was refluxed for six hours with 300 ml. of 33% (by volume) sulfuric acid. After the reflux period, a liquid–liquid extractor (for use with solvents heavier than water) was attached to the reaction flask and refluxing was continued for an additional 18 hours. The volatile material was slowly steam distilled and collected in the extractor. When the reaction was complete, the material which had steam distilled (approximately 250 mg.) was extracted with ether. The ether solution was dried with anhydrous magnesium sulfate and the filtered solution was concentrated. The steam-volatile material from five experiments employing a total of 20.45 g. of nitrile was chromatographed on 30 g. of ordinary alumina. It was put on the column with petroleum ether (boiling point 35–45°) and elution was begun with the same solvent, 15- to 20-ml. fractions being collected. Approximately 450 mg. of material, ranging from oily solid to crystals, was collected in fractions 1–6. This material is believed to be biphenyl because of its odor, mixed melting point with authentic biphenyl, and absence of a carbonyl band in the infrared spectrum. Fractions 7–16 gave nothing with petroleum ether and the solvent was changed first to 10% and then to 20% ether–petroleum ether. In fractions 20–30 a total of 805 mg. of odorless crystals was obtained which was recrystallized slowly once from petroleum ether to give 743 mg. (4% of theory based on the open chain dinitrile) of hard, well-formed, transparent crystals, m.p. 66–66.7°. The compound showed an asymmetric but unresolvable carbonyl stretching band at 1702 cm.$^{-1}$ (carbon tetrachloride), which was similar in form to that shown by cycloöctanone itself at the same frequency.

Anal. Calcd. for $C_{14}H_{17}OCl$: C, 71.03; H, 7.24; mol. wt., 236.9. Found: C, 70.93; H, 7.43; mol. wt., 222 (Rast).

The use of lithium diphenylamide as the base in the manner described above led to no isolable yield of the desired compound.

The 2,4-dinitrophenylhydrazone was prepared in the usual way.[19] A benzene solution of the crude derivative was filtered through a small column of alumina. The benzene was evaporated, and the product was twice crystallized from ethanol, m.p. 146.8–147.3°.

Anal. Calcd. for $C_{20}H_{21}N_4O_4Cl$: C, 57.62; H, 5.08. Found: C, 57.78; H, 5.39.

A small sample of ketone IV was oxidized in a basic solution of potassium permanganate,[20] and yielded a white solid, soluble in alkali, m. p. 232–233° (sealed tube). The mixture melting point with authentic *p*-chlorobenzoic acid showed no depression, and the two samples had identical infrared spectra (in chloroform).

TABLE I

DIPOLE MOMENT DATA FOR 5-(4-CHLOROPHENYL)-CYCLOOCTANONE IN BENZENE AT 25°

N_2	D.	ϵ
0.0046382	0.875419	2.3482
.0023639	.873978	2.3105
.0017956	.873623	2.3001
.0012689	.873254	2.2942
.0008233	.873023	2.2855
.0004573	.872768	2.2798
.0000000	.872482	2.2723

$\alpha = 16.3056$, $\beta = 0.633352$, $P_{2\infty} = 301.374$ cc., $\epsilon_1 = 2.2723$, $d_1 = 0.872480$, $\mu = 3.39$ D.

Dipole Moments.—The apparatus used for the dielectric constant measurements has been described.[21] The benzene solvent was purified by refluxing thiophene-free benzene with sodium followed by distillation from sodium. The density of the solution and its dielectric constant were measured at 25° at various mole fractions as indicated in Table I. The calculations were made following the general procedure of Halverstadt and Kumler[22] as described earlier.[23] The molar refractivity was calculated from standard values[24] of atomic refractivities and had the value 65.929 cc. Atomic polarization was neglected. Experimental error is about 0.02 D.

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[19] R. L. Shriner, R. C. Fuson and D. Y. Curtin, "The Systematic Identification of Organic Compounds," fourth edition, John Wiley and Sons, Inc., New York, N. Y., 1956, p. 219.

[20] Reference 19, p. 250.

[21] M. T. Rogers, THIS JOURNAL, **77**, 3681 (1955).

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

[23] N. L. Allinger, *ibid.*, **79**, 3443 (1957).

[24] J. A. Leermakers and A. Weissberger, in H. Gilman "Organic Chemistry," Vol. II, second edition, John Wiley and Sons, Inc., New York, N. Y., 1947, p. 1751.

