according to the relative importance of the two effects:

1. Pyridine < 4- < 3- < 2-picoline
2. Pyridine < 3- < 4- < 2-picoline

Although no estimate of the relative importance of the two effects can be made, it is evident that 2-picoline should be a considerably stronger base than pyridine and 3- and 4-picoline should fall somewhere between.

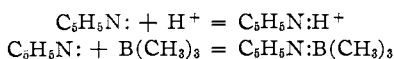
The accuracy of the available data for the dissociation constants of pyridine and the picolines leaves much to be desired (Table I). However, it seems safe to conclude that the introduction of a methyl group into the pyridine molecule markedly increases the strength of the resulting base, and such a methyl group in the 2-position is particularly effective.

TABLE I  
BASE DISSOCIATION CONSTANTS OF PYRIDINE AND THE PICOLINES AT 25°

Amine	$K \times 10^6$	Reference
Pyridine	2.24	<i>a</i>
	2.4	<i>b</i>
	3.0	<i>c</i>
2-Picoline	10.5	<i>a</i>
	45	<i>b</i>
	32	<i>c</i>
3-Picoline	11	<i>c</i>
4-Picoline	11	<i>c</i>

<sup>a</sup> Barron, *J. Biol. Chem.*, **121**, 313 (1937). <sup>b</sup> Goldschmidt and Salcher, *Z. physik. Chem.*, **29**, 114 (1899). <sup>c</sup> Constam and White, *Am. Chem. J.*, **29**, 46 (1903).

In the absence of other factors, it would be anticipated that the relative ability of the nitrogen atoms in the four pyridine bases to donate electron pairs to hydrogen ion, *i. e.*, their relative base strengths, should correlate well with the relative ability of these atoms to donate their free electron pairs to the boron atom of the trimethylboron molecule.



This expectation is fulfilled in the case of three of the four bases: pyridine, and 3- and 4-picoline. Examination of the dissociation data (Table II) reveals that the addition compounds of 3- and 4-picoline are slightly more stable than the corre-

TABLE II  
SUMMARY OF THE DISSOCIATION DATA FOR THE ADDITION COMPOUNDS OF TRIMETHYLBORON WITH PYRIDINE AND THE PICOLINES

Amine component	$K_{100}$	$\Delta F_{100}$	$\Delta H$	$\Delta S$
Pyridine	0.301	890	17,000	43.2
2-Picoline	Too highly dissociated to be measured			
3-Picoline	0.138	1468	17,810	43.9
4-Picoline	0.105	1671	19,400 <sup>a</sup>	47.5 <sup>a</sup>

<sup>a</sup> Subject to greater uncertainty than the remaining data; see Results.

sponding pyridine derivative. However, 2-picoline, which from its ionization constant would have been expected to form the most stable of the four addition compounds, actually forms the least stable derivative. Moreover, its stability is of an entirely different order of magnitude. Instead of a heat of dissociation in the neighborhood of 17–19 kcal. shown by the other derivatives, the heat of dissociation of the corresponding 2-picoline compound is markedly smaller, definitely less than 13 kcal. and probably in the neighborhood of 10 kcal.<sup>10</sup>

This marked difference in the behavior of the 2- derivative from that of the corresponding unsubstituted or 3- and 4-derivatives is typical of that group of phenomena which have become known as "ortho effects." In view of the considerations advanced by Watson,<sup>5</sup> it is highly significant that in the present instance the "ortho effect" involves a simple equilibrium and, because of the geometry of the amine component and the nature of the addition compound, the explanation for the observed behavior cannot possibly involve hydrogen bonding of any kind.

A simple and reasonable explanation of the marked instability of the 2-derivative is available, however, in terms of the F-strain concept discussed and applied in previous papers of this series.<sup>11</sup> Consideration of the dimensions of the atoms and groups involved and the geometry of the molecule (Fig. 1) indicate that sufficient steric strain must be present to account for the observed low stability of 2-picoline-trimethylboron.

The difference in the behavior of the four pyridine bases upon comparison with the two reference acids, the proton and trimethylboron, is plausibly ascribed to marked differences in the steric requirements of the two reference acids. This interpretation strongly suggests that Watson's observation that the strength of most *ortho* substituted acids and bases appear to show no effects which are not found in the *para* isomerides, whereas the reactions of the same and similar compounds indicate a strong *ortho* effect, has a similar explanation: differences in the steric requirements of the two systems.

In other words, the ionization of *ortho* substituted acids and bases is not greatly affected by the *ortho* substituent<sup>12</sup> because of the small steric requirements of the proton. Reactions involving such acids and bases, however, may be markedly affected because of the much greater steric requirements of the reacting components involved in the formation of the transition complex. This

(10) Many addition compounds with large steric strains cannot, because of their resulting low stability, be studied quantitatively by the present technique. Yet these substances with large strains are frequently of particular interest. For that reason a calorimetric method is being developed which will allow quantitative determination of the strains in unstable addition compounds of this kind.

