and then allowed to stand until darkened in a closed flask, which indicates a hydride transfer mechanism for this decomposition.

Our studies in this area are continuing with the investigation of solid state spectra, determination of association constants and examination of the charge-transfer spectra of substituted tropenium halides.

Acknowledgment.—We wish to thank Ann B. Harmon for considerable technical assistance.

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

Molecular Geometry. II. Methyl-cyclohexanes and Cycloheptanes[1,2]

BY JAMES B. HENDRICKSON[3]

RECEIVED DECEMBER 23, 1961

Machine computation is applied to the calculation of the energy difference between axial and equatorial methyls on cyclohexane. A value of 1.01 kcal./mole is obtained. Similar calculations for methyl groups on various discrete conformations of the flexible cycloheptane ring are also calculated and the use of these values in delineating the conformational analysis of substituted cycloheptanes is discussed.

The energy difference between axial and equatorial substituents on cyclohexane has long been a central feature of conformational analysis. The values generally accepted for this difference vary from 1.6–2.0 kcal./mole for axial *vs.* equatorial methyl groups, derived from spectroscopic and thermodynamic considerations.[4] The problem of calculating the energy difference[2] between axial and equatorial methylcyclohexane seemed to be an important one for several reasons. Firstly, since this energy difference is made up mostly of a large number of fairly minor non-bonded interactions between the differently placed methyls and the ring, it provides an especially delicate test of the efficacy of a computer approach as well as of the accuracy of the non-bonded interaction functions chosen. Secondly, of course, the computed results may be compared with reliable experimental values, and, finally, should the computer technique provide a reasonable approximation to the empirical values it might be used with some confidence to afford as well the corresponding energies of methyls on more complex rings. The latter is of particular importance in providing a semi-quantitative basis for conformational analysis in the conformationally more complex cycloheptane system.

Dissection of the problem for machine computation (see Fig. 1) involves assignment of a specific conformation to the ring and calculation of the total energy of the molecule with the methyl group attached at a given carbon, first in one orientation (*cf.* axial) and then in the other (*cf.* equatorial); subtraction then affords the desired energy difference. The choice of functions here follows the discussion in part I[2]; energy terms were considered to be those arising from bond angle bending, torsional strain around single bonds and non-bonded interactions between hydrogens; these are separately calculated, using the functions discussed in part I,[2] and added to provide the total strain energy of the molecule. The energy so calculated is more or less meaningless in absolute terms, as it contains no assessment of bond or coulombic energies or of zero-point energies or terms for vibration and rotation of the various bonds. The exclusion of these terms is largely justified on the ground that they will cancel in any calculation of energy *differences* between closely related conformers. Nevertheless, such an approximation of second-order contributions probably puts a serious limitation on the accuracy of the values calculated. In any event the availability of empirical values for some of the energy differences so calculated can serve as a check on the validity of this approximation, as in the examples of part I.[2]

As the sum of the three energy terms considered here (angle bending, torsional strain and non-bonded interactions of hydrogens) was already available from the previous computations[2] for the parent ring itself, without added methyl, it was deemed simpler to start with this ring value and add to it the changes occasioned by attaching the methyl group. This involves adding the change in angle bending energy[5] at the site of the new methyl, the torsional strain due to rotation (ω_M) of the methyl group around its bond to the ring, and finally the sum of the new non-bonded H–H interactions from the methyl hydrogens to the ring hydrogens and subtraction of those interactions due to that hydrogen replaced by the methyl group on the parent ring. The various H-H distances to be calculated from the methyl hydrogens A, B and C are functions of the bond angles ϕ_M, θ_2, θ_3, etc., and of the dihedral (torsional) angles, ω_M, ω_1, ω_2, etc.; the latter are given as part of the definition of the parent ring and are modified for these distance calculations to substituents (CH_3 or H) by addition or subtraction of the relevant projection angle, as μ_M, in Fig. 2.

In a general program for the computer, these interactions are all separately computed and added for each given parent ring conformation. Also, in

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(1) This work was supported in part by a generous grant from the National Institutes of Health.

(2) Paper I of the series: J. B. Hendrickson, *J. Am. Chem. Soc.*, **83**, 4537 (1961).