DETROIT 2, MICH.

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY OF WAYNE STATE UNIVERSITY]

Conformational Analysis. V. 2-Bromocycloöctanone[1,2]

BY JANET ALLINGER AND NORMAN L. ALLINGER

RECEIVED MARCH 26, 1959

Theoretical considerations indicate that 2-bromocycloöctanone is a mixture of several conformational isomers. The dipole moment of 2-bromocycloöctanone in benzene solution has been found to have the value 3.36 D. The carbonyl stretching band in the infrared spectrum in various solvents is broad and poorly resolved. These data offer qualitative support for the correctness of the theoretical predictions.

Introduction

Earlier studies have shown that it is possible to determine the axial or equatorial nature of a halogen adjacent to a carbonyl in a cyclohexanone by means of various physical methods such as dipole moments,[3] infrared spectra,[4] ultraviolet spectra[5] and rotatory dispersion.[6] The infrared and ultraviolet spectra have also been examined and interpreted for α-bromocyclanones having rings larger than six membered.[7] It is clear from earlier work[2] that a simple cycloöctanone derivative will exist as an equilibrium mixture containing comparable amounts of crown (I) and boat (II) forms. In the special case of 2-bromocyclo-

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[1] Sponsored by the Office of Ordnance Research, U. S. Army. Some of the results of this work were recorded earlier; A.C.S. Meeting Abstracts, San Francisco, Calif., April, 1958, p. 29N.

[2] Paper IV, THIS JOURNAL, **81**, 5733 (1959).

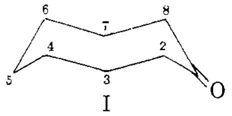
[3] W. D. Kumler and A. C. Huitric, *ibid.*, **78**, 3369 (1956).

[4] (a) R. N. Jones D. A. Ramsay, F. Herling and K. Dobriner, *ibid.*, **74**, 2828 (1952); (b) E. J. Corey, *ibid.*, **75**, 2301, 3297 (1953); **76**, 175 (1954); E. J. Corey, T. H. Topie and W. A. Wozniak, *ibid.*, **77**, 5415 (1955).

[5] R. C. Cookson, *J. Chem. Soc.*, 282 (1954).

[6] (a) C. Djerassi and L. E. Geller, *Tetrahedron*, **3**, 319 (1958); (b) C. Djerassi and W. Klyne, THIS JOURNAL, **79**, 1506 (1957).

[7] N. J. Leonard and F. H. Owens, THIS JOURNAL, **80**, 6039 (1958). The authors wish to thank Dr. Leonard for making this manuscript available to them in advance of its publication.



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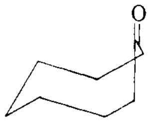
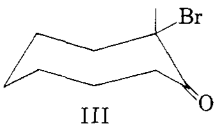
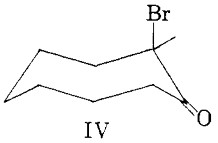


II

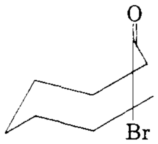
octanone, the compound may be expected to be a mixture of four conformational isomers (III-VI). Each of these structures is rather flexible, but each lies in a potential well separated from the others by an energy barrier.



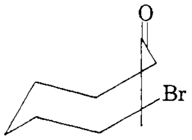
III



IV



V



VI

Discussion

The objectives of the present work were the calculation of the equilibrium composition of 2-bromocyclooöctanone in terms of structures III-VI from previously established principles and available data, and the experimental confirmation of these calculations.

For the calculations it was convenient to approach the problem as was done by Corey[4b] for 2-bromocyclohexanone. The total relative energy of each of the structures can be divided into three parts: (1) the electrostatic energy from the dipole interactions, (2) the conformational energy of the bromine atom and (3) the conformational energy of the ring. These component energies are each dependent on the exact geometry of the ring.