(11) Brown, Bartholomay and Taylor, *THIS JOURNAL*, **66**, 435 (1944), and subsequent papers in *THIS JOURNAL*.

(12) Indirect effects such as those due to chelation or inhibition of resonance are not here under consideration.

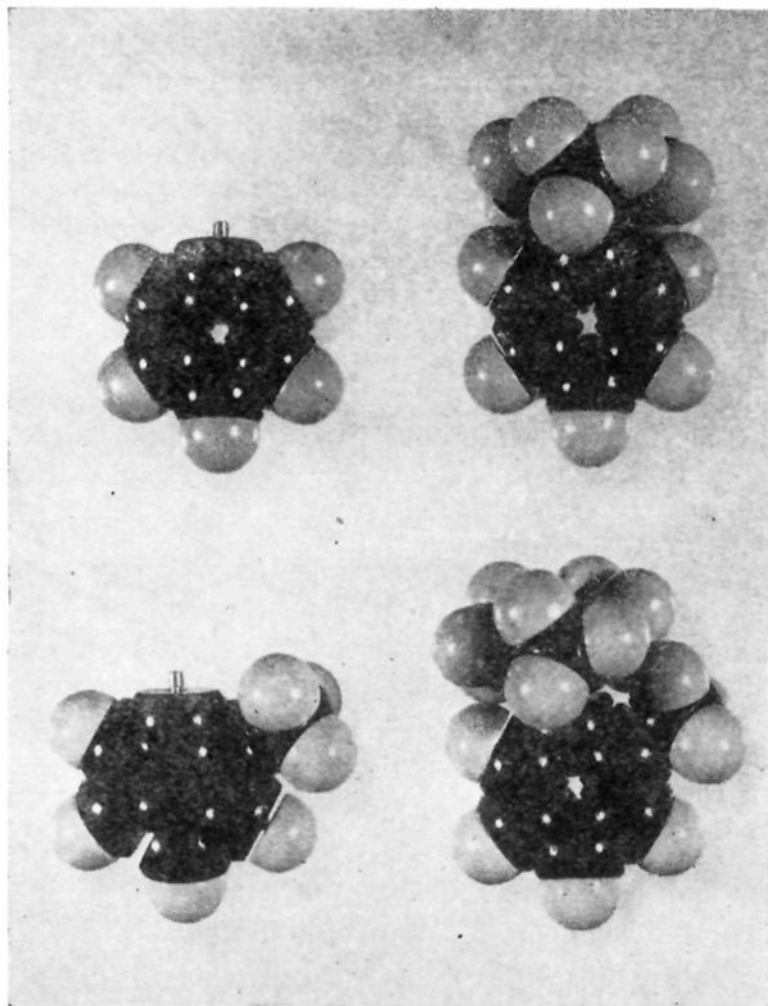
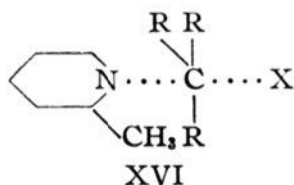


Fig. 1.—Molecular models: above, pyridine and pyridine-trimethylboron; below, 2-picoline and 2-picoline-trimethylboron.

interpretation suggests that the slowness with which *ortho* substituted compounds participate in displacement reactions<sup>13</sup> may in large part be due to steric strain in the transition complex (XVI).



Such strain should result in an increase in the activation energy of the reaction. This suggests that the common assumption<sup>14</sup> that steric hindrance should be reflected only by a decrease in the probability factor,  $P$ , and not by any change in the activation energy,  $E$ , in the equation,  $k = PZe^{-E/RT}$ , should be modified. The results reported by Baker and Nathan<sup>15</sup> on the reaction of pyridine and 2-picoline with a number of benzyl halides appear to contradict this conclusion. In our opinion, this apparent contradiction is due

(13) Menshutkin gives the following reaction rates (in parentheses) for the reaction between the given amine and alkyl halide in benzene solution at 100°: allyl bromide with pyridine (276), 3-picoline (435), 2-picoline (55); methyl bromide with quinoline (96), 4-methylquinoline (159), 2-methylquinoline (23), *p*-toluquinoline (115), *ortho*-toluquinoline (0). Menshutkin, *Chem. Zentr.*, **73**, II, 86 (1902).

(14) Watson, reference 5, p. 249.

(15) Baker and Nathan, *J. Chem. Soc.*, 519 (1935).

to the fact that these investigators compared the behavior of 2-picoline with pyridine rather than with the corresponding 3- and 4-derivatives. We shall elaborate upon this point in a later publication.

Summing up, the results of the present investigation support the view that geometrical steric effects still offer the most reasonable explanation for most of the phenomena classified as "ortho effects" and "steric hindrance effects."

