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Highly Strained Bicyclic Systems. VII.^{1,2} Dipole Moments and the Configurations of Some Bicyclo[2.2.1]heptanes and Bicyclo[2.1.1]hexanes

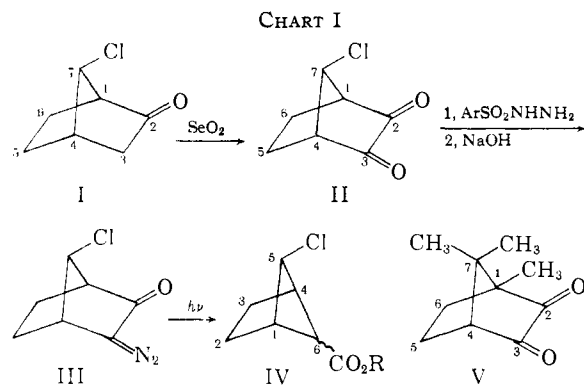
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This work was undertaken to ascertain the configurations of some newly prepared 5-chlorobicyclo[2.1.1]hexanes (IV). The configuration of the chlorine atom was determined by dipole moment measurements on a precursor of IV, 7-chlorobicyclo[2.2.1]heptane-2,3-dione, which was shown to have the *syn* configuration (II). The major acid obtained by photolysis of the diazoketone III derived from II is shown to be *exo*-5-chlorobicyclo[2.1.1]hexane-*exo*-6-carboxylic acid IVa on the basis of the dipole moment of its methyl ester IVb. Finally, the observed moment of the methyl ester derived from the more stable epimer of IVa is in agreement with expectations for the ester of *exo*-5-chlorobicyclo[2.1.1]hexane-*endo*-6-carboxylic acid (IVc).

Introduction

In exploring the chemistry of the bicyclo[2.1.1]hexanes, establishing configurations is a prerequisite for the rational interpretation of observed properties and reactions. A synthetic route to a group of bicyclo[2.1.1]hexanes bearing a chlorine atom of readily definable configuration on one of the one carbon bridges has recently been carried to completion,⁴ and is outlined in Chart 1. The unusual long-range spin-spin couplings between protons on C₅ and C₆ of the bicyclo[2.1.1]hexane nucleus which have been observed recently⁵ have made this knowledge of configurations especially desirable.



The *exo* configuration for the chlorine atom in IV is established by assuming that no unforeseen rearrangement accompanied the ring contraction scheme and as long as the *syn* configuration of the 7-chlorobicyclo[2.2.1]heptane precursors I and II can be considered to be certain. The stereochemistry of I would appear to follow from its method of synthesis (addition of hypochlorous acid to bicyclo[2.2.1]heptene, followed by oxidation), and has been supported by dipole moment evidence.⁶ Since Compound I was obtained as a

waxy material, which may not have been homogeneous, and since the agreement of the observed dipole moment with expectation was fair rather than excellent, we considered it worthwhile to obtain additional support for the configuration of our starting materials. This first objective was reached by a study of the dipole moments of the crystalline chloro α -diketone II, obtained by oxidation of I with selenium dioxide, and of a non-chlorinated model compound, camphorquinone (V).

Results

The theoretical dipole moment of camphorquinone (V) can be calculated from the moment of camphor of 3.05 D.,⁷ assuming that the angles given by Wilcox⁸ for the bicyclo[2.2.1]heptane nucleus are still reasonable approximations when trigonal carbons are introduced. The angle at carbon atom 2 would be 104°, which means that the carbonyl dipoles would make an angle of 180° - 104° = 76° with one another. The resultant dipole moment of camphorquinone would then be

$$\mu = \sqrt{(3.05)^2 + (3.05)^2 + 2 \times 3.05 \times 3.05 \cos 76^\circ} = 4.82 \text{ D.}$$

This is identical within the experimental error with the moment of 4.81 ± 0.01 D., which is a better agreement than need be expected.

