

DIPOLE MOMENTS OF SOME SUBSTITUTED CYCLOHEXANONES

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(Received in the UK 1 January 1969; Accepted for publication 27 January 1969)

Abstract—The electric dipole moments of some aryl substituted cyclohexanones have been measured in benzene solution at 30°. From the data on 3-(*p*-bromophenyl)cyclohexanone, a free energy change of -1.4 kcal/mole at 30° has been obtained for moving an axial aryl group to the equatorial position. The measurements indicate that 3,3,5-trimethyl-5-phenylcyclohexanone and 5-(*p*-bromophenyl)-3,3,5-trimethylcyclohexanone exist in non-chair conformations.

DETERMINATION of dipole moments is a valuable method for establishing the geometry and conformation of molecules. The presence of a highly polar group in cyclohexanones makes dipole moment measurements a convenient method for studying their conformation. Mention can be made of studies on 2-bromocyclohexanone,^{1,2} cyclohexane-1,4-dione,^{3,4} 4,4-dimethylandrostan-3,17-dione and 2,2-dimethylandrostan-3,17-dione.⁵ As a continuation of our work on phenyl-substituted cyclohexane derivatives,^{6,7} the electric dipole moment of a number of substituted cyclohexanones were measured and the results are presented below.

Dipole moments

The dielectric constants (ϵ_{12}) and densities (d_{12}) of dilute benzene solutions were measured at 30° and the empirical constants α and β for each compound were calculated from the equations,⁸

$$\begin{aligned}\epsilon_{12} &= \epsilon_1(1 + \alpha w_2) \\ d_{12} &= d_1(1 + \beta w_2).\end{aligned}$$

Where ϵ_1 , and d_1 , are the dielectric constant and density of the solvent respectively, and w_2 is the weight fraction of the solute.

The molar polarization (P_2) of the solute was calculated from the relation,⁸

$$P_2 = M_2 \frac{(\epsilon_1 - 1)(1 - \beta)}{(\epsilon_1 + 2)d_1} + \frac{3M_2\alpha\epsilon_1}{d_1(\epsilon_1 + 2)^2},$$

where M_2 is the molecular weight of the solute. The dipole moment μ was calculated from

$$\mu = 0.01281 [(P_2 - R_D) T]^{\frac{1}{2}}$$

R_D is the molar refraction of the solute for the sodium *D* line and *T* the absolute temperature. The results are summarized in Table 1.

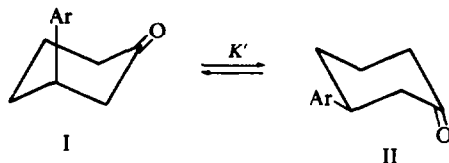
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TABLE I. POLARIZATION DATA AT 30°

No.	Compound	α	$-\beta$	P_2 (ml)	R_D (ml)	μ (D)
1	Cyclohexanone	9.73	0.099	212.0	27.8	3.02
2	3-Phenylcyclohexanone	5.20	0.208	220.9	52.1	2.90
3	Phenylcyclohexane	0.278	0.075	59.6	52.0	0.62
4	3-(<i>p</i> -Bromophenyl)cyclohexanone	3.17	0.428	206.7	60.2	2.70
5	<i>p</i> -Bromophenylcyclohexane	1.94	0.311	147.7	61.4	2.07
6	3,3,5-Trimethylcyclohexanone	6.51	0.015	220.7	41.9	2.98
7	3,3,5-Trimethyl-5-phenylcyclohexanone	4.70	0.168	256.2	65.1	3.08
8	5-(<i>p</i> -Bromophenyl)-3,3,5-trimethylcyclohexanone	5.30	0.378	365.0	70.7	3.82

DISCUSSION

From the data given in Table 1 the equilibrium constant K for chair-chair interconversion of 3-arylcyclohexanone and the free energy preference of the phenyl group for the equatorial position can be evaluated. The exact geometry of an ideal



chair form of cyclohexanone was calculated by Corey and Sneen.⁹ Using their data, the dipole angle between the carbonyl group and an axial or equatorial substituent at position 3 was calculated. From these angles and employing the experimentally determined dipole moments of cyclohexanone (3.02D) and phenylcyclohexane (0.62D) as representing the moments of the carbonyl group and the phenyl group respectively, the dipole moments of conformations I and II were calculated. Similarly, the dipole moments of the two corresponding conformations of 3-(*p*-bromophenyl)cyclohexanone were calculated making use of the measured dipole moment of *p*-bromophenylcyclohexane (2.07D). The calculated values (μ) were obtained by substituting the dipole angle (θ) and the component bond moments (μ_1 and μ_2) in the equation,

$$\mu^2 = \mu_1^2 + \mu_2^2 + 2\mu_1\mu_2 \cos \theta$$

The values are recorded in Table 2, below.