### Apparatus and Techniques

The dissociation data reported in this paper were obtained by measuring the pressures of an equilibrium mixture, *e. g.*,  $C_5H_5N:B(CH_3)_3 \rightleftharpoons C_5H_5N + B(CH_3)_3$ , in which all of the reactants and products were gaseous. In brief, the procedure is as follows: in each of two matched tensimeters is placed one of the two components of the addition compound. The temperature is raised sufficiently high so that deviations due to van der Waals forces are negligible and the pressures accurately measured (to  $\pm 0.01$  mm.). The sizes of the two samples are next adjusted until the pressures calculated to a common temperature (usually 0°) are identical. The two components are then brought together in one of the tensimeters and an accurately measured sample of the addition compound is thereby synthesized directly in the reaction vessel. The temperature of the tensimeter which contains the sample is now raised until all of the addition compound is in the gas phase, and the pressures exerted are measured, usually at 5° intervals over a 50° range. If the addition compound vaporized without dissociation, the measured pressure for the completely volatilized sample would be equal to the value of the pressure for each of the components (usually calculated to 0°) corrected to the temperature of measurement. This calculated value of the pressure (assuming no dissociation) is given in the tabulated data (Tables IV, VII, and IX) in the column headed "Pressure, mm., Calculated." From the difference between this pressure, calculated for no dissociation, and the observed pressure for the dissociated compound, the degree of dissociation  $\alpha$  is readily calculated with the aid of the equation:  $\alpha = (P_{obs.} - P_{calcd.})/P_{calcd.}$

A detailed description of the apparatus and techniques used in these studies is contained in an earlier paper of this series.<sup>16</sup>

### Materials

Pyridine (Mallinckrodt Reagent Grade) was distilled through a short column of 15 theoretical plates; the middle fraction, which distilled constantly at 114.9° at 750 mm., was collected and introduced into the high vacuum apparatus. The pyridine sample was then placed in a tube containing freshly sublimed phosphorus pentoxide. The dried product was then distilled in the vacuum apparatus through a series of U-tubes maintained at successively lower temperatures. The middle portion which was trapped in a U-tube at -33° was collected and utilized

(16) Brown, Taylor and Gerstein, *THIS JOURNAL*, **66**, 431 (1944).

for the preparation of the addition compound. The sample of pyridine exhibited a vapor pressure of 4.65 mm. at 0.0° and 15.82 mm. at 20.0°.

The picolines were products of the Reilly Tar and Chemical Corporation. They were purified before use as follows.

2-Picoline was distilled through a Stedman column of 100 theoretical plates. A middle fraction which distilled at 129.1° at 751 mm. was collected and dried over potassium hydroxide. This material was introduced into the high vacuum apparatus where it was again distilled and the fore and hind fractions discarded. The resulting sample had a vapor pressure of 2.31 mm. at 0.0° and 8.55 mm. at 20.3°.

3-Picoline was distilled through the same Stedman column and the middle fraction which distilled at 143.3° at 745 mm. was refluxed over phosphorus pentoxide for twenty-four hours to remove the 2- and 4-isomers.<sup>17</sup> The remaining liquid was fractionated in the high vacuum apparatus through a series of U-tubes and the middle fraction, trapped at -10°, was collected and used for the preparation of the addition compound. The sample thus obtained exhibited a vapor pressure of 1.13 mm. at 0.0° and 4.46 mm. at 20.0°.

4-Picoline was purified through its slightly soluble derivative with calcium chloride.<sup>18</sup> The base was dissolved in toluene and treated with a deficiency of aqueous calcium chloride. The mixture was heated under reflux for thirty minutes, allowed to cool, and the solid complex salt separated from the mother liquor. The solid was thoroughly washed, first with toluene and then with ether, and the last traces of the organic solvents removed under high vacuum. The base was then liberated from the complex salt with concentrated sodium hydroxide and dried over solid potassium hydroxide. The product was then introduced into the high vacuum apparatus and subjected to fractionation. A middle fraction, which was collected in a U-tube at -10°, exhibited vapor pressures of 1.10 mm. at 0.0° and 4.29 mm. at 20.0°.

The preparation and purification of trimethylboron is described in an earlier paper.<sup>11</sup>

## Results

**Pyridine-trimethylboron, C<sub>5</sub>H<sub>5</sub>N:B(CH<sub>3</sub>)<sub>3</sub>.**—The compound formed by the union of equimolar quantities of trimethylboron and pyridine is a white solid which melts at 53.8–55.1°. The substance showed a marked tendency to exist as a supercooled liquid at temperatures 20 to 30° below its melting point. The saturation pressures were measured from 0.0 to 100.0°. The data are listed in Table III and represented graphically in Fig. 2A. The solid-vapor data can be represented by the equation

$$\log P_{\text{solid}} = -(3908/T) + 12.650$$

and the liquid-vapor data by the equation

$$\log P_{\text{liquid}} = -(3509/T) + 11.290$$

The lines defined by these equations intersect at 52.4°; the extrapolated "boiling point" is 143.9°.