(3) Alfred P. Sloan Foundation Fellow.

(4) W. G. Dauben and K. S. Pitzer, Chap. 1 of "Steric Effects in Organic Chemistry," ed. M. S. Newman, John Wiley and Sons, Inc., New York, N. Y., 1956; C. W. Beckett, K. S. Pitzer and R. Spitzer, *J. Am. Chem. Soc.*, **69**, 2488 (1947).

(5) The change in angle bending strain at C_1 (Fig. 1) is computed by adding the angle strain of the present attached groups, *i.e.*, $2E\phi_M$ + $3E\psi_M$, and subtracting the angle strain due to the two hydrogens on C_1 in the parent ring (see Fig. 1, ref. 2).

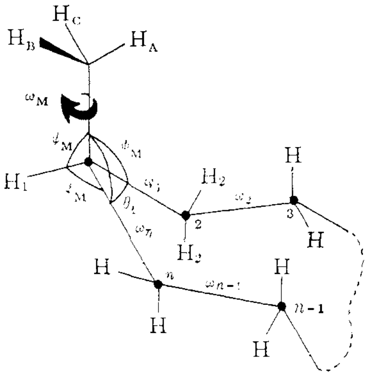

Fig. 1.—Geometry of methyl on a general C$_n$-ring. The rotation ω_M of the methyl group is defined, counterclockwise, from an $\omega_M = 0°$ position defined with H_A antiparallel as shown above to H_1:

$$\tan \psi_M = \frac{2(\cos \phi_M - 1)}{\sqrt{2(\cos \theta_1 + 1) - 4\cos^2\phi_M}}$$

order to search further for a minimum-energy conformation of the added methyl, both ϕ_M and ω_M are varied independently as well; variation of ϕ_M represents a tilting of the appended methyl from the tetrahedral while ω_M represents rotation of the methyl, which will presumably be at minimum torsional strain with H_A antiparallel to H_1 (ω_M = 0°) and will duplicate in configuration with each 120° of rotation.

Results

Methylcyclohexane.—When axial and equatorial methyl groups are compared on the simple chair cyclohexane (all bond angles tetrahedral, all $\omega_i = 60°$) the difference in energy between the two forms is calculated as 1.53 kcal./mole. Both equatorial and axial forms are found to be at a minimum with $\omega_M = 0°$, as expected. Furthermore, as expected, no alteration of the equatorial methyl from the simple chair with $\phi_M = 109.5°$ and ω_M = 0° gave a lower energy, so that the equatorial methyl is certainly most stable in this form. When the axial methyl is tilted somewhat, however, a considerable release of strain is provided, passing through a minimum at $\phi_M = 112°$ with $\Delta E = 1.04$ kcal./mole and $\omega_M = 0°$. Yet another mode of conformational variation is possible, however, by changing the entire cyclohexane ring. In the previous work[2] a program was set up to define the cyclohexane geometry as the ring was progressively warped toward the transition shape between the chair and twist-boat, in which the dihedral at one bond is forced to 0°. An axial substituent on that bond will concomitantly be forced out into a more equatorial orientation and so free itself of nonbonded hydrogen interactions, although at the expense of increased angle strains in the ring itself. In the passage from $\omega_1 = 60°$ to $\omega_1 = 0°$, then, one may expect a conformation which balances these strains with a minimum of total energy. Accordingly, the same calculations, varying ω_M and ϕ_M, were performed for each of the previously computed minimum-energy cyclohexane rings with successive values of ω_1 decreasing from 60°. In this way an over-all minimum energy configuration was found

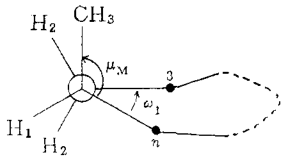

Fig. 2.—Projection down C$_1$–C$_2$ bond:

$$\cos \mu_M = \frac{\cos \phi_M}{\sin \phi_M}\left(\frac{1 - \cos \theta_1}{\sin \theta_1}\right)$$

for the axial methylcyclohexane at $\omega_1 = 58°$, ϕ_M = 112° and ΔE = 1.01 kcal./mole. It will be seen that it is very similar to the minimum secured by simply bending the methyl group back on a normal cyclohexane. The energy difference is composed 66% of H–H interactions in the latter case, however, whereas it is 78% in the former. Thus it may roughly be said that, using the present energy functions between a quarter and a third of the axial–equatorial methyl energy difference arises from angle and torsional strains, the rest from nonbonded interactions of hydrogens. The actual figure of 1.01 kcal./mole obtained is of course lower than the empirical value by a substantial proportion. On the other hand, when the uncertainty of the energy parameters is taken into account, the result may be accounted a satisfactory one.

