Cholesteric Liquid Crystal Induced Circular Dichroism (LCICD). VI. LCICD Behavior of Benzene and Some of Its Mono- and Disubstituted Derivatives

F. D. Saeva,* P. E. Sharpe,[1] and G. R. Olin[1]

Contribution from the Xerox Corporation, Rochester Research Center, Webster, New York 14580. *Received May 14, 1973*

Abstract: Liquid crystal induced circular dichroism (LCICD) studies on a series of mono- and disubstituted benzene derivatives show both spectroscopic and conformational effects as a function of aromatic ring substitution. The sign of the extrinsic circular dichroism (CD) within the ^1L_b electronic transition in monosubstituted benzenes depends on the ortho,para directing ability of the substituent, similar to that found in magnetic circular dichroism studies. LCICD spectra of some ortho-, meta-, and para-disubstituted benzenes show the para isomer to exhibit oppositely signed CD within the ^1L_b transition from the less symmetrical ortho and meta derivatives. This para effect is attributed to conformational variations between the isomers in a cholesteric mesophase of a single chirality.

We have recently reported[2] that achiral molecules dissolved in cholesteric liquid crystalline mesophases display circular dichroism (CD) in the region of their electronic transitions. The observed extrinsic CD arises from the helical ordering of the solute within the cholesteric mesophase. This phenomenon has been termed cholesteric liquid crystal induced circular dichroism (LCICD).

The sign of the LCICD was found to be dependent on the chirality of the cholesteric helix,[2] orientations of the electric transitions dipoles,[3] and the cholesteric matrix.[4] LCICD has been suggested as a technique for determining the existence and chirality of cholesteric mesophases.[5] In the previous paper,[4] the dependence of LCICD intensity and sign on the cholesteric matrix pitch, temperature, texture, and solute concentration was discussed.

In this paper we present the results of an investigation into the LCICD behavior of benzene and some of its derivatives. The experimental observations from this investigation are compared with those of magnetic circular dichroism (MCD) studies on these same compounds and interpreted in terms of spectroscopic and conformational variations that occur as a function of substituent type and position on the phenyl ring.

Experimental Section

Circular dichroism spectra were run on a Cary 61 spectropolarimeter. Samples consisted of thin films (10–25 μ) of the liquid crystal between 1 in. × $^1/_8$ in. quartz disks. Cell thicknesses were determined, in those cases where Mylar spacers were not employed, by relating absorption spectral intensities in films of unknown thickness to films of known thickness. The texture of the cholesteric mesophase was the Grandjean in all samples. The temperature was 22°, and molecular ellipticity, $[\theta]$, was calculated by means of the following equation

$$[\theta] = \theta \mathrm{MW}/10lc \text{ (deg cm}^2\text{/dmol)}$$

where θ is the observed ellipticity in degrees, MW, molecular weight, l, path length in cm, and c, concentration in g/ml.

Materials. The mono- and disubstituted benzenes used in this study were purchased from Eastman Organic Chemicals, Rochester, N. Y., and Aldrich Chemical Co. Cedar Knolls, N. J., and were characterized by ir and nmr, and possessed boiling and melting points in agreement with literature values. Cholesteryl chloride (mp 96°) and cholesteryl nonanoate (78–92° cholesteric) were purchased from Eastman Kodak Co., Rochester, N. Y., and were recrystallized twice from *n*-propyl alcohol prior to use. A supercooled cholesteric mesophase composed of 70:30 (wt %) cholesteryl nonanoate (CN)–cholesteryl chloride (CC) was the matrix used throughout this study.

Results and Discussion

LCICD measurements on benzene and some mono- and disubstituted benzenes were confined to the $^1A_{1g} \rightarrow {}^1B_{2u}$ transition ($^1A \rightarrow {}^1L_b$ Platt notation) at approximately 260 nm ($\epsilon \sim$100–3000) due to absorption limitations of the cholesteric matrix. Care was taken to minimize thermal degradation of the cholesteric matrix (*i.e.*, cholesteryl chloride decomposing to cholestadiene which absorbs at longer wavelength than either CN or CC).

LCICD of Benzene and Monosubstituted Derivatives. In benzene the ^1L_b transition is symmetry forbidden and has nonzero intensity resulting from vibronic interactions with higher lying electronic states. In substituted benzenes, however, aromatic ring substitution perturbs the electronic structure so that the transition to the ^1L_b state becomes formally allowed. Detailed studies on the effect of substituents on the intensity of the electronic transitions in benzene derivatives have been previously discussed by Petruska[6] and Stevenson.[7]

The LCICD of benzene and a series of eight monosubstituted benzenes were measured in a single, right-handed helical,[8] cholesteric mesophase along with their electronic spectra (see Table I).

The LCICD of benzene in the cholesteric environment shows negative CD in the region of the ^1L_b transition. However, only the molecular ellipticity, $[\theta]$, for the 262-nm transition in benzene is recorded in Table I due to the uncertainty in estimating θ for higher energy vibrational bands within the ^1L_b transition as a

---

[1] Rochester Institute of Technology Co-op.