The dissociation of the addition compound was studied over the temperature range from 95.2 to 139.9°. The dissociation data are listed in Table IV and represented graphically in Fig. 2B. The values of the dissociation constants are expressed by the equation

$$\log K_p = -(3721/T) + 9.453$$

The heat of dissociation is 17.02 ± 0.2 kcal. and

(17) Cislak and Wheeler, U. S. Patent 2,338,571 (Jan. 4, 1944).

(18) Reimers, U. S. Patent 2,336,502 (Dec. 14, 1943).

TABLE III

SATURATION PRESSURES OF PYRIDINE-TRIMETHYLBORON

Temp., °C.	0.0	10.0	20.0	32.0	41.4	49.8	60.4
Press., mm.	0.03	0.07	0.20	0.66	1.63	3.46	7.46
Temp., °C.	70.8	76.6	80.9	90.5	95.4	100.0	30.2
Press., mm.	14.8	21.3	27.5	48.0	62.8	80.0	0.81 <sup>a</sup>

<sup>a</sup> Saturation pressure of the supercooled liquid.

the value of the dissociation constant at 100° is 0.303.

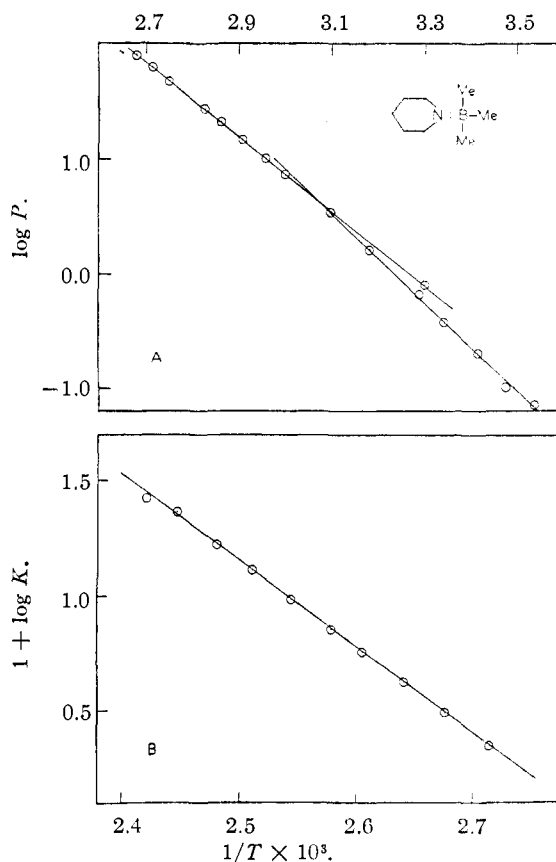


Fig. 2.—Pyridine-trimethylboron: A, saturation pressure data; B, dissociation data.

A duplicate determination yielded values of 16.98 ± 0.2 kcal. for the heat of dissociation and 0.299 for the dissociation constant at 100°.

**2-Picoline-trimethylboron, 2-CH<sub>3</sub>C<sub>5</sub>H<sub>4</sub>N:B(CH<sub>3</sub>)<sub>3</sub>.**—The compound formed from 2-picoline and trimethylboron is a white solid whose melting point is markedly dependent upon the relative size of the sample and volume of the vessel in which the sample is contained. For example, a sample which melted at 28–33° in a tube with a volume of 25 ml. melted in the neighborhood of 19° in the dissociation tensimeter with a volume of 380 ml. This behavior is ascribed to extensive

TABLE IV

## DISSOCIATION DATA FOR PYRIDINE-TRIMETHYLBORON

Temp., °C.	Pressure, mm.		Degree of dissociation, $\alpha$	Dissociation constant, $K$ (atm.)
	Obs.	Calcd. <sup>a</sup>		
95.2	51.12	27.24	0.8766	0.223
100.5	52.65	27.64	.9048	.313
105.6	53.93	28.01	.9253	.425
110.5	55.12	28.38	.9422	.573
114.7	56.00	28.68	.9525	.720
119.9	57.07	29.09	.9635	.964
125.1	58.07	29.45	.9717	1.29
130.0	58.96	29.82	.9775	1.66
135.4	59.93	30.22	.9835	2.32
139.9	60.65	30.55	.9854	2.66

<sup>a</sup> The pressure of pyridine and of trimethylboron in the dissociation tensimeters was 20.20 mm. (calculated to 0°).

dissociation of the addition compound at temperatures at which the 2-picoline is only slightly volatile. The values of the saturation pressures are also somewhat dependent upon the relative sizes of the sample and its container. The data given in Table V are to be taken as merely representative of the general range of volatility exhibited by this unstable compound.