Methylcycloheptane.—The same program used by the computer for computing the energy of a methyl group on a six-membered ring serves to compute that of the seven-membered ring cases as well. However, whereas in the methylcyclohexanes the basic chair ring conformation is clearly indicated by its unique position at the bottom of a potential energy well, the position of placement of a methyl on the seven-membered ring constitutes a much more complex problem. In the course of pseudorotation of the flexible chair cycloheptane, a given substituent, such as methyl, passes through a smoothly changing continuum of conformational position or environment and this may be characterized by a sequence of fifteen distinguishable conformational positions on the two symmetrical cycloheptane rings, chair (C$_S$) and twist-chair (C$_2$), through which the pseudorotation passes.[2] This sequence of fifteen conformational positions on the two symmetrical ring forms is the *pseudorotation itinerary* and consists of four axial and four equatorial positions in the chair cycloheptane and an axis-carbon (C-1) plus three axial and three equatorial positions on the twist-chair form. The two symmetrical cycloheptanes themselves are each characterized by four bond angles and four dihedral angles and it was found previously that the most stable conformations of these had bond angles somewhat larger than tetrahedral.[2]

If we consider the methylcycloheptane to be "frozen" in each one of these forms we can calculate for each separate position the energy of the added methyl on the ring as with cyclohexane above. For each such case we can further flex the ring angles and the angle at which the methyl is attached in order to find that particular molecular shape having the least energy. In the course of searching previously for the most stable parent cycloheptane ring we had examined the energies of a variety of

TABLE I

ENERGIES OF METHYLCYCLOHEPTANE CONFORMERS

Methyl position	ΣE[a]	ΔE[b]	ϕ_M	ω_M	Ring description[c]
			Twist-chair ring		
1 (axis)	10.65	0.03	τ	0°	Normal
2e	10.61	−0.01	τ	0°	Normal
2a	14.92	4.27	114°	− 4°	$\theta = 114°$
3e	10.62	0.00	τ	0°	Normal
3a	15.50	4.88	114°	−26°	$\theta = 114°$
4e	10.63	0.01	τ	0°	Normal
4a	12.05	1.43	112°	−14°	Normal
			Chair ring		
1e	12.77	2.15	τ	0°	Normal
1a	14.59	3.97	τ	0°	$\theta = 115°$
2e	12.77	2.15	τ	0°	Normal
2a	14.41	3.79	112°	4°	$\theta = 113, 111, 116°$
3e	12.77	2.15	τ	0°	Normal
3a	19.97	9.35	116.5°	36°	$\theta = 113, 111, 117°$
4e	12.85	2.23	τ	0°	Normal
4a	13.64	3.02	110.5°	−10°	Normal

[a] ΣE is the total calculated energy of ring with methyl attached and compensation for the replaced hydrogen at that carbon, in kcal./mole. [b] ΔE represents the difference from the average equatorial energy of 10.62 kcal./mole. [c] The geometry of the rings is given below:

	θ_1	θ_2	θ_3	θ_4	ω_1	ω_2	ω_3	ω_4
Twist-chair: Normal	112°	112°	112°	112°	−41.2°	97.0°	−75.8°	52.9°
$\theta = 114°$	114	114	114	114	−39.7	91.7	−72.2	50.8
Chair: Normal	τ	112	111	116	69.9	−91.8	70.6	0.0
$\theta = 115°$	115	115	115	115	55.3	−86.0	71.7	0.0
$\theta = 113, 111, 116°$	τ	113	111	116	68.2	−91.4	70.6	0.0
$\theta = 113, 111, 117°$	τ	113	111	117	70.0	−90.2	68.8	0.0

rings with various bond angles[6] so that these were available for calculation of the effect of substituting one methyl group by the above computer program, varying independently in each case the bond angle ϕ_M of attachment of that methyl and its dihedral angle ω_M of rotation around the C–CH_3 bond. For each case, the choice of parent rings used[6] did in fact afford an energy minimum for the methyl. The values obtained are summarized in Table I.

