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Optically Active Aromatic Chromophores. XI.[1] Circular Dichroism Studies of Some 1-Substituted 2-Phenylcyclohexanes

Lawrence Verbit* and Howard C. Price[2]

*Contribution from the Department of Chemistry,
State University of New York at Binghamton, Binghamton, New York 13901.*

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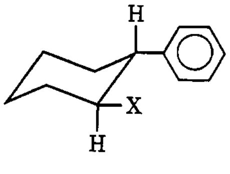
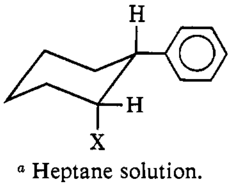
Abstract: A circular dichroism study of the following phenylcyclohexane derivatives has been carried out: (1*S*,2*R*)-(+)-*trans*-2-phenylcyclohexanol, (1*S*,2*R*)-(+)-*trans*-2-phenylcyclohexylamine, (1*S*,2*S*)-(+)-*trans*-2-phenylcyclohexanecarboxylic acid, (1*S*,2*S*)-(+)-*trans*-2-phenylcyclohexanecarbonyl chloride, (1*S*,2*S*)-(+)-*trans*-1-hydroxymethyl-2-phenylcyclohexane, (1*R*,2*R*)-(−)-*cis*-2-phenylcyclohexanol, and (1*R*,2*R*)-(−)-*cis*-2-phenylcyclohexylamine. The absolute configuration of (+)-*trans*-2-phenylcyclohexanecarboxylic acid was determined by its oxidation cleavage to (1*S*,2*S*)-(+)-*trans*-1,2-cyclohexanedicarboxylic acid. Variable temperature nmr measurements indicate that the compounds exist almost exclusively in the conformation having the phenyl group equatorial. Infrared hydrogen-bonding studies are reported for the alcohols in the series. The Cotton effects appearing in the 210–220-nm region are considered to be primarily associated with the ^1L_a transition of the aromatic ring. It is proposed that CD Cotton effects due to this transition in appropriate phenyl-containing compounds may be characterized by typical widths at half-height of 10–20 nm. A quadrant rule is formulated for the sign of the ^1L_a Cotton effect in monosubstituted benzene derivatives.

Chiroptical methods, as Prelog[3] terms optical rotatory dispersion (ORD) and circular dichroism (CD), are playing increasingly important roles in investigations of optically active molecules in solution. Much of the work is aimed ultimately at an understanding of the biological functions of proteins and other macromolecules in terms of their conformation in solution.[4] However, such complex molecules possess many chiral centers and, usually, several different chromophores. The large number of variables renders difficult the interpretation of the corresponding chiroptical spectra.

Aromatic chromophores[5] occur widely in molecules of biological importance, and for some time[6] we have been interested in obtaining a better understanding of their chiroptical properties. Our approach to the problem has been an empirical one: the study of model compounds of sufficient simplicity so that a maximum number of variables may be fixed. The present communication describes a circular dichroism study of a series of phenylcyclohexane derivatives whose structural formulas are given in Chart I.

Chart I





Compd	X	Configuration	$[\alpha]^{27}D$ (methanol)
1	OH	1*S*,2*R*-(+)	+55°
2	NH_2	1*S*,2*R*-(+)	+45°
3	COOH	1*S*,2*S*-(+)	+68°
4	COCl	1*S*,2*S*-(+)	+31° [a]
5	CH_2OH	1*S*,2*S*-(+)	+51°
6	OH	1*R*,2*R*-(−)	−106°
7	NH_2	1*R*,2*R*-(−)	−59°

[a] Heptane solution.

The present work was undertaken in order to gain information on the interpretation and assignment of Cotton effects in compounds of known stereochemistry containing the phenyl chromophore. The cyclohexane framework was chosen in order to make use of the

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[1] Paper X: L. Verbit and H. C. Price, *Chem. Commun.*, 1366 (1971).

[2] This work is based on the Ph.D. thesis of H. C. P., State University of New York at Binghamton, 1971.

[3] V. Prelog, *Proc. Kon. Ned. Akad. Wetensch., Ser. B*, 71, 108 (1968).

[4] G. D. Fasman, Ed., "Poly α-Amino Acids," Marcel Dekker, New York, N. Y., 1967.

[5] Review: P. Crabbé and W. Klyne, *Tetrahedron*, 23, 3449 (1967).

[6] L. Verbit, *J. Amer. Chem. Soc.*, **87**, 1617 (1965).

wealth of conformational information available for this system. In addition, the cis and trans isomers in this series have dihedral angles which are nearly identical (*ca.* 60°) but which are oppositely signed. Thus, for the alcohols and amines, **1**, **2**, **6**, and **7**, the effect of substituent orientation on the benzene π system could be investigated.

Results and Discussion

Configurational Assignments. The 1*S*,2*S* configuration has been assigned[7] to (+)-*cis*-2-phenylcyclohexanol (enantiomer of **6**) by relating it *via* stereoselective reactions to (*S*)-(+)-2-phenyladipic acid.

Huitric and coworkers[8] have used the octant rule to assign the absolute configurations of several 2-arylcyclohexanols *via* the corresponding 2-arylcyclohexanones. Their chiroptical assignments were verified in the case of (+)-*trans*-2-*o*-tolylcyclohexanol by an X-ray determination of the 3-nitro-4-bromobenzoate ester.[9] Their results indicate that for both cis- and *trans*-2-arylcyclohexanols and cyclohexylamines, the alcohol or amine having the 1*S* configuration exhibits a positive Cotton effect in the 210–220-nm region.

CD data for compounds **1–7** in methanol solution are given in Table I. The (+)-*trans*-cyclohexanol, **1**, has a positive Cotton effect at 218 nm while the cis isomer, **6**, has a corresponding negative band at 216 nm. This evidence[7–9] allows us to assign the 1*S*,2*R* configuration to **1**, and the 1*R*,2*R* configuration to the (−)-cis isomer, **6**.

Table I. CD Maximum Values for Some 1-Substituted 2-Phenylcyclohexanes[a]

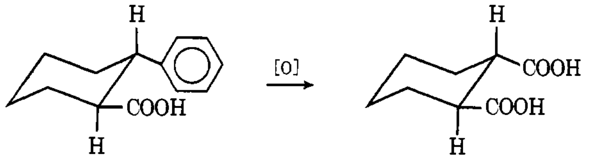
	Short wavelength Cotton effect		^1L_b Cotton effect[b]	
Compd	λ, nm	[θ], deg cm^2/dmol	λ, nm	[θ], deg cm^2/dmol
1	218	+4700	268	+110
			261	+110
			253	+66
2	217	+3600	*c*	
3	217	+4000	268	−170
			261	−170
			254	−80
4	209.5	+6400	268	−1300[d]
			251	−2500
5	221	−1300	268	−700
			261	−770
			255	−480
6	216	−6800	268	+470
			261	+540
			255	+380
7	218	−6500	268	+700
			261	+800
			255	+530

[a] All values refer to methanol solution at 27° except for **4** which was measured in heptane. [b] The ^1L_b Cotton effects contain vibrational fine structure. Ellipticity values of the three most intense peaks are given. [c] Cotton effect was too weak to be measured reliably. [d] A broad Cotton effect; see text.