The Catalin models of the regular forms were made, and for each the dihedral angle between the halogen and the carbonyl was directly measured. It has previously been suggested[2] that compound I will skew in a particular way to minimize the energy. Because of the asymmetry introduced by the bromine, III and IV can skew in two different ways. The energetically preferred structure of the crown form of cyclooöctanone (I) is the skewed arrangement in which the axial hydrogen on carbon 5 and the oxygen are twisted in together below the ring, and either the pair of axial hydrogens on carbons 2 and 6, or the pair on carbons 4 and 8 are twisted in together on top of the ring. With the 2-bromo derivative, these skewed forms lead to two axial and two equatorial conformations which have bromine–carbon–oxygen dihedral angles of 166, 183, 40 and 63°, respectively. The form with the 183° dihedral angle has the bromine pushed back into the center of the ring where it interferes badly with the transannular axial hydrogen, and it is assumed that this form is of very low stability and can be neglected.

The boat form of the ring, as in structures V and VI, is relatively inflexible. There are then really five conformations to be considered for 2-bromocyclooöctanone: IIIa with a 40° dihedral O–C–Br angle, IIIb where the angle is 63°, and IV-VI.

The electrostatic energy (E_e) of each conformation is a function of the actual angle between the C—Br and the C=O dipoles and of the effective dielectric constant in the vicinity of these dipoles. The former can be readily calculated from the dihedral angles measured for each conformation (Table I). The latter changes with solvent and a suitable theoretical method to calculate effective dielectric constants for various media is not available. An empirical evaluation of these quantities is obtainable with use of the relationship given by equation 1 if the appropriate energies *in vacuo* and in a medium are available. In earlier work with 2-bromocyclohexanone,[8] the difference in electrostatic energy of axial and equatorial 2-bromocyclohexanone in vacuum was calculated. From the dipole moment data[3] and from the analysis of the infrared spectrum of that compound, the total energy difference between the two conformers (E_t) in a variety of solvents was experimentally determined. Subtraction of the steric energy (0.36 kcal./mole, see below) from E_t gave $E_{e\,\mathrm{solv}}$. The ratio of $E_{e\,\mathrm{vac}}$ to $E_{e\,\mathrm{solv}}$ then gave the effective dielectric constants for the solvents of the present study. The quantity for the electrostatic energy in vacuum was calculated as described[8] for III-VI (Table I) and the above-obtained effective dielectric constants and equation 1 were used to estimate the electrostatic energies in different solvents (Table II).

$$\Delta E_{\mathrm{solv}} = \Delta E_{\mathrm{vac}}/D_{\mathrm{eff}} \qquad (1)$$

TABLE I

COMPONENT ENERGIES OF CONFORMERS OF 2-BROMOCYCLOOCTANONE

Conformation	ϕ	χ^a	$E_e(D = 1)$	E_s	E_r
IIIa	40°	63°	−0.61	0	0.25
IIIb	63	78	−1.86	0	.25
IV	166	163	−4.41	2.19	.25
V	132	135	−4.14	0.36	0
VI	12	51	+0.54	0.36	0

[a] $\cos \chi = \sin\theta_1 \sin\theta_2 \cos\phi - \cos\theta_1 \cos\theta_2$, where χ is the desired angle between the dipoles, ϕ is the dihedral angle and θ_1 and θ_2 have the values 120° and 109° 28′.

TABLE II

ELECTROSTATIC ENERGIES (KCAL./MOLE) OF CONFORMERS OF 2-BROMOCYCLOOCTANONE IN SOLVENTS OF VARYING EFFECTIVE DIELECTRIC CONSTANT

Conformation	Solvent ($D_{\mathrm{eff.}}$) Vac.	Heptane	Benzene	Dioxane
	(1.00)	(4.83)	(6.44)	(10.27)
IIIa	−0.61	−0.13	−0.09	−0.06
IIIb	−1.86	− .39	− .29	− .18
IV	−4.41	− .91	− .68	− .43
V	−4.14	− .86	− .64	− .40
VI	+0.54	+ .11	+ .08	+ .05

The steric energy of a bromine (E_s) is rather small.[9] An axial bromine on a cyclohexane ring is destabilized relative to the equatorial one by

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(8) J. Allinger and N. L. Allinger, *Tetrahedron*, **2**, 64 (1958).

(9) E. L. Eliel and R. G. Haber, THIS JOURNAL, **81**, 1249 (1959).