To illustrate the procedure in more detail let us examine the calculation of the 2-axial methyl on the twist-chair cycloheptane. A set of angles representing one parent ring is selected; the program then computes the energy of adding methyl at a bond angle ϕ_M and rotating it in increments of $\Delta\omega_M$ through 120°. This yields a minimum at some orientation, ω_M, of the methyl group attached at an angle ϕ_M to the ring. The procedure is repeated for values of ϕ_M increasing from τ until the balance of the strain of enlarging ϕ_M and the release of H–H interaction energy affords a minimum energy for a methyl group in the 2-axial position on one particular parent cycloheptane ring. In the case of the ring with all bond angles equal to 112° (the preferred parent ring[2]), ΣE = 25 kcal./mole at $\phi_M = \tau$ and drops to a minimum of 15.8 kcal. at ϕ_M = 116.5°, *i.e.*, as the methyl is bent back away from the compressed axial environment. Similar variations of ΣE with ϕ_M and ω_M can be found for each of the parent rings available[6] and from the whole set the conformation and energy of the particular 2-axial-methyl twist-chain cycloheptane of lowest energy can be located. In this case the parent ring with all bond angles 114° afforded the lowest ΣE *vs.* ϕ_M minimum at 14.92 kcal./mole and ϕ_M = 114.0° (Table I). The parent rings with spread angles[6] afforded no minima below 15.8 kcal. In every instance the minima were found at rotations, ω_M, of the 2-axial methyl group between 90° and 120° (−30° and 0°).

In searching for minima, the rotation ω_M occasionally exhibited two minimum-energy positions; the clearest example was the 1-axial-methyl in the chair conformation, for which the two minima always occurred at ω_M = 0° and 60°, positions which balance symmetrically the H–H interactions of the methyl with the 3a-hydrogens, usually but not always with the lower minimum at ω_M = 0°, *i.e.*, with one methyl hydrogen in the mirror plane of the ring and between the two 3a-hydrogens. The latter position has more severe van der Waals repulsions but has the advantage of no torsional strain, whereas the conformation with ω_M = 60° has the methyl eclipsed but suffers least from H–H repulsion. (Most of the preferred configurations of the methyl will be observed to be at or near ω_M = 0°, the configuration with no torsional strain.)

Another effect of interest observed in the 1-axial-methyl computations was that as the parent rings chosen afforded minima closer and closer to that of the best case, the value of ϕ_M at the minimum decreased nearer to τ, the value of ϕ_n in the best case. This implies that in the successive chosen rings the 3a-hydrogens are being spread farther apart until, in the best case, they are beyond reach of the 1-axial-methyl, which need not be tilted away from its axial position at all to avoid them. In the other cases, such ring spreading combined with this tilting (ϕ_M) to produce the preferred orientation.

Increments of 2° for ω_M and 0.5° for ϕ_M were finally used in obtaining the minimum energies and the latter are given to two decimal places, not to imply a useful accuracy of this degree but to show how closely the various equatorial methyls on different positions of one ring come to being equal in these computations. Since it would certainly be expected that they should be equal it is heartening to find this to be the case.

The data of Table I can now be applied to tracing an energy contour of the pseudorotation, as shown in Fig. 3. The curve follows the strain energy encountered by the methyl group as it passes through the pseudorotation itinerary, plotted as the abscissa. A number of interesting features emerge from examination of these data: 1. The calculations show that all the equatorial positions on one ring conformation prefer $\phi_M = \tau$ and have the same energy; also, as would be expected, the ring form for mini-

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(6) The cycloheptanes used as parent rings for these methyl-substitution trials were both chair and twist-chair forms, either with all bond angles equal, from 109.5° to 115°, or with a "spread" ring in which C_1 = 109.5° and C_2, C_3 and C_4 are varied independently from 109.5° to 117°.