(+)-*trans*-2-Phenylcyclohexylamine (**2**) was related by use of the asymmetric hydroboration reaction[10] to (+)-*trans*-2-phenylcyclohexanol (**1**). The (+) amine and (+) alcohol were both prepared from the same trialkylborane solution obtained by hydroborating 1-phenylcyclohexene with (−)-di-3-pinanylborane (from (+)-α-pinene), followed by reaction with hydroxylamine-*O*-sulfonic acid and alkaline hydrogen peroxide, respectively. In another system, the absolute configuration of amine and alcohol prepared from the same solution by this method has been shown to be the same.[11] In addition, many examples are known in which amine and alcohol of the same configuration have the same sign of rotation.[12] Hence, (+)-*trans*-2-phenylcyclohexylamine (**2**) and (+)-*trans*-2-phenylcyclohexanol (**1**) are assigned the same configuration which, as indicated above for **1**, is 1*S*,2*R*.

The configuration of (−)-*cis*-2-phenylcyclohexylamine (**7**) is arrived at by comparison of its CD spectrum with that of the corresponding cyclohexanol, **6**, whose configuration has been assigned above. Both compounds have negative Cotton effects at 216–218 nm and positive Cotton bands in the 260-nm region. Not only are the signs of these bands the same but their magnitudes are very similar. Hence, **7** also has the 1*R*,2*R* configuration.

The configuration of (+)-*trans*-2-phenylcyclohexanecarboxylic acid (**3**) was determined by oxidative cleavage of the aromatic ring to give (1*S*,2*S*)-(+)-1,2-cyclohexanedicarboxylic acid of established absolute configuration.[13,14] Hence, (+)-**3** possesses the 1*S*,2*S* configuration. This corresponds to the same absolute configuration as (+)-**1** and (+)-**2** although the priorities of the Sequence rule[15] lead, in the case of **3**, to a different designation at C-2.



(+)-**3** 1*S*,2*S*-(+)

Conversion of the carboxylic acid, **3**, to the acid chloride, **4**, and to the alcohol, **5** (see Experimental Section), does not involve any bond breaking to a chiral center. Hence, **4** and **5** must possess the same absolute configuration as **3**, which for all three compounds corresponds to 1*S*,2*S*.

All compounds are considered to be essentialy optically pure. This is based in part on the fact that resolution of the same compound with different alkaloids gave products which exhibited rotations of equal magnitude. For **1** and **6**, the rotational vaues were the same as reported[7] for material prepared by stereoselective reactions while the conversion of **3** to (+)-*trans*-1,2-cyclohexanedicarboxylic acid gave the latter having 95% enantiomeric purity. Additionally, nmr

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[7] C. Berti, J. Macchia, and L. Monti, *J. Org. Chem.*, 33, 4045 (1968).

[8] D. R. Galpin, Ph.D. thesis, University of Washington, 1966; D. R. Galpin and A. C. Huitric, *J. Pharm. Sci.*, 57, 447 (1968); T. G. Cochran, D. V. Wareham, and A. C. Huitric, *ibid.*, 60, 180 (1971); T. G. Cochran and A. C. Huitric, *J. Org. Chem.*, 36, 3046 (1971).

[9] A. Camerman, L. H. Jensen, T. G. Cochran, and A. C. Huitric, *J. Pharm. Sci.*, 59, 1675 (1970).

[10] J. D. Morrison and H. S. Mosher, "Asymmetric Organic Reactions," Prentice-Hall, Englewood Cliffs, N. J., 1971, Chapter 6.

[11] L. Verbit and P. J. Heffron, *J. Org. Chem.*, 32, 3199 (1967).

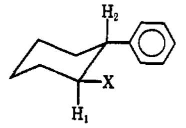
[12] L. Verbit, *Progr. Phys. Org. Chem.*, 7, 51 (1970).

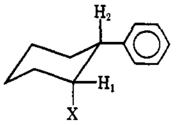
[13] D. E. Applequist and M. D. Werner, *J. Org. Chem.*, 28, 48 (1963).

[14] We thank Professor Prelog for suggesting this synthetic route.

[15] R. S. Cahn, C. K. Ingold, and V. Prelog, *Angew. Chem., Int. Ed. Engl.*, 5, 383 (1966).

Table II. 100-MHz Nmr Data for Some 1-Substituted 2-Phenylcyclohexanes[a]



	H₁			H₂			Other protons			
X	δ, ppm	Band width, Hz[b]	J_{obsd}, Hz	δ, ppm	Band width, Hz[b]	J_{obsd}, Hz	Proton	δ, ppm	Band width, Hz[b]	J_{obsd}, Hz
OH	3.39	24.4	10.0, 9.8, 4.5	2.25	24.0	10.4, 10.2, 3.3	OH	1.74	(2)[d]	Singlet
NH_2	2.73	23.5	10.0, 10.0, 3.5	2.14[c]	23.0	10, 10, 3.3	NH_2	0.88	(2)[d]	Singlet
COOH	2.45	(25)[d]	Overlaps with H_2	2.70	(25)[d]	Overlaps with H_1				
COCl	3.00	(25)[d]	Overlaps with H_2	2.80	(25)[d]	Overlaps with H_1				
CH_2OH				2.24[c]	23.5	10, 10, 3	OH	2.68	(2)[d]	Singlet
							CH_2OH	2.94	16.6	10.5, 6.2
								3.16	13.6	10.5, 3.2
										
OH	3.77	6.0	Unresolved multiplet	2.57	18.4	12.1, 3.8, 2.3	OH	1.35	(2)[d]	Singlet
NH_2	3.21	8.0	Unresolved multiplet	2.71	18.0	12.2, 3.7, 2.2	NH_2	1.19	(2)[d]	Singlet

[a] Data obtained on 1 *M* solutions in CCl_4 at 27°. [b] The distance between outermost lines of the band or, for poorly resolved bands, the width at half-height. [c] Partially obscured by other protons. [d] Band widths in parentheses are ±10%.

analysis of the *O*-methylmandelates[16] of the amines and alcohols in the series confirmed the enantiomeric purity of these compounds to be >95%.

Conformational Assignments. The conformational mobility of the 1-substituted 2-phenylcyclohexanes was investigated by nuclear magnetic resonance (nmr) and infrared (ir) techniques in order to define the stereochemistry of these compounds as rigorously as possible.

Although the conformational free energy of the phenyl group is 3.0 kcal/mol,[17] one cannot, *a priori*, assume that the compounds in the present study will necessarily exist in that conformation in which the phenyl group is equatorial. Eliel[18] has pointed out that for 1,2-disubstituted cyclohexanes, the effects of substituent–substituent interactions can be important. Nmr data for compounds **1–7** are given in Table II.

It is well established in the cyclohexane series that the band width of an axial α proton is broader than that of an equatorial α proton due to smaller couplings (J_{ae}, J_{ee}) to the latter. Examination of the data in Table II indicates that the H_1 and H_2 band widths and observed coupling constants are in agreement with a conformation in which the phenyl substituent resides in an equatorial conformation.[19]

For the cis compounds **6** and **7**, H_1 is equatorial and exhibits a band width of 6–8 Hz, the sum of three coupling constants of 1–4 Hz each resulting from gauche interactions with the protons on adjacent carbons. The H_2 protons are axial and have band widths of approximately 18 Hz, reflecting one trans (J = ~12 Hz) and two gauche (J = ~3Hz) couplings.[19] For the trans members of the series, H_1 and H_2 are both axial and have band widths of ~23 Hz, resulting from two trans couplings (J = ~10 Hz) and one gauche (J = ~3Hz) coupling.[19]

The *exo*-methylene protons of **5** are anisochronous,[20] Table II. They differ in chemical shift by 0.22 ppm and give rise to an ABX octet with a geminal coupling constant of 10.5 Hz and vicinal coupling constants of 6.2 and 3.2 Hz. The average chemical shift (3.05 ppm) is 0.27 ppm less than that for the corresponding protons of cyclohexylmethanol,[21] the difference due principally to the paramagnetic shielding of the phenyl ring.