0.73 kcal./mole. This energy arises from interaction of the axial bromine with the axial hydrogens on carbons 4 and 6 of the six-membered ring. The situation is different for conformational isomer V because the axial bromine interferes only with the hydrogen on carbon 8, the axial hydrogen on carbon 4 being on the opposite side of the ring. Thus, by analogy to Klyne's interpretation[10] of the "3-alkyl ketone effect," the steric energy of the axial bromine in V will be only one-half as great as in the six-membered ring, or 0.36 kcal./mole.

From Klyne's work,[10] the interaction of an axial methyl group with a single β-hydrogen involves about the same amount of energy as does eclipsing the methyl by a carbonyl oxygen. Assuming that the same ratio exists for the steric interaction of a bromine as for a methyl, this eclipsing interaction increases the energy of conformer VI by 0.36 kcal./mole. (In 2-bromocyclohexanone this leads to a difference in steric energy of 0.36 kcal./mole favoring the equatorial conformation. The value 0.4 kcal. was used earlier,[4b,8] as no direct experimental value was available, but the newer value has been used for the calculations of the present study.) These interactions appear to be unimportant for IIIa and IIIb.

There is a very sizable steric interaction between the bromine of IV and the β-axial hydrogens. Models indicate that this interaction is much worse than that of a bromine in a six-membered ring. The value assigned to this interaction is 2.19 kcal., or three times that in the six-membered ring. The total energy of IV turns out to be sufficiently high that not much of this conformational isomer is present in the equilibrium mixture anyway, so the exact value used here has little effect on the final result.

The conformational energy of the ring (E_r) was evaluated earlier.[2] The boat form (II) is of lower energy than the crown form (I) by 0.25 kcal./mole.

Summation of the component energies provides the total energy, E_t, of each conformer III-VI. From the relationship $-\Delta F = RT \ln K$, the percentage composition of 2-bromocycloöctanone in terms of III-VI in each solvent was calculated for a temperature of 25°. These data are summarized in Table III.

TABLE III

CALCULATED PERCENTAGE COMPOSITION OF 2-BROMOCYCLOOCTANONE

Conformation	Vac.	Heptane	Benzene	Dioxane
IIIa	1	16	19	22
IIIb	2	26	27	28
IV	4	2	1	1
V	93	47	41	34
VI	0	9	12	15

Results

There are three convenient physical methods of determining conformation which have been used in the present work, the infrared and the ultraviolet spectra, and the dipole moment. These measurements are not sufficient to obtain unambiguously the amount of each conformational isomer in each solution. The best that can be done is to show that the available experimental data is consistent with the theoretical calculations.

The dipole moment for an equilibrium mixture containing given percentages of III-VI can be calculated in a straightforward manner. For each conformational isomer the moment can be calculated knowing the group moments and the angle between them.[8] The moments of IIIa, IIIb, IV, V and VI so calculated are 4.06, 3.72, 1.14, 1.99 and 4.30 D., respectively. With the aid of the equation: $\mu = [\sum_i N_i\mu_i^2]^{1/2}$ and the percentages of each conformational isomer calculated for the compound (Table III), a dipole moment of 3.28 D. was calculated for benzene solution. This value is probably a little too small, since part of the steric energy of the bromine in form V could not be evaluated, and was neglected. This energy would destabilize V and decrease its concentration in the mixture. The result would be a slightly increased moment over that calculated. The dipole moment of the compound was measured in benzene and an experimental value of 3.36 D. was obtained.

Introduction of a halogen into the axial position on the 2-carbon of a cyclohexanone causes no change in the carbonyl stretching frequency in the infrared, but introduction of the halogen into the corresponding equatorial position causes a diminution in intensity as well as a shift of the absorption maxima to higher frequency. Apparently the shift will occur to a large extent if $\phi = 0$, but not at all if $\phi = 90°$. The studies by Bellamy and Williams[11] on the chloroacetaldehydes indicate that no frequency shift is to be expected from $\phi = 90°$ to $\phi = 180°$. This is what would be expected from a purely electrostatic effect. In the absence of other data, it will be assumed that the frequency shift varies from 13 to 0 cm.$^{-1}$ as ϕ varies from 0 to 90°. The shift, $\Delta\gamma$, then is related to ϕ by (2).