It can be seen that the experimentally determined values are very close to those calculated for the conformation II, which should preponderate in the equilibrium. The equilibrium constant K can be evaluated employing the equation,

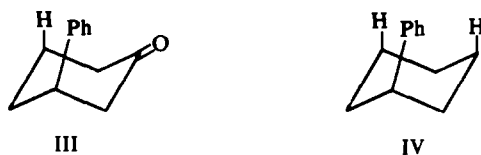
$$\mu^2 = N_e \mu_e^2 + N_a \mu_a^2$$

TABLE 2

	2-Phenylcyclohexanone (D)	3-(<i>p</i> -bromophenyl)cyclohexanone (D)
μ_a , Calculated with the aryl group axial ($\theta = 60^\circ$)	3.30	4.23
μ_e , Calculated with the aryl group equatorial ($\theta = 125^\circ$)	2.73	2.50
μ , Observed	2.90	2.70

where μ is the observed dipole moment, μ_e is the calculated moment for the equatorial conformation and μ_a is that for the axial conformation and N_e and N_a (which is $1 - N_e$) are the mole fractions of the respective conformations. Substitution of appropriate values in the equation gave K values of 2.6 for 3-phenylcyclohexanone and 10.1 for 3-(*p*-bromophenyl)cyclohexanone at 30° , corresponding to a free energy change of -0.58 and -1.39 kcal/mole respectively. The large variation in the values of K and ΔG° for the two similar groups should be attributed to the closeness of the experimentally determined dipole moment with that calculated for the equatorial conformer. Furthermore, the value of -0.59 kcal/mole obtained for 3-phenylcyclohexanone is probably less accurate because of the low moment contributed by the phenyl group. Therefore, the value of -1.39 kcal/mole obtained for 3-(*p*-bromophenyl)cyclohexanone may be considered as a more accurate value representing the free energy change for moving a phenyl group from the axial to the equatorial position in a 3-substituted cyclohexanone.

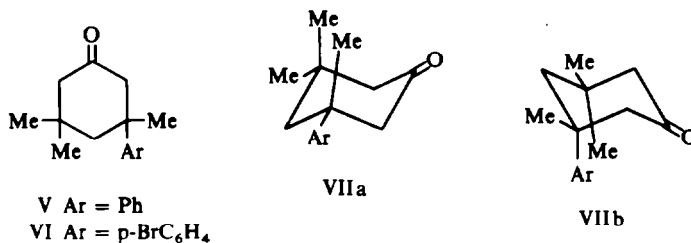
The axial phenyl in 3-phenylcyclohexanone (III) is subjected to nonbonded interaction with only one axial hydrogen, whereas in phenylcyclohexane (IV) two



axial hydrogen atoms are involved. Consequently, the free energy preference of the phenyl group for the equatorial position in 3-phenylcyclohexanone should be nearly half that in phenylcyclohexane. Indeed, the value of about -1.4 kcal/mole obtained for 3-(*p*-bromophenyl)cyclohexanone is half that of -2.8 kcal/mole obtained for the phenyl group in cyclohexane from kinetic data.¹¹ This value compares favourably with that of -2.0 kcal/mole at 25° reported¹² on the basis of dipole moment data on 4-*p*-chlorophenyl-4-methylcyclohexanone.

The presence of two *syn*-axial methyl groups results in the distortion of the chair form of the cyclohexane ring.¹³ The stereochemical course of reduction of 3,3,5-trimethyl-5-phenylcyclohexanone (V) (with two *syn*-axial methyl groups) with

lithium aluminium hydride could be interpreted only on the basis of a twist conformation for the ring.⁷ In order to gain further information with regard to the conformation, the dipole moments of V and 5-(*p*-bromophenyl)-3,3,5-trimethylcyclohexanone, were determined. The most likely chair conformation of these compounds is the one in which the aryl group is equatorial (VIIa). The inverted chair form (VIIb) should be excluded from consideration because of the severe Me-Ar *syn*-axial interaction.



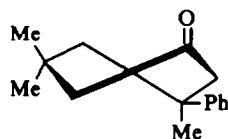
Assuming an ideal chair form, the dipole moment of the two conformations was calculated. The experimentally determined dipole moment of 3,3,5-trimethylcyclohexanone was used as the moment of the carbonyl group. Table 3 lists the calculated and observed dipole moments.