Two opposing effects are operative on the hydroxyl protons of the alcohols **1** and **6**: the deshielding effect caused by *intermolecular* hydrogen bonding and the paramagnetic shielding effect of the benzene ring caused by *intramolecular* hydrogen bonding. In the special case of hydrogen bonding to an aromatic nucleus where the proton is bonded approximately to the center of the π cloud, the ring current effect leads to a relatively large upfield shift which predominates over any deshielding due to other factors.[19a] This appears to be the only situation in which hydrogen bonding results in an upfield, rather than a downfield shift.

Infrared measurments (see below) indicate that at *ca.* 1 *M* concentration, both **1** and **6** are predominantly hydrogen bonded (intramolecularly and as intermolecular dimers). The hydroxyl proton nmr bands of these compounds appear at relatively high field[17] (approximately 1.5 ppm), indicating that the hydroxyl

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(16) M. Raban and K. Mislow, *Tetrahedron Lett.*, 3961 (1966); M. Raban and K. Mislow, *Top. Stereochem.*, 2, 199 (1967).

(17) J. A. Hirsch, *ibid.*, 1, 199 (1967).

(18) E. L. Eliel, *Angew. Chem., Int. Ed. Engl.*, 4, 761 (1965).

(19) Coupling constants of related cyclohexane systems may be found in (a) F. A. Bovey, "Nuclear Magnetic Resonance Spectroscopy," Academic Press, New York, N. Y., 1969, pp 363–364; (b) A. A. Bothner-By, *Advan. Magn. Resonance*, 1, 195 (1965).

(20) K. Mislow and M. Raban *Top. Stereochem.*, 1, 1 (1967).

(21) Sadtler Standard Spectra No. 4208M, Sadtler Research Laboratories, Philadelphia, Pa.

Table III. O–H Stretching Frequencies[a]

Compound	ν_{O-H}, cm^{-1}			
			Intermolecular	
	Free	Intramolecular	Dimeric	Polymeric[b]
trans-2-Phenylcyclohexanol (**1**)[c]	3618 (15) (s)	3596 (20)	3480 (bd)	3280 (bd)
cis-2-Phenylcyclohexanol (**6**)	3623 (20) (s)	3600 (25)[d]	3480 (120)	None
trans-1-Hydroxymethyl-2-phenylcyclohexane (**5**)	3639 (30)	3598 (25)	3510 (bd)	3240 (bd)
β-Phenylethanol[e]	3638 (20)	3609 (20)		
cis-2-Benzylcyclohexanol[f]	3640			
trans-2-Benzylcyclohexanol[f]	3634	3618		
cis-2-Isopropylcyclohexanol[g]	3630.5 (19)			
trans-2-Isopropylcyclohexanol[g]	3628 (33)			

[a] In CCl_4. Maximum errors for free and intramolecular O–H stretching frequencies (and half-band widths) are ±5 cm^{-1}. Half-band widths ($\Delta\nu_{1/2}$) are entered in parentheses; (bd) indicates $\Delta\nu_{1/2} \geq 200$ cm^{-1}; (s) indicates shoulder. [b] Nujol mull. [c] Values of 3621 and 3598 cm^{-1} are given in ref 24. [d] Reference 25 reports 3596 cm^{-1}. [e] This work. M. Oki and H. Iwamura, *J. Amer. Chem. Soc.*, **89**, 576 (1967), report 3636 (18.4) and 3606.4 (24.4) cm^{-1}. [f] M. Boyer, M.-M. Claudon, and J. Lemaire, *Bull. Soc. Chim. Fr.*, 2152 (1964). [g] H. S. Aaron, C. P. Ferguson, and C. P. Rader, *J. Amer. Chem. Soc.*, **89**, 1431 (1967).

1 **6** **5**

Figure 1. Free and π-bonded O–H group stretching vibrations of **1**, **5**, and **6** in dilute CCl_4 solution.

group is directed mainly toward the benzene ring, thus placing the hydroxyl proton in the shielding region. In comparison, the hydroxyl proton of **5** appears at *ca.* 1 ppm lower field (2.68 ppm), indicating that this compound has a significant population of rotamers with the hydroxyl group directed away from the benzene ring. This is in agreement with the ir evidence discussed below, namely, that **5** is considerably less intramolecularly hydrogen bonded than are the cyclohexanols **1** and **6**.

The amino protons of **2** and **7** are also considerably affected by the paramagnetic shielding of the phenyl ring. They occur at *ca.* 0.5 ppm higher field than the NH_2 proton resonances in *trans*- and *cis*-3-phenylcyclohexylamines.[22]

Variable Temperature Nmr Studies. To confirm that the compounds under study exist predominantly in the equatorial phenyl conformation, the H_1 band of **1** was measured over the temperature ranges from −80 to +35° in methanol-d_4 and from −7 to +58° in CCl_4. Although some loss of resolution occurred below −60°, the half-band width remained constant (24 ± 1 Hz) over the entire range of temperatures.

The cis compounds, with one substituent occupying an axial position, would be expected to have a lower barrier to ring inversion.[18,23] An attempt was made to obtain an observable population of a less stable conformer. The H_1 and H_2 resonances of **6** were recorded at 100 MHz over the temperature range from +27 to +155° in hexachloroacetone solution. The half-band widths of both protons remained unchanged over the entire temperature range, as did the chemical shift difference between them (1.20 ppm). The chemical shift separation of these protons is a particularly sensitive indicator of conformational change since upon significant population of a less stable conformer, the H_1 peak would shift upfield and the H_2 peak would shift downfield.[23] Hence, the change in separation would be twice the average change in individual chemical shifts.

Thus, the nmr evidence clearly indicates that the 1-substituted 2-phenylcyclohexanes examined exist essentially exclusively in the conformation having the phenyl group equatorial. In the case of the *cis*-cyclohexanol, **6**, no solvent dependence of the cyclohexyl protons was observed using methanol-d_4 and carbon tetrachloride.

Infrared Studies. In order to facilitate interpretation of the CD spectra of the alcohols, the factor of intramolecular hydrogen bonding of the hydroxyl group to the π orbitals of the phenyl ring must be taken into account. A concentration-dependence study in the O–H stretching region of the alcohols **1**, **5**, and **6** was carried out in CCl_4 solution. The information obtained in this nonpolar solvent may be compared with the CD data obtained in heptane solution, the latter serving as a bridge to methanol solution which was the preferred medium for the bulk of the CD work. Table III summarizes the ir data obtained for the three alcohols and also includes representative data on some related compounds. Concentration-*independent* bands for **1**, **5**, and **6** are given in Figure 1.

The high frequency shoulder of the trans alcohol, **1**, has been assigned to free O–H stretching and the major band at 3600 cm^{-1} to π-bonded O–H.[24] Galántay[25] has likewise attributed the low frequency band of the cis alcohol, **6**, to intramolecular O–H---π bonding. Free O–H stretching frequencies for comparable 2-alkylcyclohexanols generally appear in the 3615–3640-cm^{-1} range (Table III and ref 26). There is little

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(22) Reference 21, No. 5519M and 5520M.

(23) J. W. Emsley, J. Feeney, and L. H. Sutcliff, "High Resolution Nuclear Magnetic Resonance Spectroscopy," Pergamon Press, Oxford, 1965, Chapters 9 and 10.

(24) P. v. R. Schleyer, C. Wintner, D. S. Trifan, and R. Backsai, *Tetrahedron Lett.*, No. 14, 1 (1959).

(25) E. Galántay, *Tetrahedron*, 19, 319 (1963).

(26) M. Tichy, *Advan. Org. Chem.*, 5, 115 (1965).