At 45° the compound was at least 99% dissociated; at 55° the dissociation was apparently

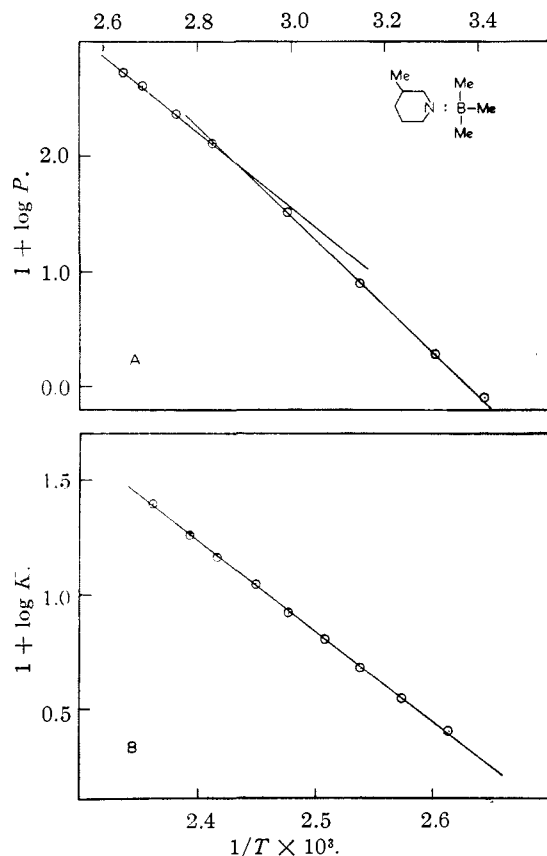


Fig. 3.—3-Picoline-trimethylboron: A, saturation pressure data; B, dissociation data.

TABLE V

## SATURATION PRESSURES OF 2-PICOLINE-TRIMETHYLBORON

Temp., °C.	0.0	10.0	15.1	19.5	26.0
Press., mm.	3.2	9.3	16.5	27.9	37.6

complete. The addition compound is therefore far less stable than the pyridine derivative and much too unstable to permit thermodynamic data to be determined by the present technique.<sup>10</sup>

**3-Picoline-trimethylboron,** 3-CH<sub>3</sub>C<sub>5</sub>H<sub>4</sub>N:B-(CH<sub>3</sub>)<sub>3</sub>.—The addition compound from 3-picoline and trimethylboron melted sharply at 72.5 to 73.0°. Its saturation pressures were measured over the temperature range from 0.0 to 105.4°; the data are given in Table VI and Fig. 3A. The solid-vapor data may be represented by the equation

$$\log P_{\text{solid}} = -(3948/T) + 12.329$$

and the liquid-vapor data by the equation

$$\log P_{\text{liquid}} = -(3237/T) + 10.289$$

The extrapolated "boiling point" is 163.8°

TABLE VI

## SATURATION PRESSURES OF 3-PICOLINE-TRIMETHYLBORON

Temp., °C.	0.0	20.0	29.3	44.7	61.1
Press., mm.	0.02	0.08	0.19	0.80	3.29
Temp., °C.	80.0	90.0	99.8	105.4	
Press., mm.	13.1	23.7	40.5	52.8	

The dissociation of the addition compound was studied from 109.5 to 150.2°. The data, listed in Table VII and represented graphically in Fig. 3B, are summarized by the equation

$$\log K_p = -(3920/T) + 9.637$$

The heat of dissociation is calculated as 17.93 ± 0.3 kcal. and the value of the dissociation constant at 100° is 0.135.

In a duplicate determination, the heat of dissociation is calculated to be 17.70 ± 0.3 kcal. and the dissociation constant at 100° is 0.141. Average values for these quantities are listed in Table II.

TABLE VII

## DISSOCIATION DATA FOR 3-PICOLINE-TRIMETHYLBORON

Temp., °C.	Pressure, mm.		Degree of dissociation, $\alpha$	Dissociation constant, $K$ (atm.)
	Obs.	Calcd. <sup>a</sup>		
109.5	54.44	28.93	0.8818	0.251
115.1	56.01	29.35	.9082	.347
120.7	57.45	29.78	.9292	.478
125.5	58.50	30.13	.9445	.637
130.4	59.70	30.51	.9558	.829
135.2	60.75	30.87	.9656	1.10
140.6	61.83	31.28	.9731	1.44
144.7	62.65	31.59	.9781	1.81
150.2	63.70	32.01	.9835	2.47

<sup>a</sup> The pressure of 3-picoline and of trimethylboron in the dissociation tensimeters was 20.65 mm. (calculated to 0°).