$$\Delta\nu = 13 \cos\phi \ (0° < \phi < 90°) \qquad (2)$$

The limited data available also indicate that the absorption is less when $\phi = 0$ than when $\phi = 90°$ the ratio being about 0.8. This ratio is assumed to vary as $\cos\phi$ over these limits and therefore the relative extinction coefficients are given by (3)

$$\epsilon/\epsilon_0 = 1 - 0.26 \cos\phi \qquad (3)$$

The infrared spectrum of 2-bromocycloöctanone is thus calculated from (2) to consist of a series of four bands, shifted to higher frequency from the position of the unbrominated parent compound by 0, 6, 10 and 13 cm.$^{-1}$: IV and V both contribute to the first band, IIIb, IIIa and VI contribute to the other three, respectively. The relative optical densities are taken as proportional to the relative concentrations times the relative extinction coefficients which for the four bands listed have the values 1.00, 0.88, 0.80 and 0.76. In general, it might be anticipated that such a series of bands would result in a broad poorly resolved carbonyl absorption. The real shifts will vary somewhat from the averages calculated, and actual

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[10] W. Klyne, *Experientia*, **12**, 119 (1956).

[11] L. J. Bellamy and R. L. Williams, *J. Chem. Soc.*, 3465 (1958).

resolution will be somewhat fortuitous. The calculated relative absorption intensities for each of the four bands are given in Table IV.

TABLE IV

CALCULATED RELATIVE CARBONYL INTENSITIES

Conformation	$\Delta\mu$	Heptane	Benzene	Dioxane
IV + V	0	53	47	40
IIIb	6	25	26	27
IIIa	10	14	17	20
VI	13	8	10	13

The high resolution carbonyl infrared spectra were obtained in various solvents, and are shown in Fig. 1. The order of effective solvent polarity is assumed to be the same as was found earlier for 2-bromocyclohexanone. Except for the spectra in heptane, dimethyl sulfoxide and carbon tetrachloride, there is a strong band at low frequency, and a decreasing absorption at higher frequency, in qualitative agreement with the calculated values. In dimethylsulfoxide, the most polar solvent used, there are two observable bands, the one at higher frequency being more intense. The resolution may result from the three bands at the higher frequency being separated a little further from the low frequency band in this solvent. No resolution is evident in carbon tetrachloride. In heptane a very intense[12] anomalous band occurs at a slightly higher frequency and blots out the features of interest. The source of this band is not clear. It does not occur as a result of association in the non-polar solvent, since freezing point measurements in cyclohexane show the compound is monomeric at this concentration. The shape of the curve in carbon tetrachloride appears to indicate more equatorial halogen than is calculated. The half-band width of the bromo compound is 30–70% greater than that of the parent compound in each solvent when the optical densities are equal. The over-all agreement between the calculated and found infrared spectra is regarded as reasonably satisfactory.

The ultraviolet spectrum is more difficult to interpret. Cookson has shown[5] that an axial bromine adjacent to a carbonyl gives rise to a substantial shift in the band resulting from $n \rightarrow \pi^*$ transition, both in intensity and wave length, while an equatorial bromine produces no such shift. Since this shift appears to result from an overlap of the π^* orbital of the carbonyl with the 4p orbital of the bromine, there seems to be no simple way to judge the dependency of the band intensity or position on the dihedral angle (ϕ). Numerical data are available only for compounds having dihedral angles of 16, 60 and 102°, so no sound empirical interpolation is possible either.

Leonard and Owens[7] have pointed out that the apparent complimentary nature of the shifts of the carbonyl bands in the infrared and ultraviolet spectra are fortuitous since they depend on completely different things. The infrared frequency is related to the conformation of the ground state whereas the ultraviolet spectrum also involves an excited state, the properties of which are harder to predict.

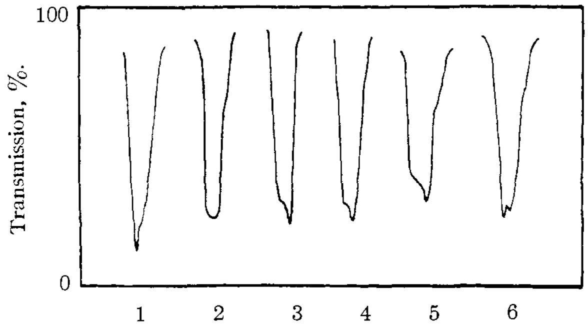

Fig. 1.—Observed infrared carbonyl bands for 2-bromocyclooctanone in various solvents. The numbers correspond to the solvents as follows: 1, *n*-heptane; 2, carbon tetrachloride; 3, chloroform; 4, benzene; 5, dioxane; 6, dimethyl sulfoxide.