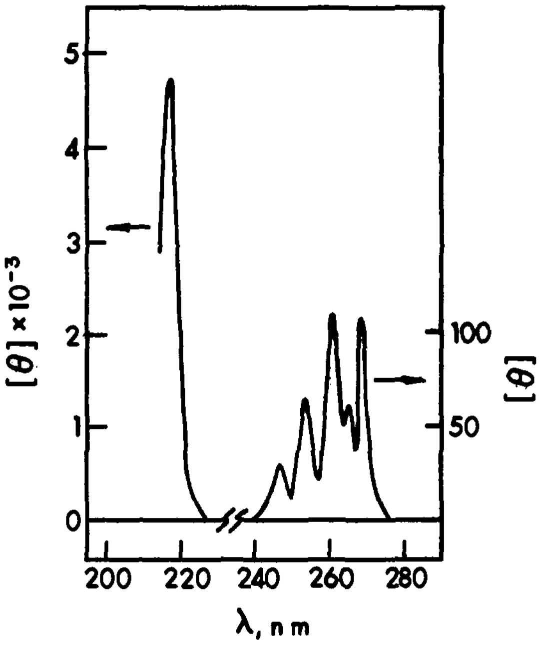

Figure 2. CD spectrum of (1S,2R)-(+)-*trans*-2-phenylcyclohexanol (**1**) in methanol. Because of the relative weakness of the Cotton effect in the 260-nm region, the CD curves (which are continuous) were divided into two parts; the right-hand ordinate refers to the ^1L_b Cotton effect and the left-hand ordinate refers to the short wavelength Cotton band.

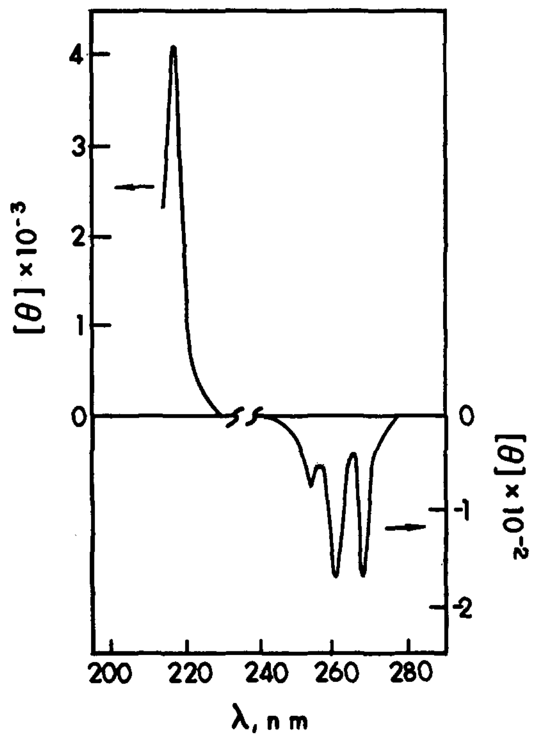

Figure 3. CD spectrum of (1S,2S)-(+)-*trans*-2-phenylcyclohexanecarboxylic acid (**3**) in methanol.

doubt, then, that the bands at *ca.* 3620 and 3600 cm^{-1} in the ir spectra of the 2-phenylcyclohexanols **1** and **6** are correctly assigned to free O–H and intramolecularly bonded O–H, respectively. Assuming comparable molar absorptivities for free and intramolecularly bonded O–H, the appearance of the free O–H as weak shoulders on the major intramolecular bands indicates that at low concentrations, both alcohols exist predominantly in the intramolecularly bonded form.

The bands of the hydroxymethyl compound, **5**, at 3639 and 3598 cm^{-1}, Figure 1, are attributed to free and intramolecularly bonded O–H, respectively. The free O–H band has a width at half-height ($\Delta\nu_{1/2}$ = 30 cm^{-1}) which is significantly greater than that of the cyclohexanols **1** and **6** ($\Delta\nu_{1/2}$ = 20 cm^{-1}). The expanded scale ir spectrum also shows an asymmetric bulge on the low frequency side of the band. These differences, together with the greater intensity of the free O–H relative to the intramolecular peak, reflect the increased rotational freedom (more contributing rotamers) and attendant decrease in steric restrictions resulting from the presence of a methylene group between the hydroxyl function and the cyclohexane ring.

Concentration-dependent intermolecular hydrogen bonding peaks were observed only at concentrations greater than 0.01 *M*. Consequently, the CD spectra of these compounds, obtained using *ca.* 0.005 *M* solutions, can be concluded to be essentially free of this type of solute–solute interaction.

Iwamura[27] has recently reported a correlation of the intramolecular O–H stretching frequencies of molecules possessing the β-phenylethanol structure with the dihedral angle formed by the ethyl C–C bond and the plane of the phenyl ring. The frequency of ~3600 cm^{-1} exhibited by **1** and **6** corresponds to a dihedral angle of about 60°. This would suggest that the preferred conformation of these compounds is one in which the plane of the benzene ring is approximately perpendicular to the mean plane of the cyclohexane ring. Corey–Pauling space-filling molecular models of the 2-phenylcyclohexanols also indicate that the phenyl substituent is oriented with its nodal plane approximately perpendicular to the cyclohexane ring. The molecular models further suggest relatively severe restriction to free rotation of the phenyl group, and at room temperature it is probably limited to librational movement about the phenyl–C-2 bond. The recent theoretical calculations of Allinger and Tribble[28] are in complete agreement with our conclusions.

In summary, the ir evidence indicates that in nonpolar solvent the hydroxyl protons of **1** and **6** are predominantly directed over the benzene ring, whereas in the case of **5** the hydroxyl group is directed predominantly away from the aromatic ring.

CD Studies. Monosubstituted benzene rings exhibit three electronic transitions in the spectral region accessible to present day ORD and CD instruments: a weak, highly structured band, termed ^1L_b in the Platt notation,[29] centered near 260 nm and corresponding to a symmetry-forbidden π–π^* transition; two stronger bands, designated ^1L_a and $^1B_{a,b}$, occuring near 210 and 190 nm, respectively. The ^1L_a band is also forbidden but probably contains a contribution from the first allowed π–π^* transition which overlaps it at shorter wavelength.

Any other chromophore in the molecule which absorbs near one of these aromatic transitions can give rise to Cotton effects which complicate the interpretation of the chiroptical spectra. For phenyl-containing

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(27) H. Iwamura, *Tetrahedron Lett.*, 2227 (1970).

(28) N. L. Allinger and M. T. Tribble, *ibid.*, 3259 (1971).

(29) J. R. Platt, *J. Chem. Phys.*, 17, 484 (1949).

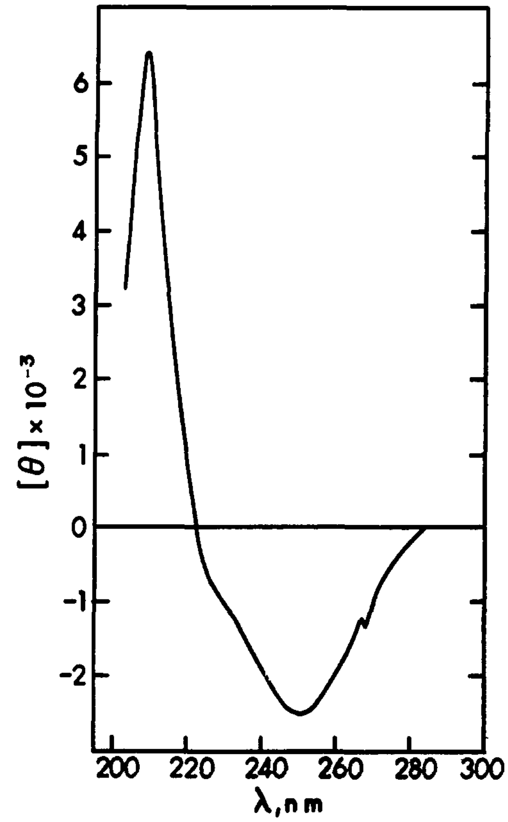

Figure 4. CD spectrum of (1*S*,2*S*)-(+)-*trans*-2-phenylcyclohexanecarbonyl chloride (4) in heptane.