[2] F. D. Saeva and J. J. Wysocki, *J. Amer. Chem. Soc.*, **93**, 5928 (1971).

[3] F. D. Saeva, *ibid.*, **94**, 5135 (1972).

[4] F. D. Saeva, P. E. Sharpe, and G. R. Olin, *ibid.*, **95**, 7656 (1973).

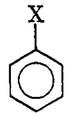
[5] F. D. Saeva, *Mol. Cryst. Liquid Cryst.*, **18**, 375 (1972).

[6] J. Petruska, *J. Chem. Phys.*, **34**, 1120 (1961).

[7] P. E. Stevenson, *J. Chem. Educ.*, **41**, 234 (1964).

[8] The chirality of the cholesteric mesophase is that indicated by the handedness of circular polarized light transmitted in the region of the pitch band, *i.e.*, a cholesteric mesophase that selectively transmits left-handed circular polarized light in the region of the pitch band is a left-handed helix.

Table I. Liquid Crystal Induced Circular Dichroism (LCICD) of Benzene and a Series of Monosubstituted Benzenes



X	$[\theta]^a$	λ, nm	ϵ^b	λ_0, nm^c
Dimethylamino	+19,889	312	2297^d	620
Hydroxyl	−26,161	282	1591	764
	−31,393	274	1949	
	−20,231	268	1559	
Methoxy	−12,170	278	1704	628
	−11,529	272	1877	
	−3,330	266	1339	
Hydrogen	−4,769	262	218	610
Chloro	<−1,000	272	80	623
	+1,187	266	107	
	+1,380	259	105	
Bromo	f	272	87	656
	+2,074	267	141	
	+3,582	260	140	
Cyano	+3,996	278	436	765
	+4,416	272	445	
	+3,197	264	330	
Carboxyl	+73,211	285	759	545
	+56,332	276	1003	
Nitro	−510,239	257^e	5424	620

[a] Molecular ellipticity, $[\theta]$, is a function of wavelength, sample, solvent (matrix), temperature, pitch, and texture. [b] Anisotropic molar absorptivities. [c] Reflective wavelength of the cholesteric matrix ($\lambda_0 = 2np$, where n = refractive index, p = pitch). [d] Molar absorptivity for 300-nm band. Due to overlapping of circular dichroism (CD) bands of positive and negative signs the λ_{max} of the longest wavelength band occurs at 312 nm. [e] ^1L_b state is underlying the ^1L_a state due to a blue shift of ^1L_b transition with nitro substitution. [f] No observable CD.

result of severe overlapping with the matrix CD (all bands possessed negative CD, however).

The experimental observations presented in Table I show the CD of the ^1L_b transition 0-0 band for a variety of mono-substituted benzenes to be of negative sign when the substituent is ortho,para directing, except for dimethylamino, and of positive sign when the substituent is meta directing. The correlation between LCICD sign and phenyl substituent electronic behavior is similar to that found in MCD studies,[9] where dimethylamino was also found to behave anomalously.

The monosubstituted benzenes listed in Table I are in order of decreasing ortho,para directing ability (dimethylamino being the strongest ortho,para directing substituent). The signs of the LCICD of all the vibrational bands within the ^1L_b transition for the hydroxyl and methoxy substituent compounds were of negative sign. As the ortho,para directing ability of the substituent decreases as in chloro, for example, both negative (0–0) and positive CD bands are observed indicating mixed polarization,[10,11] or a result of overlapping with higher electronic states. Strongly meta directing substituents on benzene such as cyano and carboxyl, on the other hand, produce positive CD throughout the entire ^1L_b transition.

The change in LCICD sign as a function of aromatic ring substituent is suggested to be a result of a spectroscopic variation and not a conformational effect of the solute in the liquid crystal. This conclusion is supported by the results obtained in MCD studies[9] on isotopically oriented benzene and some of its derivatives where a similar correlation was found.

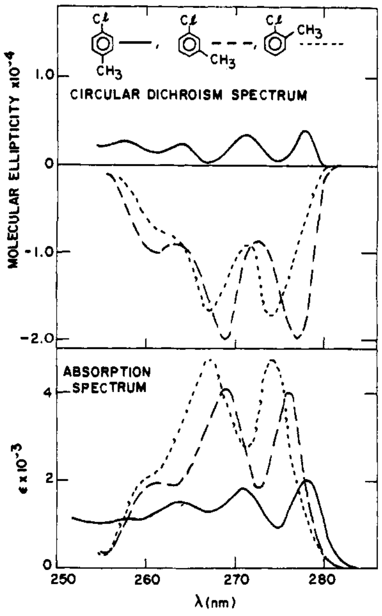


Figure 1. Circular dichroism and absorption spectra for *o*-, *m*-, and *p*-methylchlorobenzene.

The LCICD intensity in the monosubstituted benzenes appears to be proportional to the molecule absorptivity, *i.e.*, high values of $[\theta]$ are associated with high ϵ values. Substituents such as chloro, bromo, and cyano on benzene give LCICD bands within the ^1L_b transition of lower CD intensity than hydroxyl, methoxy, and carboxyl.