TABLE 3. OBSERVED AND CALCULATED DIPOLE MOMENTS

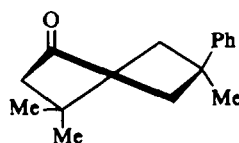
μ	3,3,5-Trimethyl-5-phenyl- cyclohexanone (D)	5-(<i>p</i> -Bromophenyl)-3,3,5-tri- methylcyclohexanone (D)
Calc. for conformation VII a, $\theta = 125^\circ$	2.67	2.47
Calc. for conformation VII b, $\theta = 69^\circ$	3.26	4.19
Calc. for 'reversed' cyclohexanone:		
Ar, Equatorial, $\theta = 131^\circ 25'$	2.60	2.24
Ar, Axial, $\theta = 51^\circ 20'$	3.40	4.57
Observed at 30°	3.08	3.82

X-ray analysis of the crystal structure of 2,6-dibromo-3,3,5,5-tetramethylcyclohexanone and 2-bromo-3,3,5,5-tetramethylcyclohexanone showed that the cyclohexanone ring is highly distorted in these compounds.¹⁴ The experimentally determined atomic co-ordinates of these compounds agreed closely with those calculated for a "reversed" cyclohexanone, in which the angle at C₄ is 120° and that at C₁ is 109.5° . This angular strain was attributed to the rocking apart of the *syn*-axial methyl groups. Table 3 also gives the dipole moments calculated for a "reversed" cyclohexanone structure using the data given by Goaman and Grant.¹⁴ It is obvious from the data given in Table 3 that the experimentally determined dipole moments of 3,3,5-trimethyl-5-phenylcyclohexanone and 5-*p*-bromophenyl-3,3,5-trimethylcyclohexanone do not agree with the moments calculated for either VIIa or VIIb or for the corresponding conformations with the angle at C₁ and C₄ reversed. Even though the experimentally determined dipole moments are intermediate between

those calculated for VIIa and VIIb, this cannot be attributed to an equilibrium between these two chairs because of the severe Ar-CH₃ axial interaction present in VIIb. Therefore, the two cyclohexanones should exist in a non-chair conformation. Either of the twist conformations VIIIa or VIIIb or an equilibrium between them could satisfy the observed dipole moments. The lack of data on the exact co-ordinates of these conformations preclude the calculation of their dipole moment. An examination of the scale models indicate that these are free from severe nonbonded steric interactions. The steric course of the hydride reduction of 3,3,5-trimethyl-5-phenylcyclohexanone was also satisfactorily accounted for by these conformations.⁷



VIIIa



VIIIb

EXPERIMENTAL

Materials

The cyclohexanones used were purified through their semicarbazones which were crystallized to constant m.p. and hydrolysed by treatment with aqueous oxalic acid. The liberated cyclohexanone was isolated and used after distillation or crystallization to constant m.p.

3-Phenylcyclohexanone. This was prepared as described⁷ by catalytic hydrogenation of 3-phenylcyclohex-2-en-1-one, b.p. 136–140°/6–7 mm; n_D^{30} 1.5399; d_4^{30} 1.049. The semicarbazone had a m.p. of 168°.

Phenylcyclohexane. This was obtained by Wolff-Kishner reduction of 3-phenylcyclohexanone. A soln of the ketone (7 g), KOH (4.8 g), hydrazine hydrate (6 ml, 90%) in diethylene glycol (50 ml) was heated on a free flame (1 hr) and then allowed to distil slowly till the internal temp reached 185°. The upper layer of the distillate was transferred to the reaction flask and the reflux continued (5 hr). Isolation afforded the hydrocarbon as a colourless liquid (4 g) which after distilling over Na had b.p. 95°/10 mm; n_D^{30} 1.5220; d_4^{30} 0.9390. Lit.,¹⁵ b.p. 107°/13 mm.

3-(*p*-Bromophenyl)cyclohexanone. A filtered ethereal soln of *p*-bromophenylmagnesium bromide¹⁶ prepared from magnesium (7 g) and *p*-dibromobenzene (60 g) was mixed with cuprous chloride (0.5 g), stirred (1 hr) at 5° and treated with cyclohex-2-en-1-one¹⁷ (12 g) in dry ether (60 ml). After stirring at room temp (5 hr) and refluxing (1 hr), isolation afforded a viscous liquid (11 g) boiling at 175–185°/12 mm. Treatment of this with an aqueous ethanolic soln of semicarbazide hydrochloride and NaOAc afforded the semicarbazone of the cyclohexanone. After crystallization (EtOH) to constant m.p., it melted at 195–196° (yield, 8 g). (Found: C, 50.09; H, 5.42. C₁₃H₁₆BrN₃O requires: C, 50.31; H, 5.20%).