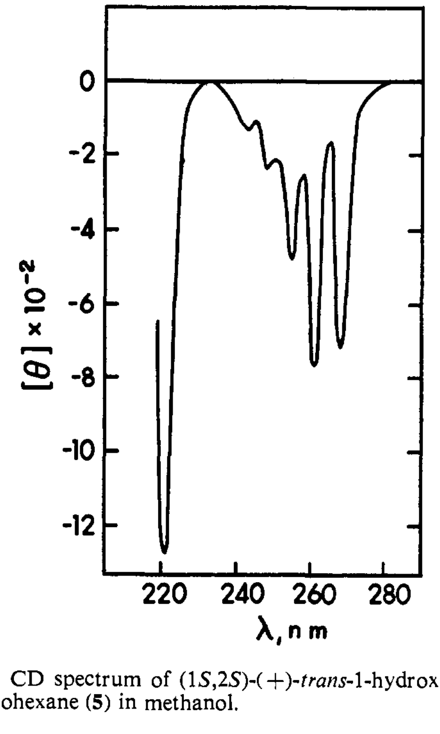

Figure 5. CD spectrum of (1*S*,2*S*)-(+)-*trans*-1-hydroxymethyl-2-phenylcyclohexane (5) in methanol.

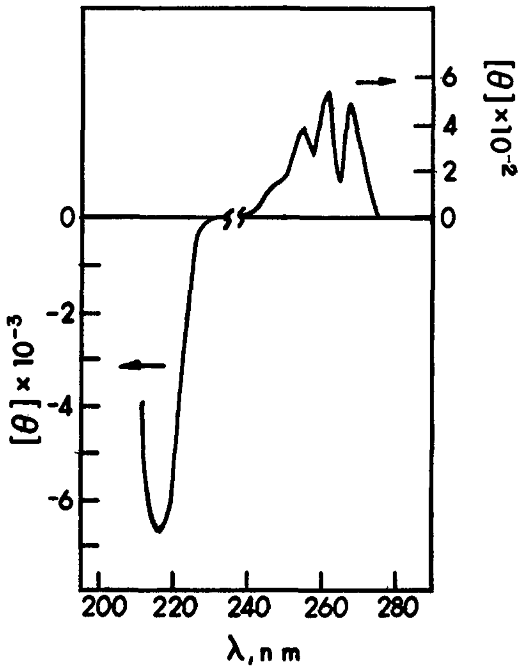

Figure 6. CD spectrum of (1*R*,2*R*)-(−)-*cis*-2-phenylcyclohexanol (6) in methanol.

compounds, particularly those of biological interest, other common functional groups are the amino, hydroxyl, and carboxyl. None of these groups has an absorption band in the 260-nm region, so that in molecules *containing only a phenyl ring and one of these groups*, the ^1L_b Cotton effect may be unambiguously characterized by its low intensity and vibrational fine structure.[6,30]

The lowest energy transitions of the amino and hydroxyl functions involve n–σ^* transitions which occur below *ca.* 190 nm. However, in certain cases, charge-transfer bands to acceptor π^* orbitals may be observed[31] in the 230–245-nm region. In addition, the n–π^* transition of the carboxyl chromophore (λ_{max} *ca.* 210 nm) appears in the region of the phenyl ^1L_a band. Overlapping Cotton effects can cause serious complications in assignment of the spectroscopic origins of these bands. Depending upon the relative signs, magnitudes, and degree of overlap, the observed composite Cotton effect may differ substantially in wavelength and magnitude from that of its component bands.[32]

The CD spectra in methanol solution (except **4** in heptane) of all compounds are shown in Figures 2–7. In general, methanol was preferred because of larger ellipticity values for most (but not all) compounds in this solvent and, hence, better uv penetration, as well as for maintaining consistency with previous work.[33,34] The Cotton effect in the 260-nm region of the trans amine, **2**, was too weak to be determined reliably, either in methanol or heptane. The only observable Cotton effect in this compound is compared with that of the cis isomer, **7**, in Figure 7.

An important factor in methanol solution is the effect of solvation on the orientation of the substituent in the 1 position, particularly for the alcohols **1**, **5**, and **6**, which had been studied by ir spectroscopy in CCl_4 solution. Accordingly, the CD spectra of the alcohols **5** and **6**, and the carboxylic acid **3**, were determined in

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(30) A. Moscowitz, A. Rosenberg, and A. E. Hansen, *J. Amer. Chem. Soc.*, **87**, 1813 (1965); L. Verbit, *ibid.*, **88**, 5340 (1966).

(31) J. C. Craig and W. E. Pereira, Jr., *Tetrahedron*, **26**, 3457 (1970); *Tetrahedron Lett.*, 1563 (1970).

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(33) L. Verbit and Y. Inouye, *ibid.*, **89**, 5717 (1967).

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the nonpolar solvent, heptane. In addition to the ^1L_b Cotton effect in the 260-nm region, one other band is observed at shorter wavelength. The data in methanol and heptane solution are compared in Table IV. It is interesting that for all three compounds, the position of the Cotton band does not shift upon changing the solvent from methanol to heptane. However, the intensities of the Cotton effects change appreciably, increasing in the case of the cis alcohol, **6**, and decreasing in the case of **3** and **5**. The cis alcohol, **6**, has been shown by ir to exist in dilute CCl_4 solution with its O–H group hydrogen bonded to the π orbitals of the phenyl ring. In methanol, the hydroxyl group is undoubtably extensively hydrogen bonded to solvent so that the increased intensity of the Cotton effect in heptane compared with methanol should be related to the change in orientation of the hydroxyl group to that required for intramolecular hydrogen bonding.

Table IV. Solvent Dependence of the Short Wavelength CD Cotton Effects

Compd	λ_{max}, nm ([θ], deg cm^2/dmol) Methanol	 Heptane
3	217 (+4000)	217 (+2500)
5	221 (−1300)	221 (−1000)
6	216 (−6800)	216 (−11,000)

In contrast, the ir studies above indicate that **5** in CCl_4 solution is much less intramolecularly hydrogen bonded and exists largely in the orientation having the O–H group directed away from the aromatic ring (hence, with the methylene hydrogens *toward* the phenyl ring). Therefore, the change in Cotton effect intensity on going from methanol to heptane solution is attributed primarily to a change in solvent polarity and only secondarily to a change in rotameric conformation of the hydroxymethyl group. Whether this same reasoning can be applied to **3** is problematical, since comparable ir studies could not be carried out on the acid.

The fact that the position and sign of the Cotton effects in **3**, **5**, and **6** do not change from methanol to heptane solution indicates that no substantial conformational changes have occurred and allows the extrapolation of information obtained from the nmr and ir studies to the CD results in methanol solution.

For all compounds, the longest wavelength Cotton effect is in the 260-nm region and displays the typical intensity and vibrational fine structure of the ^1L_b transition.[6,30] In the case of the acid chloride, **4**, this Cotton band is overlapped by a much stronger one centered near 250 nm (see below), but a peak corresponding to the ^1L_b Cotton effect can be discerned at 268 nm, Figure 4.