**4-Picoline-trimethylboron,** 4-CH<sub>3</sub>C<sub>5</sub>H<sub>4</sub>N:B-(CH<sub>3</sub>)<sub>3</sub>.—The addition compound formed from

TABLE VIII

SATURATION PRESSURES OF 4-PICOLINE-TRIMETHYLBORON							
Temp., °C.	0.0	17.5	29.9	42.5	49.8	59.7	70.0
Press., mm.	0.00	0.05	0.13	0.40	0.82	1.99	4.63
Temp., °C.	75.0	79.8	91.1	95.5	100.2	105.3	109.9
Press., mm.	6.88	9.80	19.3	24.9	33.2	43.1	54.0

trimethylboron and 4-picoline is the highest melting, 78.5–80.0°, and least volatile of the three isomers. The saturation pressure values, measured from 0.0 to 109.9°, are listed in Table VIII and shown in Fig. 4A. These data are represented by the equations

$$\log P_{\text{solid}} = -(4102/T) + 12.620$$

$$\log P_{\text{liquid}} = -(3360/T) + 10.510$$

The lines defined by these equations intersect at 78.5° (Fig. 4A). The calculated "boiling point" is 167.3°.

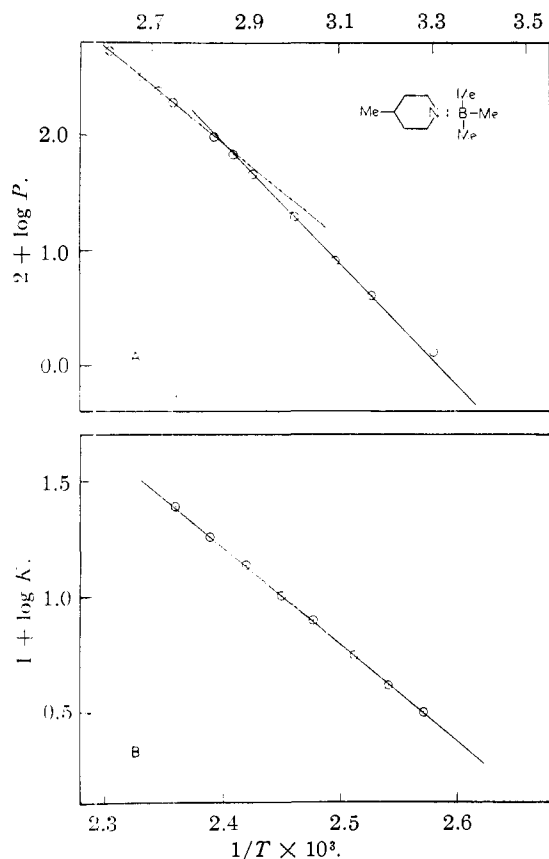


Fig. 4.—4-Picoline-trimethylboron: A. saturation pressure data; B. dissociation data.

The dissociation of the addition compound was studied over the relatively short temperature range from 115.8 to 150.6°. The low volatility of the compound prevented its study at lower tem-

peratures; at higher temperatures certain difficulties were encountered in obtaining reproducible measurements of the pressures due to unsatisfactory operation of the mercury seal<sup>16</sup> in the dissociation tensimeter at these temperatures. The dissociation data for this compound, Table IX and Fig. 4B, are therefore less accurate, particularly at the upper range, than similar data reported in this series for more volatile derivatives and an error of the order of 0.5 to 1.0 kcal. in the heat of dissociation is probable. However, the data do permit the conclusion that 4-picoline-trimethylboron is definitely less dissociated than the corresponding pyridine derivative and somewhat less than the 3-picoline derivative.

TABLE IX

DISSOCIATION DATA FOR 4-PICOLINE-TRIMETHYLBORON

Temp., °C.	Pressure, mm.		Degree of dissociation, $\alpha$	Dissociation constant, $K$ , (atm.)
	Obs.	Calcd. <sup>a</sup>		
115.8	71.28	38.02	0.8748	0.313
120.4	73.07	38.47	.8995	.408
125.0	74.78	38.92	.9214	.554
130.6	76.61	39.46	.9413	.784
135.0	77.90	39.90	.9525	1.00
140.2	79.34	40.40	.9638	1.36
145.3	80.65	40.90	.9718	1.80
150.6	81.96	41.42	.9787	2.45

<sup>a</sup> The pressure of 4-picoline and of trimethylboron in the dissociation tensimeters was 26.70 mm. (calculated to 0.0°).

The change of the dissociation constants with temperature can be reproduced by the equation

$$\log K_p = -(4253/T) + 10.426$$

The dissociation constant at 100.0° is 0.106 and the heat of dissociation is  $19.47 \pm 1.0$  kcal.

A duplicate determination yielded a value of 0.104 for the dissociation constant at 100.0° and a value of  $19.31 \pm 1.0$  kcal. for the heat of dissociation. Average values for these two determinations are listed in Table II.

**Acknowledgment.**—This research program at Wayne University on the effects of steric strains has been made possible by Grants No. 710 and 776 from the Penrose Fund of the American Philosophical Society. This assistance is gratefully acknowledged.

### Summary

1. The addition compounds of trimethylboron with pyridine, 2-, 3- and 4-picoline have been prepared and characterized.

2. The dissociation of these addition compounds in the vapor phase has been studied and values of  $\Delta H$ ,  $\Delta F^\ddagger$  and  $\Delta S$  for three of the four compounds have been obtained. 2-Picoline-trimethylboron is too highly dissociated for these thermodynamic quantities to be determined.