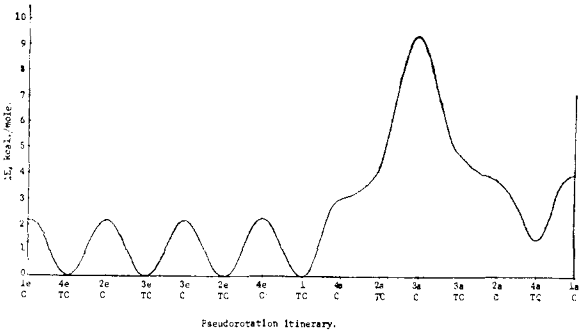

Fig. 3.—Pseudorotation of methylcycloheptane.

mum energy is the same with an equatorial methyl as it is for the minimum-energy parent cycloheptane ring itself. The energy of the equatorial-methyl-cycloheptanes is lower by 0.5 kcal./mole than that calculated for the ring itself (chair, 13.30; twist-chair, 11.14 kcal.[2]), reflecting the net increase in dispersion or attractive interactions (H-H distances $\gtrsim$ 2.2Å.) when the methyl is attached to the ring. Methyl-cycloheptane should be expected to partition among the twist-chair forms with equatorial methyls, these forms being freely interconvertible through pseudorotation.

2. The axis-carbon (C–1) of the twist-chair has two equivalent substituent positions, unlike any of the other carbons of cycloheptane (or cyclohexane); inasmuch as these previously have been considered to be intermediate in energy between axial and equatorial,[2] it is important to note that the calculated energy of these positions is in fact virtually the same as that of the equatorial positions. This has the important consequence that a *gem*-dimethyl cycloheptane (and, by a reasonable extension, any 1,1-disubstituted cycloheptane) will take up preferentially the single conformation of a twist-chair with the two methyls on the axis-carbon; the preference for this form should be 1.4 kcal./mole, this being the energy difference between the axial and equatorial methyls on the next best position (twist-chair, 4e-4a) and hence the energy difference between 1,1-dimethyl- and 4,4-dimethyl-cycloheptanes (twist-chair). A comparable situation does not, of course, exist in cyclohexane cases.

3. The higher relative energy values for axial positions in methylcycloheptanes over methylcyclohexane is part of a trend from the slight distinction between axial and equatorial orientations in the many minimum-energy cyclopentane conformations[2,7] to the very severe interactions which exist on "inside" positions of the medium (C_{8-12}) rings,[8] where even the hydrogens are sterically crowded so that the relative energies of "axial" methyls at those positions would be enormous.[9] The highest axial energy in the cycloheptanes is that of the chair 3a-methyl (9.35 kcal./mole) and represents the height of the barrier to free pseudorotation among all the methylcycloheptane conformations.

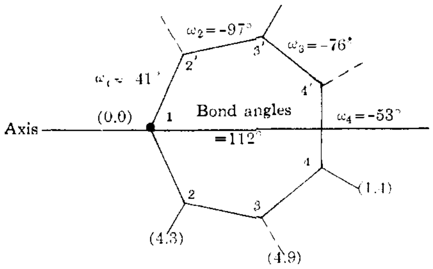

Fig. 4.—Equatorial positions on cycloheptane (twist-chair form; axial-methyl energies in parentheses).

Since it is less than the barrier to chair–boat interconversion in cyclohexane,[2,10] we may assume that a rapid, thermal pseudorotation occurs in methylcycloheptane at ordinary temperatures. Although the calculated value for axial methylcyclohexane above is actually lower than the empirical value, it does not necessarily follow that the axial methylcycloheptane values given in the table are similarly low since many of the involved van der Waals interactions will be computed from different regions of the curve of $E = f(r)$, which may indeed vary in accuracy.

4. The values of ΔE in Table I are somewhat high since they all were calculated assuming only variations of ring shape which retained plane or axial symmetry in the parent cycloheptane ring. However, they should be essentially comparable to the 1.04 kcal./mole difference calculated in the cyclohexane case in which the chair symmetry was retained for the ring. Since this is very close to the 1.01 kcal./mole figure obtained by also warping the ring out of symmetry, the present figures for cycloheptane probably would be little changed by slight warping actions of this kind.