In addition to the ^1L_b band, all seven compounds exhibit a more intense Cotton effect in the 210–220-nm region. The intensities range from [θ] = −1300 for **5** to [θ] = −6800 for **6**. For the phenylcyclohexanols **1** and **6**, and the phenylcyclohexylamines **2** and **7**, this Cotton effect is assigned to the ^1L_a transition of the aromatic ring, the only chromophore in the molecule absorbing above 200 nm. In the case of the cis amine, **7**, the entire Cotton effect could be obtained, with measurements extending to 208 nm. An oppositely signed band, having its maximum below 200 nm, overlaps the ^1L_a Cotton effect. Falling light-source intensities with concomitant decreasing signal-to-noise ratios precluded further investigation of this band which could be due to a higher energy phenyl transition or one involving the unshared electrons of the amino group.

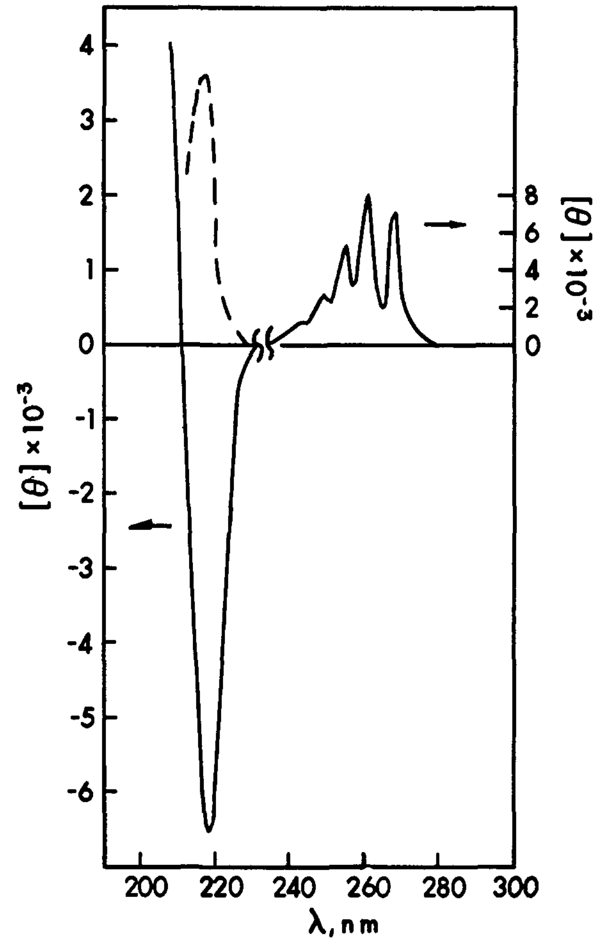

Figure 7. CD spectra of (1*S*,2*R*)-(+)-*trans*-2-phenylcyclohexylamine (**2**) (- - - -), and (1*R*,2*R*)-(−)-*cis*-2-phenylcyclohexylamine (**7**) (——); both in methanol.

The band shape of the 218-nm Cotton effect of **7**, Figure 7, illustrates an important point. The width at half-height of this band is 12 nm. For other compounds in the series, widths at half-height of the respective short wavelength Cotton effects can be estimated to be 12–16 nm. Other examples in the literature[33–35] of Cotton effects attributable to the ^1L_a aromatic transition also have widths at half-height in this same range. Because the methods presently available for determining the orbital origins of electronic transitions are rather limited, *e.g.*, analysis of gas-phase rotational fine structure, polarized reflection spectra of single crystals, etc., we propose to utilize the observed CD band shapes to identify the phenyl ^1L_a and the carbonyl n–π^* transitions (see below) in much the same way as the solvent shift technique has been used in isotropic absorption spectroscopy.

For monosubstituted benzene derivatives which may also contain an amino, carboxyl, or hydroxyl function, *the Cotton effect due to the ^1L_a aromatic transition may*

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(35) J. C. Craig, W. E. Pereira, Jr., B. Halpern, and J. W. Westley, *Tetrahedron*, 27, 1173 (1971).

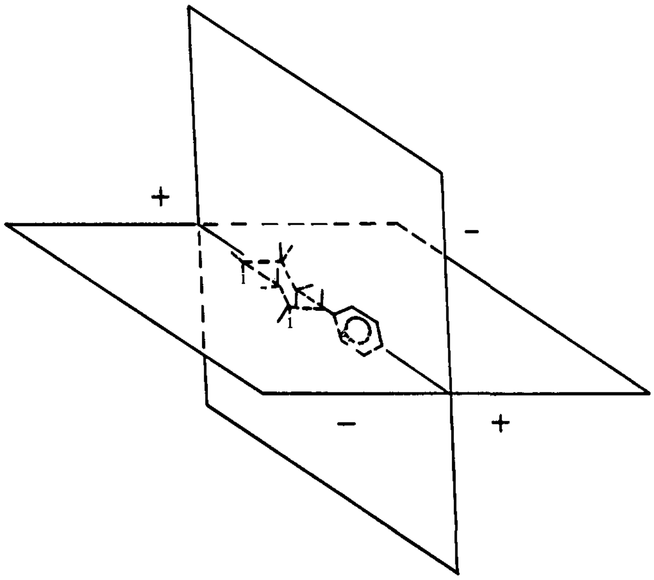


Figure 8. Quadrant projection for the ^1L_a transition.

be characterized by a width at half-height of 10–20 nm.[36] The decrease in rotational strength with increased distance between the aromatic ring and the chiral center is well known. Hence, it should be made clear that our present proposal relates to a phenyl ring directly attached to a chiral center. Since overlap of adjacent Cotton effects tends to cause band broadening,[32] this proposal is relatively restrictive and subject to further experimental testing. It is utilized below in the assignment of several Cotton effects.

The short wavelength Cotton effect in the carboxylic acid, **3**, occurs in the same spectral region and has similar magnitude to those of the amines and alcohols **1**, **2**, **6**, and **7**. However, the n–π* transition of the carboxyl chromophore[37] occurs in this same region and the observed Cotton effect in **3** may be associated with this transition.

Several research groups[31,38,39] have examined the CD spectra of simple carboxylic acids. In general, they exhibit broad Cotton effects near 210 nm with widths at half-height typically of the order of 30–35 nm.

The estimated width at half-height of the short wavelength Cotton effect of **3**, 14 nm, is in the range of values observed for other ^1L_a Cotton effects.[33–35] Hence, we assign the 217-nm Cotton effect in **3** mainly to the phenyl ^1L_a transition. The optically active carboxyl n–π* transition is either buried under the 217-nm Cotton effect, as is the case in the corresponding isotropic absorption spectrum, or is shifted by overlap[32] to shorter wavelength. Information bearing on this latter point is obtained from consideration of the CD spectrum of the acid chloride, **4**, which was prepared from **3**.

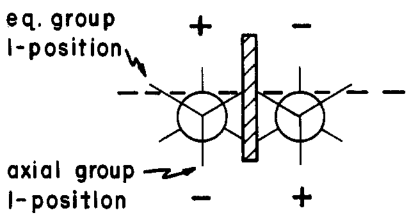
Replacement of the hydroxyl portion of the carboxyl group by chlorine (COOH → COCl) results in a bathochromic shift of the n–π* transition of approximately 35 nm so that for acid chlorides this band appears in the 240–245-nm region.[1,40] Hence, in the case of **4**, the n–π* transition clearly lies at longer wavelength than the ^1L_a phenyl transition. The CD spectrum of the acid chloride, **4**, Figure 4, exhibits a positive Cotton effect at 209.5 nm, $[\theta] = +6400$, and a broad negative band centered at 251 nm, $[\theta] = -2500$. The latter band overlaps and almost obscures the ^1L_b Cotton effect in the 260-nm region.