Experimentally, it was found that a large shift in λ_{max} was obtained for 2-bromocycloöctanone relative to cycloöctanone in each solvent. The extinction coefficient of the former was considerably larger and both the λ_{max} and the ϵ were fairly independent of solvent. In the six-membered ring it was found that ϵ for the axial bromine (ϕ = 102°) was six times that of its equatorial counterpart (ϕ = 16°).[13] Consequently the presence of any appreciable amount of axial isomer gave a λ_{max} characteristic of the axial form and an intermediate value for ϵ. The values found here are similar to those found for 2-bromocyclohexanone, but contrary to the six-membered ring there is almost no change with solvent. The interpretation of the latter fact that is consistent with the other available data and the theoretical calculations is that the shift in conformational composition with solvent change is relatively small and leads to little net change in the ultraviolet spectrum.

Acknowledgment.—The authors are indebted to Dr. Max Rogers, Michigan State University, for kindly allowing them to use his apparatus for the dipole moment measurements described in this paper.

Experimental[14]

2-Bromocycloöctanone.—To a stirred solution of 8.0 g. of cycloöctanone,[15] 150 ml. of ether and a few drops of 10% hydrobromic acid in acetic acid at 10–15° was added dropwise a solution of 14.2 g. of bromine in 20 ml. of acetic acid. Stirring was continued for a few minutes at 10°, and the solution was then allowed to warm to room temperature. The ether solution was washed well with water, dilute sodium bicarbonate solution, and water, was then dried with sodium sulfate, and the solvent was evaporated. The residue was fractionally distilled through a two-foot Podbielniak type column. After a forerun of cycloöctanone, the product was collected, wt. 8.1 g. (50%), b.p. 69° (1 mm.), $n^{25}{}_D$ 1.5163. reported[16] b.p. 79–81° (1 mm.), $n^{25}{}_D$ 1.5161.

Molecular Weight Determinations.—The molecular weights of 2-bromocycloöctanone and cycloöctanone in cyclohexane solution were determined in the manner described earlier[8] employing concentrations closely similarly to those used in the infrared study. The bromoketone, actual molecular weight 205.2, had an experimentally determined molecular weight of 237.5 at 0.167 molar concentration in

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[12] Quantitative measurement showed that this band had an apparent extinction coefficient 3 times greater in heptane than in the other solvents.

[13] N. L. Allinger and J. Allinger, THIS JOURNAL, **80**, 5476 (1958).

[14] The spectral measurements were made by Miss P. Burcar.

[15] Prepared *via* a Ziegler reaction with azelaonitrile (ref. 2).

[16] A. C. Cope and H. E. Johnson, THIS JOURNAL, **79**, 3889 (1957).

cyclohexane solution. In the same solvent the parent ketone, actual molecular weight 126.2, had the experimentally determined molecular weight 216.1 at 0.164 molar concentration.

Thus cyclooctanone itself is associated to a considerable extent in cyclohexane, as is cyclohexanone. The bromo derivative in the eight-membered ring on the other hand is not appreciably associated under these conditions.

Spectra.—The infrared spectra were obtained using a Beckman IR-4 spectrophotometer with a scanning speed of 0.02 μ/min. The ultraviolet spectra were obtained with a Beckman DU spectrophotometer with a Spectracord attachment. The observed infrared carbonyl spectra are plotted in Fig. 1. The frequency data are listed in Table V.

Table V

Infrared Carbonyl Spectrum of 2-Bromocyclooctanone

Solvent	ν, cm.$^{-1}$	$\Delta\nu^a$
Heptane	..	..
CCl_4	1708	6
	1715	13
$CHCl_3$	1702	12
	1712	22
C_6H_6	1705	5
	1714	14
Dioxane	1706	6
	1716	16
Me_2SO	1704	10
	1712	18

[a] $\Delta\nu = \nu_{\text{bromoketone}} - \nu_{\text{ketone}}$.

The ultraviolet data are summarized in Table VI.