Figure 4 summarizes the more stable twist-chair cycloheptane, showing the ΔE of axial-methyl substituents for each position as well as the approximate bond and dihedral angles (these vary slightly with the substituent; see Table I). At each position the equatorial bond is shown, alternately above and below the molecular plane as in chair cyclohexane; both positions at the axis-carbon are equatorial. This diagram is useful for assigning the preferred conformations of polymethylcycloheptanes and will be valid for this purpose as long as the substituents are not both *cis* and axial, in which case repulsions between the substituents themselves became important.

In using the diagram one can see that in 1,2-*trans*-dimethylcycloheptane any pair of vicinal ring positions are suitable to provide *trans* di-equatorial sites and the compound itself should partition equally among these four discrete twist-chair conformations *via* pseudorotation. The 1,2-*cis* isomer, by contrast, can achieve a minimum energy only by taking up the twist-chair conformation with one methyl on the axis-carbon. In a similar manner it is possible to examine all the possible polymethylcycloheptanes, assigning preferred conformations and minimum energies to the isomers. A table of all the di- and tri-methylcycloheptanes is appended

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[7] K. S. Pitzer and W. E. Donath, *J. Am. Chem. Soc.*, **81**, 3213 (1959).

[8] V. Prelog, *J. Chem. Soc.*, 420 (1950).

[9] Needless to say, substituents on these medium-size, flexible rings avoid the "inside" positions through pseudorotation so that examples for empirical comparison are not easily found.

[10] F. R. Jensen, D. S. Noyce, C. H. Sederholm and A. J. Berlin, *J. Am. Chem. Soc.*, **82**, 1256 (1960).

(Table II). The table suggests that all dimethylcycloheptanes will have essentially the same energy, equal minimum-energy conformations being available for all, whereas four of the thirteen possible trimethyl isomers should be of higher energy than the rest by about 1.4 kcal./mole. The only relevant cycloheptanes studied to date are the *cis*- and *trans*-3,5-dimethylcycloheptanones, which differ in energy by 0.8 kcal./mole[11] and suggest the presence of several conformations, but since the effects studied here are fairly delicate and strongly influenced by geometrical changes, the presence of a carbonyl group is very likely to vitiate conclusions drawn on the hydrocarbons, so that this case cannot be taken as a relevant test.

The presence on cycloheptanes of other substituents which, unlike carbonyls, retain the tetrahedral configuration of the ring carbon may reasonably be treated like the methyl groups above in conformational analysis. Application of Winstein's A-values[12] for different substituents to the axial-methyl energies at different conformational positions should provide a first approximation to the conformations of such derivatives of cycloheptanes. Thus, for example, all-*trans*-1-hydroxy-3,5-dimethylcycloheptane should take up the conformation with the hydroxyl group at the 4-axial position, since its steric interference is about half that of the methyl group, leaving the methyls to occupy equatorial positions at (1, 3′e) or (2e, 2′e).

TABLE II

PREFERRED CONFORMATIONS OF DI- AND TRI-METHYLCYCLOHEPTANES

Isomer[a]		Preferred conformations	ΔE,[b] kcal./mole
1,2	c	(1,2e)	0
1,2	t	(1,2e), (2e,3e), (3e,4e), (4e,4′e)	0
1,3	c	(1,3e), (2e,4e), (3e,4′e)	0
1,3	t	(1,3e), (2e,2′e)	0
1,4	c	(1,4e), (2e,3′e)	0
1,4	t	(1,4e), (2e,4′e), (3e,3′e)	0
1,2,3	c,c	(3,4a,4′e)	1.4
1,2,3	c,t	(1,2e,3e), (2′e,1,2e)	0
1,2,3	t,t	(1,2e,3e), (2e,3e,4e), (3e,4e,4′e)	0
1,2,4	c,c	(1,2e,4e), (2e,1,3′e)	0
1,2,4	c,t	(1,2e,4a), (3e,4a,3′e), (4′e,4a,2e), (4a,3e,1)	1.4
1,2,4	t,c	(1,2e,4e), (2e,3e,4′e), (3e,4e,3′e), (4′e,4e,2e), (4e,3e,1)	0
1,2,4	t,t	(2e,1,3′e), (3e,2e,2′e), (4e,3e,1)	0
1,2 5	c,c	(1,2e,4′a), (4e,4′a,1)	1.4
1,2,5	c,t	(1,2e,4′e)	0
1,2,5	t,c	(1,2c,4′e), (2e,3e,3′e), (3e,4e,2′e), (4e,4′e,1)	0
1,3,5	c,c	(1,3e,4′e), (2e,4e,3′e)	0
1,3,5	c,t	(3e,1,3′e), (4e,2e,2′e), (4e,3′e,1)	0
1,3,5	t,t	(1,3e,4′a), (2′e,2e,4a)	1.4