The relatively strong intensity and position of the 251-nm band indicates that it arises from the optically active n–π* transition of the chlorocarbonyl chromophore. The estimated width at half-height, 35 nm, is in agreement with that found for the n–π* transition of carboxylic acids.[31,38,39]

The positive Cotton effect at 209.5 nm, width at half-height 15 nm, is then due to the ^1L_a phenyl transition, shifted to shorter wavelength by overlap with the relatively intense 251-nm Cotton effect.

The similar band shape of the short wavelength Cotton effect in the carboxylic acid, **3**, to that of **4** lends weight to the assignment of the former to the phenyl ^1L_a transition.

The monosubstituted benzene ring under study has C_{2v} symmetry and should be subject to a sector rule.[41] Our data are consistent with the quadrant rule depicted in Figure 8, where plus and minus indicate the sign of the ^1L_a cotton effect. The vertical symmetry plane passes through the nodal plane of the benzene ring while the horizontal plane passes through the substitution axis. Note that the equatorial phenyl substituent makes an approximately 30° angle with the mean plane of the cyclohexane ring, resulting in the latter being tilted below the horizontal symmetry plane of the phenyl moiety. When viewed along the phenyl substitution axis, the ring system is depicted by **8**.



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For the absolute configurations of compounds **1**–**7**, an equatorial substituent in the 1 position lies in a positive quadrant while a corresponding axial substituent lies in a negative quadrant. The axially substituted cis alcohol and amine, **6** and **7**, have negative ^1L_a Cotton bands at 216 and 218 nm, respectively. The trans compounds, **1**–**4**, where both substituents are equatorial, possess positive ^1L_a Cotton effects.

The CD spectrum of **5**, Figure 5, the only primary alcohol in the series, is rather different from the other compounds studied in the short wavelength region. Derived from the carboxylic acid **3**, by reduction, it has the same absolute configuration. However, its short wavelength Cotton effect is negative and occurs at 221

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[36] Theoretically, an analogous statement can be made for the width of an ORD Cotton effect. Initially, we prefer to consider circular dichroism, since it has the simplifying property of vanishing outside of an optically active absorption band.

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nm, the longest wavelength of all the compounds in the series.

Since the phenyl group is the only chromophore in the molecule absorbing above 200 nm, the 221-nm Cotton band must arise from a transition of the aromatic ring. The estimated width at half-height, 10 nm, is in agreement with the above proposal for assignment of this band to the ^1L_a phenyl ring transition.

The negative sign of the ^1L_a Cotton effect of this diequatorial molecule is accommodated by our quadrant rule from a knowledge of the conformation of **5** in solution. Ir measurements in CCl_4 indicated that the O–H group is directed predominantly away from the aromatic ring. This orientation would be expected to prevail in the hydrogen bonding solvent, methanol. Examination of a Dreiding molecular model of **5** in the expected conformation reveals that due to the additional flexibility introduced by the methylene group in CH_2OH, the hydroxyl function lies below the horizontal symmetry plane of the phenyl ring, *i.e.*, in a negative quadrant.

Hence, for the seven compounds studied, the sign of the ^1L_a aromatic Cotton effect appears to be determined by the presence of an adjacent group capable of direct perturbation of the π electrons of the ring. By the judicious use of a simple quadrant rule, absolute configuration may be correlated with the sign of the ^1L_a Cotton effect. We would stress, however, that the quadrant rule is not meant to be a general one at this time. Further tests of its validity and usefulness are in progress.

Two other sector rules have been put forward for the ^1L_a transition. The quadrant rule of DeAngelis and Wildman,[42] derived from studies on Amaryllidaceae alkaloids, has opposite signs to the ^1L_a rule described above, while the rule proposed by Snatzke and Ho,[43] having eight small sectors whose signs are provisional, makes the correct orientation of substituents difficult and the results inconclusive.

Although several sector rules have been formulated for the ^1L_b Cotton effect,[43,44] no correlation of the sign of this band with absolute configuration is apparent in the present series.

Experimental Section

CD measurements were made using a Jasco Model ORD/UV/CD-5 instrument operating under the conditions described earlier.[34] The sensitivity in the CD mode has been increased and the instrument modified to read directly in terms of observed ellipticity, θ, in natural units of degrees.[45] The most sensitive setting is 10 mdeg per 100 mm of chart paper, which was utilized to investigate very weak Cotton effects. The CD calibration[46] was checked periodically with a standard aqueous solution (1.0 mg/ml) of (+)-camphor-10-sulfonic acid. Spectral grade solvents were used.

Ir spectra were obtained on a Perkin-Elmer Model 457 or 521 grating spectrophotometer using PCl_5-dried CCl_4. Nmr spectra were obtained on a Varian HA-100D instrument using TMS as internal reference. Ethylene glycol and methanol were used to calibrate the probe temperature for studies above and below room temperature, respectively.

Elemental analyses were performed by Galbraith Laboratories, Knoxville, Tenn. All compounds gave correct elemental analyses. Melting points are corrected.

(+)-*trans*-2-Phenylcyclohexanol. (1). The *cis*- and *trans*-2-phenylcyclohexanols were separated from a commercial mixture (Aldrich Chemical Co., 88% cis and 12% trans) by utilizing the solubility differences of the respective acid phthalates.[47] Partial separation of the mixed acid phthalates was accomplished by the higher solubility of the cis isomer in 5:8 ether–ligroin solution. The pure trans acid phthalate was obtained by fractional crystallization of the enriched trans isomer from acetone. The pure acid phthalate of *trans*-2-phenylcyclohexanol had mp 185–186° while the corresponding *cis*-phthalate had mp 128.5–130°. The isomeric phthalates were readily distinguishable by their ir spectra; carbonyl stretch for trans at 1720 and 1705; for cis at 1737 and 1699 cm^{-1}.

(+)-*trans*-2-Phenylcyclohexanol was obtained by fractional crystallization of the brucine phthalate salt from methanol. The resolved alcohol was obtained directly from the alkaloid salt by refluxing it in 6 *N* NaOH solution. **1** thus obtained was recrystallized from ligroin, mp 64–65°, $[\alpha]^{27}D$ +55° (*c* 0.100, CH_3OH) (lit.[7] $[\alpha]^{31}D$ +53° (*c* 1.56, C_6H_6)) for **1** prepared *via* a stereoselective synthesis.

Resolution of the acid phthalate of *trans*-2-phenylcyclohexanol with strychnine, followed by work-up as described above led to the levo alcohol having $[\alpha]^{27}D$ −55.5°.

(−)-*cis*-2-Phenylcyclohexanol (6). The cis-enriched acid phthalate of 2-phenylcyclohexanol obtained from the ether–ligroin extraction of the isomeric phthalates (see above) was further purified by partial recrystallization from benzene. The cis acid phthalate was more soluble in benzene and after three partial recrystallizations–evaporations of the mother liquor, pure cis acid phthalate was obtained, mp 128.5–130°. Hydrolysis of the acid phthalate in 50% methanolic KOH solution yielded the pure racemic cis alcohol, mp 42–43° (ligroin) (lit.[48] mp 41–42°).

6 was resolved by fractional crystallization of the strychnine salt of the acid phthalate from a mixture of heptane, chloroform, and absolute ethanol (7.5:3:2, v:v:v). **6** thus obtained has mp 32–33°, $[\alpha]^{27}D$ −106° (*c* 0.20, CH_3OH) (lit.[7] $[\alpha]^{27}D$ −102.2° (*c* 1.18, C_6H_6)) for **6** prepared *via* a stereoselective synthesis.