The theoretical moment of *syn*-7-chloronorcamphorquinone (II) can be calculated by taking the angle of 109°⁸ between the two larger bridges of II. This means the angle between planes 147 and 1234 is 1/2 (360° - 109°) = 125.5°. The angle between plane 147 and the C-Cl bond for the *syn* compound is calculated to be 34.5° + 90° = 124.5°, using the unit vector values from the Wilcox paper.⁸ The angle between the resultant of the two C=O dipoles and the C-Cl dipole is then 70° and the theoretical dipole moment for the *syn* compound is

$$\mu = \sqrt{(4.81)^2 + (1.9)^2 + 2 \times 4.81 \times 1.9 \cos 70^\circ} = 5.72 \text{ D.}$$

The angle between the resultant of the two C=O dipoles and the C-Cl dipole in the *anti* compound is 125.5° + (90° - 34.5°) = 181°. The theoretical dipole moment of this isomer is then 2.91 D.

The observed moment of 5.33 D. as shown in Table I indicates very clearly that the compound has the expected *syn* configuration. The differ-

(1) Presented in part before the Division of Organic Chemistry at the 139th National Meeting of the American Chemical Society, March 21-30, 1961, in St. Louis, Mo. (Abstracts p. 39-O).

(2) For Part VI see J. Meinwald, A. Lewis and P. G. Gassman, *J. Am. Chem. Soc.*, in press.

(3) Fellow of the Alfred P. Sloan Foundation.

(4) The details of these synthetic studies, initiated by Mrs. Charlotte B. Jensen and completed by Dr. A. Lewis, are now being prepared for publication.

(5) J. Meinwald and A. Lewis, *J. Am. Chem. Soc.*, **83**, 2769 (1961).

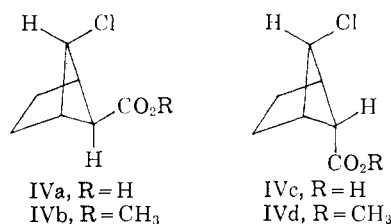
(6) J. D. Roberts, F. O. Johnson and R. A. Carboni, *ibid.*, **76**, 5692 (1954).

(7) K. Higashi, *Bull. Inst. Phys. Chem. Res. (Tokyo)*, **11**, 729 (1932).

(8) C. F. Wilcox, Jr., *J. Am. Chem. Soc.*, **82**, 414 (1960).

ence of 0.39 D. between the observed and the theoretical moment for this compound may be due to the electrostatic interactions between the carbon-chlorine and carbonyl components; in any case it is no greater than the expected error arising from some of the assumptions used in arriving at the angles. An almost identical difference (0.38 D.) between the observed and theoretical moment for a somewhat analogous compound (2-(a)bromo-4-*t*-butylcyclohexanone) was recently reported,⁹ although in that case the theoretical moment was smaller than the observed moment.

With the configuration of the chlorine atom in II confirmed, the C-Cl dipole moment may be used as a reference vector of known direction in the problem of establishing the carboxyl group configuration in the bicyclo[2.1.1]hexanes of interest (IVa and IVc). It should be noted that this problem is not readily soluble by calculations of expected non-bonded repulsions, since the two isomers appear to differ insignificantly when the relevant internuclear distances are calculated.⁸



The theoretical dipole moments for the corresponding methyl esters IVb and IVd were calculated using Wilcox's unit vectors to arrive at the angles the bonds make with the bicyclic ring system. The angle an ester group dipole makes with the bond between the ester carbonyl carbon and the attached α -carbon was taken as 64° , following Smyth.¹⁰ The equation for calculation of the moment assuming free rotation about this bond was one used previously.¹¹