3. The high instability of 2-picoline-trimethylboron is attributed to conflicting steric requirements of the trimethylboron molecule and the methyl group in the  $\alpha$  position. The notable



difference in the behavior of the four amines toward a reference acid such as hydrogen ion on the one hand and toward a reference acid such as trimethylboron on the other, is attributed to differences in the steric requirements of the two reference acids.

4. Many of the phenomena classified under the term "ortho effects" or "steric hindrance effects" are better explained in terms of the older

geometrical concepts than in terms of hypothetical "hydrogen bridging" in the transition complex, recently postulated to account for the phenomena. It is further suggested that "steric hindrance" is largely a result of "steric strain" in the transition complex and as such would be expected to affect both the energy of activation and the probability factor of the rate expression.

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[CONTRIBUTION FROM THE CHEMISTRY DIVISION OF THE NAVAL RESEARCH LABORATORY]

## Organic Fungicides. II. The Preparation of Some $\alpha$ -Bromopropionamides

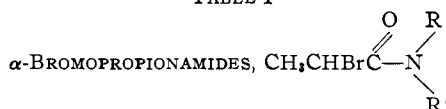
By W. E. WEAVER AND W. M. WHALEY

The first paper of this series recorded the synthesis of  $\alpha$ -bromoacetyl derivatives of a number of aliphatic amines.<sup>1</sup> In order to investigate systematically the fungicidal activity of alpha bromo amides, the synthesis of corresponding  $\alpha$ -bromopropionamides was undertaken.

As in the case of the  $\alpha$ -bromoacetamides, there is little information in the literature regarding the

dimethyl- $\alpha$ -bromopropionamide<sup>3</sup> were prepared by treating the amine dissolved in ether with the acid bromide or chloride. As may be seen from Table I, the constants given by Freudenberg and Markert for the dimethyl derivative differ markedly from those found in the present work. The identity of their product was not supported by analytical data.