(+)-*trans*-2-Phenylcyclohexanecarboxylic Acid (3). The racemic acid was prepared by the Na in 1-pentanol reduction of 2-biphenylcarboxylic acid as described by Cook and coworkers,[49] mp 105.5–107.5° (lit.[50] mp 107–108°). Attempts to resolve the acid with brucine, strychnine, and cinchonidine in a number of solvent systems were unsuccessful. However, both *d*-amphetamine and (−)-α-phenylethylamine gave immediate precipitates of salts from methanol solutions of the acid. The latter amine was the preferred resolving agent since the acid obtained from its once-recrystallized salt was of higher optical purity than that obtained from the corresponding amphetamine salt.

The *trans*-2-phenylcyclohexanecarboxylic acid thus obtained from four recrystallizations had $[\alpha]^{27}D$ +68° (*c* 0.12, CH_3OH) and mp 87–88°. Vpc analysis on a 6 ft SE-30 column indicated >99.5% pure *trans*-2-phenylcyclohexanecarboxylic acid.

(+)-*trans*-1,2-Cyclohexanedicarboxylic Acid. A stream of oxygen containing *ca.* 3% ozone was passed for 25 hr through a solution of (+)-*trans*-2-phenylcyclohexanecarboxylic acid (1.2 g, 0.006 mol) in acetic acid; 10% H_2O_2 (25 ml) was added to the reaction mixture which was then let stand overnight, after which it was evaporated to dryness under reduced pressure with the bath temperature kept below 35°. *Precautions against possible explosion were taken.* Another 15 ml of 10% H_2O_2 were added and the mixture again evaporated to dryness. This procedure was repeated three times. The solid residue was recrystallized from water to give 0.7 g (70% yield) of (1*S*,2*S*)-(+)-*trans*-1,2-cyclohexanedicarboxylic acid: mp 182–184°; $[\alpha]^{27}D$ +21.2° (*c* 5.0, acetone) (lit.[51] mp 183.5–185°; $[\alpha]^{30}D$ + 22.3° (*c* 5.3, acetone)); λ_{max} 210 (ϵ 120, methanol).

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(+)-*trans*-2-Phenylcyclohexanecarbonyl Chloride (4). Treatment of 0.4 g of the (+) acid, **3**, with $SOCl_2$ afforded 0.4 g of the acid chloride, **4**, mp 47-50°. Approximately 40 mg of the acid chloride was sublimed (bath temperature 50° (4 mm)) to give 4 mg of transparent needles of *trans*-2-phenylcyclohexanecarbonyl chloride, mp 51-52°, $[\alpha]^{27}$D +31° (*c* 0.014, heptane).

(+)-*trans*-1-Hydroxymethyl-2-phenylcyclohexane (5). The (+) carboxylic acid, **3**, $[\alpha]^{21}$D +68° (CH_3OH), was reduced with $LiAlH_4$ in Et_2O. Recrystallization of the product from pentane afforded *trans*-1-hydroxymethyl-2-phenylcyclohexane, mp 76-77°, $[\alpha]^{27}$D +51° (*c* 0.079, CH_3OH). The ir spectrum of the (+) alcohol was identical with that of the known[52] racemic compound.

(+)-*trans*-2-Phenylcyclohexylamine (2). A. *Via* **Resolution.** The racemic amine was prepared by the hydroboration–ammination[53] of 1-phenylcyclohexene, mp 57-58° (lit.[54] mp 59-60°). Resolution of the amine with *d*-tartaric acid from 3:1 (v/v) methanol–ether afforded (+)-*trans*-2-phenylcyclohexylamine, mp 36-38°, $[\alpha]^{27}$D +45° (*c* 0.074, CH_3OH). The ir spectrum of **2** was identical with that of the racemic compound.

Work-up of the mother liquors from the resolution yielded the (−) isomer, mp 37.5-39°, $[\alpha]^{27}$D −48° (*c* 0.20, CH_3OH).

B. *Via* **Asymmetric Hydroboration.** To a stirred solution of 0.050 mol of (−)-di-3-pinanylborane[55] (from (+)-α-pinene) was added 1-phenylcyclohexene (7.9 g, 0.050 mol). The mixture was stirred for 3 hr at 0° and then 24 hr at 25°. A solution of hydroxylamine-*O*-sulfonic acid (8.4 g, 0.055 mol) in 30 ml of diglyme was added and the solution was stirred at 0° for an additional 3 hr. Concentrated HCl (30 ml) was then added and the solution was poured into 200 ml of water. The mixture was washed with 3 × 200 ml of Et_2O, made basic with 6 *N* NaOH, and extracted with 2 × 200 ml of Et_2O. The combined ether extracts were washed with saturated NaCl and water, dried over Na_2SO_4, and evaporated to approximately 25 ml. The solution was distilled through a 15-cm Vigreux column at 4 mm pressure until the head temperature reached 55°. This left a pot residue of *ca.* 0.4 ml, analyzing as 30% *trans*-2-phenylcyclohexylamine (vpc on SE-30 column). The sample was further purified by preparative vpc (SE-30). The combined fractions analyzed as 62% of trans amine, the major contaminant being isopinocamphenylamine.[49] This latter amine could be effectively removed by warming the sample to 55° for a few minutes under a stream of N_2. In this manner 96% pure *trans*-2-phenylcyclohexylamine was obtained, $[\alpha]^{27}$D +16° (*c* 0.30, CH_3OH). Correcting for the optical purity of the α-pinene used (88%) and assuming that **2** obtained by resolution is essentially enantiomerically pure, (+)-*trans*-2-phenylcyclohexylamine produced by the asymmetric hydroboration reaction has an optical purity of 40%.

(+)-*cis*-2-Phenylcyclohexylamine (Enantiomer of 7). Racemic *cis*-2-phenylcyclohexylamine was obtained by selective hydrogenation of 2-aminobiphenyl over 5% rhodium on alumina. In a typical reduction, 30 g (0.177 mol) of 2-aminobiphenyl in 250 ml of acetic acid was hydrogenated over 25 g of 5% $Rh-Al_2O_3$ at 25° and 45 psig (average) for 22 hr. The residue was taken up in 300 ml of ether and the acetic acid was removed by extracting with 6 *N* NaOH solution. The ether phase was then washed with 3 × 200 ml of saturated NaCl, dried over Na_2SO_4, filtered, and concentrated on a rotary evaporator to approximately 45 ml.

The amine products (see below) from three such reactions were combined and distilled through a 15-cm Vigreux column at 3 mm pressure. Distillation was stopped when the temperature at the distilling head began to rise rapidly over the range 115-120°. Analysis of the distillate (vpc, Carbowax 20M) gave 45% of *cis*-2-phenylcyclohexylamine along with lesser amounts of 2-cyclohexylcyclohexylamine, *o*-cyclohexylaniline, and a trace of *trans*-2-phenylcyclohexylamine.

Formation of the *d*-camphor-10-sulfonate salts of the mixture and subsequent recrystallization from an equivolume mixture of $CHCl_3$–acetone led to enrichment in the desired cis amine; vpc analysis of the liberated amines showed only two amines remaining, in the ratio of 72% *cis*-2-phenylcyclohexylamine and 21% 2-cyclohexylcyclohexylamine.

Further separation was effected by conversion of the amines to their *p*-nitrobenzoate salts and recrystallization from ether–methanol. The liberated amine mixture analyzed as 96% *cis*-2-phenylcyclohexylamine, which was resolved *via* *d*-tartaric acid. The tartrate had mp 175-176.5°. Three recrystallizations from 2:1 (v/v) ether–methanol followed by conversion to the free amine by shaking an ether solution of the tartrate salt with 6 *N* NaOH solution afforded (+)-*cis*-2-phenylcyclohexylamine (>99% pure by vpc) as a colorless liquid, $[\alpha]^{27}$D +59° (*c* 0.26, CH_3OH).

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