In the 6-*exo* compound IVb, the angle the C-Cl and the C-C bonds make with the Z-axis (Wilcox's notation) is 12.5° , which means they then are at an angle σ of 25° with one another. The methoxy group is assumed to occupy an *s-trans* position, so the ester group has a moment of 1.7 D. and this rotates at an angle of 64° with the C-C bond. The dipole moment for the above structure, assuming free rotation, is then

$$\mu_{i.r.} = \sqrt{(1.9)^2 + (1.7)^2 + 2 \times 1.9 \times 1.7 \cos 25^\circ \cos 64^\circ \cos 0^\circ} = 3.03 \text{ D.}$$

The minimum value of the angle between the C-Cl and ester dipole would be $64^\circ - 25^\circ = 39^\circ$, and the resulting $\mu_{\max} = 3.40$ D. The maximum angle would be $64^\circ + 25^\circ = 89^\circ$, and the resulting $\mu_{\min} = 2.58$ D.

In the 6-*endo* compound IVd, $\sigma = 12.5^\circ + 90^\circ + 37.5^\circ = 140^\circ$ and $\mu_{i.r.} = 2.07$ D. The angle

(9) N. L. Allinger, J. Allinger and N. A. LeBel, *J. Am. Chem. Soc.*, **82**, 2926 (1960).

(10) C. P. Smyth, "Dielectric Behavior and Structure," McGraw-Hill Book Co., Inc., New York, N. Y., 1955, p. 366.

(11) W. D. Kumler and I. F. Halverstadt, *J. Am. Chem. Soc.*, **63**, 2182 (1941).

between the C-Cl and the ester resultant with the ester fixed in a minimum position is 76° , and the corresponding $\mu = 2.84$ D. The maximum angle is 156° and the corresponding $\mu = 0.77$ D.

The observed moment (see Table I) for the ester of the initially predominant acid⁴ (2.68 ± 0.01 D.)

TABLE I
DIPOLE MOMENT MEASUREMENTS AT 30°
Camphorquinone in benzene

ω_2	ϵ_{12}	ν_{12}
0.0	2.2607	1.14751
.0031117	2.3047	1.14684
.0061977	2.3484	1.14644
.0101178	2.4084	1.14551
.0135037	2.4556	1.14484
.0168177	2.5058	1.14418
$\epsilon_1 = 2.2596$	$\alpha = 14.5888$	$\nu_1 = 1.14753$
$\beta = -0.19814$	$P_{20} = 509.82$	$P_{E_2} = 45.65$
$\mu = 4.81 \pm 0.02$		

7-Chloronorcamphorquinone in benzene

0.0	2.2607	1.14657
.0024739	2.3094	1.14524
.0066864	2.3901	1.14352
.0096625	2.4481	1.14193
.0146668	2.5422	1.14061
.0199389	2.6404	1.13798
$\epsilon_1 = 2.26223$	$\alpha = 19.0446$	$\nu_1 = 1.14635$
$\beta = -0.41736$	$P_{20} = 605.99$	$P_{E_2} = 34.99$
$\mu = 5.33 \pm 0.01$		

Methyl ester of *exo*-5-chlorobicyclo[2.1.1]hexane-*exo*-6-carboxylic acid (IVb) in heptane

0.0	1.9056	1.47497
.00300467	1.9165	1.47343
.00573415	1.9255	1.47211
.00875311	1.9360	1.47058
.0126603	1.9493	1.46839
.0171318	1.9639	1.46556
$\epsilon_1 = 1.90601$	$\beta = 3.399819$	$\nu_1 = 1.475129$
$\beta = -0.54433$	$P_{20} = 195.49$	$P_{E_2} = 51.22$
$\mu = 2.68 \pm 0.01$		

Methyl ester of *exo*-5-chlorobicyclo[2.1.1]hexane-*endo*-6-carboxylic acid (IVd) in heptane