Hydrolysis of the semicarbazone with aqueous oxalic acid (20%, 150 ml) afforded 3-(*p*-bromophenyl)cyclohexanone as a colourless liquid (4.5 g), b.p. 180–181°/9 mm; n_D^{30} 1.5726; d_4^{30} 1.386. (Found: C, 56.54; H, 5.46. C₁₂H₁₃BrO requires: C, 56.94; H, 5.18%).

The oxime crystallized from EtOH-H₂O as colourless needles, m.p. 136–137°. (Found: C, 53.46; H, 5.33. C₁₂H₁₄BrNO requires: C, 53.74; H, 5.26%).

***p*-Bromophenylcyclohexane.** The reduction of 3-(*p*-bromophenyl)cyclohexanone (6 g) by the Wolff-Kishner method as described afforded this as a colourless liquid (2.5 g) boiling at 132–134°/10 mm; n_D^{30} 1.5570; d_4^{30} 1.248. (Found: C, 60.48; H, 6.63. C₁₂H₁₃Br requires: C, 60.24; H, 6.32%).

3,3,5-Trimethyl-5-phenylcyclohexanone. This was obtained as described previously.⁷

5-(*p*-Bromophenyl)-3,3,5-trimethylcyclohexanone. The reaction of *p*-bromophenylmagnesium bromide (from 48 g *p*-dibromobenzene and 5.6 g magnesium) with isophorone (12 g) in the presence of cuprous chloride (0.4 g) was carried out as described for 3-(*p*-bromophenyl)cyclohexanone to give an oil (10 g) boiling at 155–170°/2 mm. The semicarbazone obtained from this, after washing several times with light

petroleum (b.p. 40–60°) and two crystallizations from dioxan–water melted at a constant temp, 170–171° (yield, 8 g). (Found: C, 54.29; H, 6.49. $C_{16}H_{22}BrN_3O$ requires: C, 54.55; H, 6.30%.)

Hydrolysis of the semicarbazone with aqueous oxalic acid (20%, 200 ml) afforded the above *cyclohexanone* as a solid (5.2 g) which crystallized as colourless stout needles from MeOH, m.p. 103–104°. (Found: C, 61.60; H, 6.22. $C_{15}H_{19}BrO$ requires: C, 61.40; H, 6.49%.)

The *oxime* crystallized as colourless glistening plates from MeOH–H₂O, m.p. 179–180°. (Found: C, 58.22; H, 6.59. $C_{15}H_{20}BrNO$ requires: C, 58.09; H, 6.50%.)

Purification of the solvents

"Analar" benzene was frozen three times, dried over Na wire and distilled over P₂O₅.

"Analar" cyclohexane was washed several times with a mixture of conc. nitric and sulphuric acids. After repeated washings with distilled water, it was dried over sodium wire, distilled, the fraction boiling at 80.5–81° collected, passed through a column of silica gel and finally distilled; the fraction boiling at 80.6° was used.

n-Butyl ether was freed from any peroxide by shaking with an acidified soln of ferrous sulphate, washed with water repeatedly, dried (anhyd CaCl₂) and distilled over Na wire using a fractionating column. The fraction boiling at 141° was used.

Physical measurements

All the dipole moment measurements were made in benzene soln. The dielectric constants were measured at $30 \pm 0.05^\circ$ using Dipolmeter DM OI, manufactured by Wissenschaftlich-Technische, Werkstätten, Weilheim (Obb), Germany. The measuring cell (supplied by the manufacturers) of suitable capacitance formed part of one of two oscillators (frequency approx. 2 mc/s) which were tuned to each other. The instrument was calibrated with purified cyclohexane, benzene and *n*-butyl ether. Assuming the dielectric constants of these liquids at 30°, the scale value of the measuring condensers was estimated through linear interpolation.

The refractive indices were measured at $30 \pm 1^\circ$. The density measurements for all solutions were made at $30 \pm 0.05^\circ$. In the case of liquids the molar refraction was calculated from the density and refractive index measurements. In the case of solids R_D was estimated from measurements made on benzene solutions with a Bellingham and Stanley refractometer of the Pulfrich type.

Acknowledgement—The authors wish to thank Professor V. Baliah for his interest and encouragement and the Government of India for the award of a research scholarship to one of them (A.D.)

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