TABLE I



R	R'	Method	Yield, %	B. p. <sup>a</sup> , °C.	M. p. <sup>a</sup> , Mm.	M. p. <sup>a</sup> , °C.	$n_D^{20}$	$d_4^{20}$	MR Calcd.	MR Obs.	Formula	Nitrogen, % Calcd. Found
CH <sub>3</sub> —	H—	III	89	80–81	2	40					C <sub>4</sub> H <sub>8</sub> BrNO	8.44 8.51 8.21
CH <sub>3</sub> —	CH <sub>3</sub> —	III	85	75	3	Liq. <sup>b</sup>	1.4979	1.4264	36.82	36.99	C <sub>6</sub> H <sub>10</sub> BrNO	7.78 8.12 7.99
		II	83	77	3							
C <sub>2</sub> H <sub>5</sub> —	H—	III	81	82	2	62°					C <sub>6</sub> H <sub>10</sub> BrNO	7.78 7.61 7.71
		II	89	82	2							
C <sub>2</sub> H <sub>5</sub> —	C <sub>2</sub> H <sub>5</sub> —	II	79	84	1.6	liq. <sup>d</sup>	1.4862	1.2947	46.06	46.16	C <sub>7</sub> H <sub>14</sub> BrNO	6.73 6.94 6.80
<i>n</i> -C <sub>3</sub> H <sub>7</sub> —	H—	II	85	81	0.45	33					C <sub>8</sub> H <sub>16</sub> BrNO	7.22 6.87 6.98
<i>n</i> -C <sub>3</sub> H <sub>7</sub> —	<i>n</i> -C <sub>3</sub> H <sub>7</sub> —	II	87	86	.31	Liq.	1.4830	1.2218	55.30	55.20	C <sub>9</sub> H <sub>18</sub> BrNO	5.93 6.13 6.08
<i>i</i> -C <sub>3</sub> H <sub>7</sub> —	H—	II	98	Sublimes		115–117					C <sub>8</sub> H <sub>16</sub> BrNO	7.22 7.25 7.20
<i>i</i> -C <sub>3</sub> H <sub>7</sub> —	<i>i</i> -C <sub>3</sub> H <sub>7</sub> —	I	74	78–80	.25	Liq.	1.4820	1.2356	55.30	54.49	C <sub>9</sub> H <sub>18</sub> BrNO	5.93 5.75 5.58
CH <sub>2</sub> =CH—CH <sub>2</sub> —	H—	II	83	84–85	.30	37–38					C <sub>6</sub> H <sub>10</sub> BrNO	7.29 7.25 7.18
<i>n</i> -C <sub>4</sub> H <sub>9</sub> —	H—	I	79	88	.37	Liq.	1.4850	1.2959	46.06	46.03	C <sub>8</sub> H <sub>16</sub> BrNO	6.73 6.45 6.80
<i>n</i> -C <sub>4</sub> H <sub>9</sub> —	<i>n</i> -C <sub>4</sub> H <sub>9</sub> —	I	80	106	.23	Liq.	1.4792	1.1605	64.54	64.58	C <sub>9</sub> H <sub>18</sub> BrNO	5.32 5.20 5.25
<i>i</i> -C <sub>4</sub> H <sub>9</sub> —	H—	I	84	88	.35	67					C <sub>8</sub> H <sub>16</sub> BrNO	6.73 6.85 6.62
<i>i</i> -C <sub>4</sub> H <sub>9</sub> —	<i>i</i> -C <sub>4</sub> H <sub>9</sub> —	I	83	102	.35	Liq.	1.4790	1.1591	64.54	64.64	C <sub>9</sub> H <sub>18</sub> BrNO	5.32 5.36 5.59
CH <sub>3</sub> CH <sub>2</sub> CH(CH <sub>3</sub> )—	H—	I	72	Sublimes		83					C <sub>7</sub> H <sub>14</sub> BrNO	6.73 6.56 6.51
CH <sub>3</sub> CH <sub>2</sub> CH(CH <sub>3</sub> )—	CH <sub>3</sub> CH <sub>2</sub> CH(CH <sub>3</sub> )—	I	76	91	.50	Liq.	1.4841	1.1981	64.54	63.06	C <sub>10</sub> H <sub>20</sub> BrNO	5.32 5.24 5.21
<i>n</i> -C <sub>5</sub> H <sub>11</sub> —	H—	I	81	105	.45	Liq.	1.4840	1.2503	50.68	50.83	C <sub>8</sub> H <sub>16</sub> BrNO	6.31 6.40 6.36
<i>n</i> -C <sub>5</sub> H <sub>11</sub> —	<i>n</i> -C <sub>5</sub> H <sub>11</sub> —	I	61	124–125	.25	Liq.	1.4778	1.1157	73.78	74.12	C <sub>10</sub> H <sub>20</sub> BrNO	4.79 4.89 4.98
CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> CH(CH <sub>3</sub> )—	H—	I	94	Sublimes		63					C <sub>8</sub> H <sub>16</sub> BrNO	6.31 6.15 6.35
<i>n</i> -C <sub>6</sub> H <sub>13</sub> —	H—	I	87	108–110	.25	Liq.	1.4820	1.2105	55.30	55.62	C <sub>9</sub> H <sub>18</sub> BrNO	5.93 6.01 5.99
CH <sub>3</sub> CH <sub>2</sub> CH(CH <sub>3</sub> )CH <sub>2</sub> —	H—	I	82	101–102	.25	Liq.	1.4862	1.2285	55.30	55.21	C <sub>9</sub> H <sub>18</sub> BrNO	5.93 6.14 5.95
<i>n</i> -C <sub>7</sub> H <sub>15</sub> —	H—	I	77	114–115	.35	ca. 20	1.4807	1.1874	59.92	59.93	C <sub>10</sub> H <sub>20</sub> BrNO	5.60 6.01 5.84
<i>n</i> -C <sub>7</sub> H <sub>15</sub> —	H—	I	77	121–122	.25	42–43					C <sub>11</sub> H <sub>22</sub> BrNO	5.32 5.53 5.35
<i>n</i> -C <sub>10</sub> H <sub>21</sub> —	H—	I	72	126–128	.06	33–34					C <sub>13</sub> H <sub>26</sub> BrNO	4.79 4.92 5.01

<sup>a</sup> All temperatures are uncorrected. <sup>b</sup> Freudenberg and Markert<sup>3</sup> reported b. p. 44° (2 mm.). <sup>c</sup> von Braun, Jostes and Heymons<sup>2</sup> reported m. p. 60° and b. p. 114–115° (16 mm.). <sup>d</sup> Freudenberg and Markert<sup>3</sup> reported b. p. 87° (2 mm.); Souo and Tchou<sup>4</sup> reported b. p. 119–121° (15 mm.). <sup>e</sup> Micro-analyses by Arlington Laboratories, Fairfax, Virginia.

synthesis and properties of aliphatic  $\alpha$ -bromopropionamides. N-Ethyl- $\alpha$ -bromopropionamide,<sup>2</sup> N,N-diethyl- $\alpha$ -bromopropionamide<sup>3,4</sup> and N,N-

Physical properties and analyses of all the compounds prepared are given in Table I. The monosubstituted amides of lowest and highest molecular weight were solid, while the intermediate compounds melted below room temperature, and all of the disubstituted amides were liquid. The first members were only slightly lachrymatory:

(1) Weaver and Whaley, *THIS JOURNAL*, **69**, 515 (1947).

(2) von Braun, Jostes and Heymons, *Ber.*, **60B**, 92 (1927).

(3) Freudenberg and Markert, *ibid.*, **60B**, 2447 (1927).

(4) Souo and Tchou, *Bull. faculté sci. univ. franco-chinoise Peiping*, No. 5, 13 (1935); *C. A.*, **30**, 4465 (1936).