0.0	1.9056	1.47453
.00316977	1.9131	1.47255
.00616802	1.9195	1.47080
.00929895	1.9265	1.46883
.0125578	1.9341	1.46686
.0161267	1.9413	1.46404
$\epsilon_1 = 1.90584$	$\alpha = 2.21938$	$\nu_1 = 1.47464$
$\beta = -0.64691$	$P_{20} = 135.88$	$P_{E_2} = 51.22$
$\mu = 2.06 \pm 0.01$		

is in fairly good agreement with the "free rotation" calculation for the 6-*exo* (3.03 D.) isomer IVb and the observed moment of the ester of the more stable epimer (2.06 ± 0.01 D.) is in excellent agreement with the "free rotation" calculation for the 6-*endo* (2.07 D.) isomer IVd. It may therefore be concluded that the chief acid formed by photolysis of III has an *exo*-carboxyl group (IVa),¹² a

(12) It should be noted that this assignment is dependent on the correctness of the previously discussed chlorine configuration. Thus, if the chlorine occupied an *endo* position, as shown in structures i and ii, the *exo* ester may be calculated to have a μ (free rotation) of 2.07 D.

TABLE II
SUMMARY OF CALCULATIONS

Compound	μ free rotation	μ maximum	μ minimum
IVb	3.03	3.40	2.58
IVd	2.07	2.84	0.77
i	2.07	2.84	0.77
ii	2.41	2.95	1.94

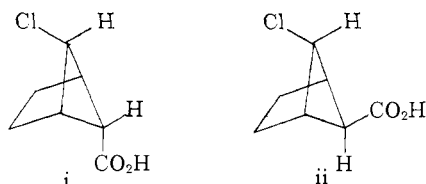
result which coincides with the steric course recently determined for the analogous ring contraction of diazocamphor (V).¹³

Acknowledgments.—The support of this work by the Alfred P. Sloan Foundation and the National Science Foundation is acknowledged with pleasure.

Experimental

The dielectric constants were measured with the Dipolemeter DMOI made by the Wissenschaftlich-Technische Werkstätten. The dipole moments were calculated using the equation and method of Halverstadt and Kumler.¹⁴

and the *endo* isomer a value of 2.41 D. These data, along with the relevant μ_{\max} and μ_{\min} calculations, are summarized in Table II.



(13) J. Meinwald, A. Lewis and P. G. Gassman, *J. Am. Chem. Soc.*, **82**, 2649 (1960); see also ref. 2.

$$p_{20} = \frac{3\alpha v_1}{(\epsilon_1 + 2)^2} + (v_1 + \beta) \frac{(\epsilon_1 - 1)}{(\epsilon_1 + 2)}$$

$$P_{20} = p_{20}M$$

$$\mu = 0.01281 \sqrt{(P_{20} - P_{E_2})T}$$

The plots of ϵ_{12} versus ω_2 and v_{12} versus ω_2 were straight lines within the limits of experimental error. The value of ϵ_1 and v_1 were calculated by the method of least squares. The standard error in the dipole moments was calculated from the equation $\delta\mu = 0.004 (M/\mu)\delta\alpha^{15}$ and the standard error in α from the equation¹⁶

$$\delta\alpha = \pm \left\{ \frac{n}{n-2} \left[\frac{\Sigma(\epsilon' - \epsilon_{12})^2}{n\Sigma\omega_2^2 - (\Sigma\omega_2)^2} \right] \right\}^{1/2}$$

where n is the number of solutions taken and ϵ' is the value from the best straight line. Errors from the scatter of the points for specific volume do not need to be considered since large errors in β produce only negligible errors in the dipole moments.¹⁷

The P_{E_2} values are from the molar refractions as calculated from the electron group refractions.

Camphorquinone, m.p. 198°, was made in the usual way by selenium dioxide oxidation of *d*-camphor.¹⁸

7-Chloronorcarnphorquinone, m.p. 111.5–112°, was made in an analogous way by selenium dioxide oxidation of *syn*-7-chlorobicyclo[2.2.1]heptan-2-one.⁴

(14) I. F. Halverstadt and W. D. Kumler, *ibid.*, **64**, 2988 (1942).