[a] As an example of the isomer notation used, "1,2,5-c,t" refers to 1,2-*cis*,2,5-*trans*-trimethylcycloheptane. [b] The energy difference from the relevant all-equatorial isomer.

In a similar vein the conclusions derived herein should provide a valid basis for conformational analysis of a wide variety of cycloheptane derivatives.

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[11] N. L. Allinger, *J. Am. Chem. Soc.*, **81**, 232 (1959).

[12] S. Winstein and N. J. Holness, *ibid.*, **77**, 5562 (1955).

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, RADIATION CENTER OF OSAKA PREFECTURE, SAKAI, OSAKA, JAPAN]

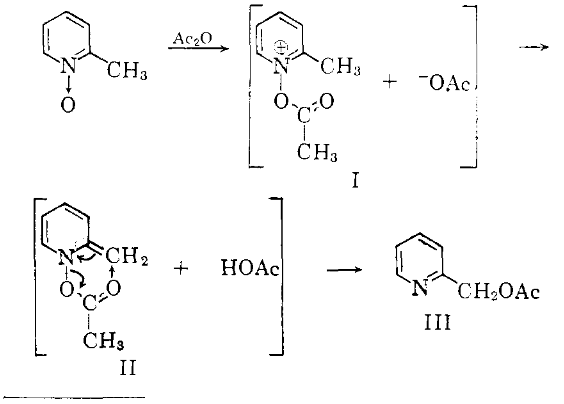
The Mechanism of the Reaction of 2-Picoline N-Oxide with Acetic Anhydride[1]

BY SHIGERU OAE, TEIJIRO KITAO AND YOSHINORI KITAOKA

RECEIVED JANUARY 31, 1962

2-Picoline N-oxide was allowed to react with acetic anhydride of which all three oxygens were equally enriched by oxygen-18, and the 2-acetoxymethylpyridine obtained was hydrolyzed to 2-pyridinemethanol. Oxygen-18 analyses of these two compounds revealed that both carbonyl and ether oxygens of 2-acetoxymethylpyridine have a mean value of one enriched oxygen-18 and one natural oxygen. The additions of large amounts of solvent and of DPPH did not affect the yield of the main product. These observations, together with earlier findings, were considered as suggesting that the reaction proceeds *via* a "free radical pair" in solvent cage.

The reaction of 2-picoline N-oxide with acetic anhydride has been shown independently by several different laboratories[2-4] to give 2-acetoxymethylpyridine. The benzoylation of quinaldine N-oxide has also been shown to give 2-benzoxymethylquinoline.[5] The mechanism suggested then for the rearrangement is shown below, and this has been generally accepted for this and related reactions.[2,4-7]



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[1] Paper III on "Rearrangements of Tertiary Amine Oxides." A preliminary report appeared in paper I of this series: S. Oae, T. Kitao and Y. Kitaoka, *Chemistry & Industry*, 515 (1961); paper II: S. Oae, T. Fukumoto and M. Yamagami, *Bull. Chem. Soc., Japan*, **34**, 1873 (1961).

[2] G. Kobayashi and S. Furukawa, *Pharm. Bull. Japan*, **1**, 347 (1953).

[3] V. Boekelheide and W. J. Linn, *J. Am. Chem. Soc.*, **76**, 1286 (1954).

[4] O. H. Bullitt and J. T. Maynard, *ibid.*, **76**, 1370 (1954).

[5] I. J. Pachter, *ibid.*, **75**, 3026 (1953).

[6] J. A. Berson and T. Cohen, *ibid.*, **77**, 1281 (1955).

[7] E. Matsumura, *Memoirs of the Institute for Arts and Sciences, Univ. of Osaka*, **1**, 1 (1952).