Table VI

Ultraviolet Spectrum of 2-Bromocyclooctanone

Solvent	$\lambda_{\max}$	ϵ	$\Delta\lambda_{\max}{}^a$	$\Delta\epsilon^b$
Heptane	313	104	22	86
CCl_4	313	106	18	88
EtOH (95%)	307	94	23	78
Me_2SO	300	85	18	58

[a] $\Delta\lambda_{\max} = \lambda_{\max}$ (bromoketone) $- \lambda_{\max}$ (ketone). [b] $\Delta\epsilon = \epsilon_{\text{bromoketone}} - \epsilon_{\text{ketone}}$.

Dipole Moment.—The moment of 2-bromocyclooctanone in benzene solution was determined at 25°. The data were treated by the method of Halverstadt and Kumler[17] as described previously.[2] The molar refractivity was calculated from standard values of atomic refractivities[18] and had the value 44.720 cc. Atomic polarization was neglected. The data are summarized in Table VII.

Table VII

Dipole Moment Data for 2-Bromocyclooctanone in Benzene

N_2	d	ϵ
0.0115006	0.882019	2.4524
.0068663	.878154	2.3792
.0043590	.875971	2.3399
.0022661	.874115	2.3071
.0012920	.873236	2.2906
.0007668	.872784	2.2833
.0000000	.872143	2.2723

$\alpha = 15.729$, $\beta = 0.850538$, $P_{2\infty} = 275.626$ cc., $\epsilon_1 = 2.2713$, $d_1 = 0.872202$, $\mu = 3.36$ D.

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(17) I. F. Halverstadt and W. D. Kumler, This Journal, **64**, 2988 (1942).

(18) J. A. Leermakers and A. Weissberger in H. Gilman, "Organic Chemistry," Vol. II, second edition, John Wiley and Sons, Inc., New York, N. Y., 1947, p. 1751.

Detroit 2, Mich.

[Contribution from the Department of Chemistry of the University of California at Los Angeles]

Electrophilic Substitution at Saturated Carbon. I. Survey of Reactions Available for Stereochemical Study[1]

By Donald J. Cram, Albert Langemann, Janet Allinger and Karl R. Kopecky

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A survey of reactions available for studies of the steric course of electrophilic substitution at saturated carbon has been made. These reactions all involve heterolytic cleavage of carbon–carbon bonds, with carbonyl or alkenyl leaving groups, and proton-donating solvents (secondary amines) as electrophiles. The reactions are all base-catalyzed, and in part are the reverse of ordinary nucleophilic addition reactions of organometallic reagents to unsaturated carbon. These transformations all gave 2-phenylbutane as product, and a rough order of reactivity was established as the character of the leaving group was varied. *For eleven different leaving groups, predominating retention of configuration at the seat of substitution accompanied by varying amounts of racemization was the observed steric course.*

In contrast to nucleophilic substitution (SN), electrophilic substitution (SE) at saturated carbon has been relatively little studied, particularly with respect to steric course. Similarly, although the stereochemical capabilities of carbonium ions have been extensively investigated, the stereochemical fate of carbanions has never been subjected to systematic scrutiny. The studies that have been made of the steric path of electrophilic substitution at saturated carbon have all involved reactions of organometallic reagents. Thus optically active alkyl halides have been converted to organometallic compounds which have been either protonated or added to double bonds. In all cases the over-all steric result for both transformations has been racemization.[2] Similar experiments applied to diastereomeric halides led to mixtures of acids whose composition was independent of the configuration of the starting halide.[3]

A number of articles have appeared in the literature in which authentic stereospecific electrophilic substitutions at saturated carbon are reported. Letsinger[4] observed that when (−)-2-iodooctane

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(2) (a) R. H. Pickard and J. Kenyon, *J. Chem. Soc.*, **99**, 45 (1911); (b) A. M. Schwartz and J. R. Johnson, This Journal, **53**, 1063 (1931); (c) C. W. Porter, *ibid.*, **57**, 1436 (1935); (d) S. Tarbell and M. Weiss, *ibid.*, **61**, 1203 (1939); (e) H. Hart, *ibid.*, **78**, 2691 (1956).

(3) (a) G. Roberts and C. W. Shoppee, *J. Chem. Soc.*, 3418 (1954); (b) H. L. Goering and F. H. McCarron, This Journal, **80**, 2287 (1958). See M. Mousseron and R. Jacquier, *Bull. soc. chim. France*, C80 (1951).

(4) R. L. Letsinger, This Journal, **72**, 4842 (1950).