(15) E. W. Randall and Rodger Raab, private communication.

(16) C. G. Le Fevre and R. J. W. Le Fevre, *J. Chem. Soc.*, 4041 (1953).

(17) K. B. Everard, R. A. W. Hill and L. E. Sutton, *Trans. Faraday Soc.*, **46**, 417 (1950).

(18) Elsevier's "Encyclopedia of Organic Chemistry," Elsevier Publishing Co., Inc., New York, N. Y., 1948, Vol. 12 A, p. 888.

[CONTRIBUTION FROM THE DEPARTMENT OF PHARMACEUTICAL CHEMISTRY, SCHOOL OF PHARMACY, UNIVERSITY OF CALIFORNIA, SAN FRANCISCO MEDICAL CENTER, SAN FRANCISCO, CALIF.]

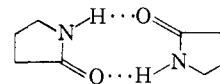
The Dipole Moment and Structure of Five- and Six-membered Lactams

BY CALVIN M. LEE AND W. D. KUMLER

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The dipole moment of 2-pyrrolidone (I), 3.79 D., is like that of a straight chain amide. The addition of a methyl group one carbon removed or on the nitrogen increases the moment (*ca.* 0.3 D.) by stabilizing the plus charge on the nitrogen in the ionic form. Spiro-(cyclohexane-1,5'-pyrrolidone) (IV) has an appreciably higher moment, 4.56 D., than I. The addition of a carbonyl group to the nitrogen of a 5- or 6-membered-lactam (N-acetyl) decreases the moment, indicating that the compound is in the *cis-trans* conformation where the carbonyl groups are farthest apart. The decrease in moment in the 6-membered ring lactam, 0.6 D., is less than the decrease in moment in the 5-membered ring lactam, 0.8 D., as the angle between the carbonyl groups in the 6-membered ring compound is less than in the 5-membered ring compound. The addition of a carbonyl group in the lactam ring forms an imide which must be in the *cis-cis* conformation. The decrease in the dipole moment in the 6-membered rings is about 1.3 D. while the decrease in the 5-membered ring is about 2.4 D. The greater decrease in the 5-membered rings is due to the greater angle between the two ring carbonyls and the opposition of the N^+O^- dipoles to the carbonyl resultant in the 5-membered ring. The substitution of a methyl group for hydrogen on lactams or imides raises the dipole moment by about 0.15 D.

The dipole moment of simple amides in dioxane at 30° is in the range of 3.7–3.9 D.¹ The dipole moment of pyrrolidone (I) in dioxane at 30°, 3.79 D is like that of the straight chain amides. Fischer² reported a value of 3.7 D. in benzene for I and Huisgen and Waltz³ give a value of 3.55 D. in benzene at 25°. In 1933, Devoto⁴ calculated a value of 2.3 D. for pyrrolidone in benzene; this low moment has been attributed to the formation of a dimer of low dipole moment²



The dipole moment of the cyclic dimer of pyrrolidone is said³ to have a value of 2.2 D. in benzene at 25°.

One cannot make a model of pyrrolidone with Stuart-Briegleb models as the compression of angles from 120° to 108° is too great. It is peculiar then that the moment of the compound is like a straight chain amide. The 5-membered ring would be expected to have more *s*-character in the exocyclic bonds and more *p*-character in the ring bonds.⁵

(1) W. D. Kumler and C. W. Porter, *J. Am. Chem. Soc.*, **56**, 2549 (1934).

(2) E. Fischer, *J. Chem. Soc.*, 1382 (1955).

(3) R. Huisgen and H. Waltz, *Chem. Ber.*, **89**, 2616 (1953).

(4) G. Devoto, *Gazz. chim. ital.*, **63**, 495 (1933).

(5) C. M. Lee and W. D. Kumler, submitted for publication.