Disubstituted Benzenes. Literature observations involving measurements of natural optical activity in isotropic solution have shown a variety of interesting effects as a function of the position of aromatic ring substitution. For example, CD studies on intrinsic optically active sulfoxides and phosphine oxides[12] show the para isomer to have, for certain electronic transitions, oppositely signed CD bands from the ortho and meta isomers even through the stereochemistry at S and P is the same for all isomers. More recently Scheraga, *et al.*, reported a para effect on the chirality of the α helix formed by poly-β-chlorobenzyl-L-aspartates.[13,14] Scheraga predicted and experimentally verified, from the sign of CD in the 225-nm region, that in all helix-supporting solvents poly-β-*p*-chlorobenzyl-L-aspartate exists as a right-handed α helix while the ortho and meta isomers are left-handed. It was our idea to investigate the spectroscopic and conformational behavior of a variety of ortho-, meta-, and para-disubstituted benzenes through the use of LCICD in a cholesteric mesophase of a known helix sense (right-handed).

Figure 1 presents the LCICD and absorption spectrum of the ortho, meta, and para isomers of methylchlorobenzene. The para isomer shows *positive* CD

---

(9) J. G. Foss and M. E. McCarville, *J. Amer. Chem. Soc.*, **89**, 30 (1967).

(10) O. E. Weigang, Jr., *J. Chem. Phys.*, **43**, 3609 (1965).

(11) J. Horwitz, E. H. Strickland, and C. Billups, *J. Amer. Chem. Soc.*, **91**, 184 (1969).

(12) F. D. Saeva, D. R. Rayner, and K. Mislow, *ibid.*, **90**, 4176 (1968).

(13) E. H. Erenrich, R. H. Andreatta, and H. A. Scheraga, *ibid.*, **92**, 1116 (1970).

(14) J. F. Yan, F. A. Momany, and H. A. Scheraga, *ibid.*, **92**, 1109 (1970).

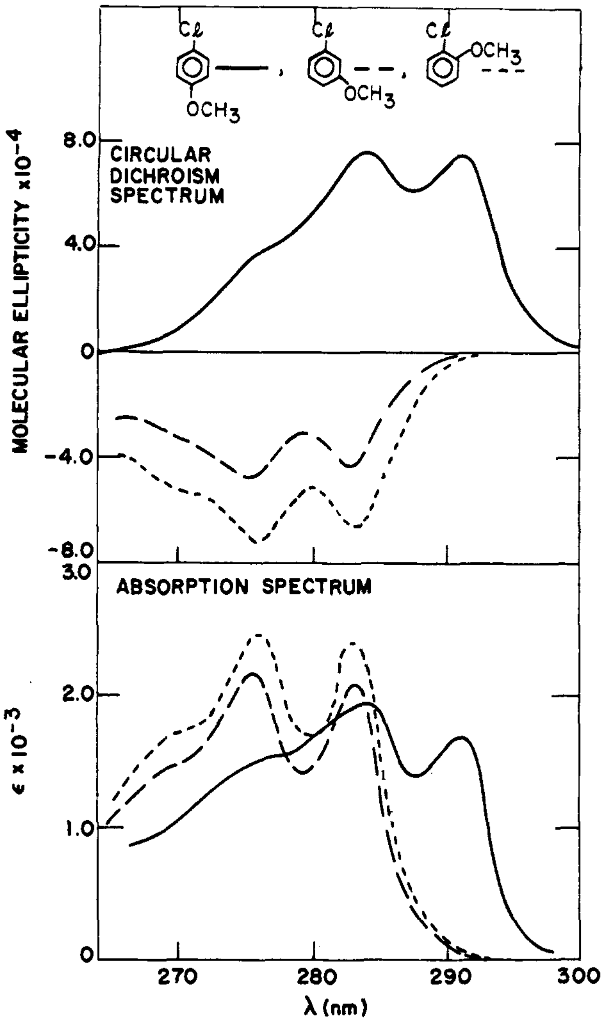


Figure 2. Circular dichroism and absorption spectra for *o*-, *m*-, and *p*-methoxychlorobenzene.

throughout the ^1L_b transition while the ortho and meta isomers show negative CD within this transition. Our first thought was to investigate the generality of this para effect as a function of substituent. Figure 2 presents the LCICD and absorption spectrum of ortho-, meta-, and para-substituted methoxychlorobenzenes. Again, at least within the ^1L_b electronic transition, the para isomer was shown to possess oppositely signed CD from its ortho and meta isomers. Table II summarizes the experimental results of LCICD and electronic absorption studies on a variety of disubstituted benzenes as a function of aromatic ring substitution. Phenyl ring substituent combinations of chloro–methoxy, chloro–methyl, methoxy–methoxy,[15] methoxy–methyl, methyl–methyl,[15] and chloro–chloro[15] show a correlation between the sign of the CD of the ^1L_b transition and the position of substitution. The ortho and meta isomers show negative CD bands while the para isomer shows positively signed bands. However, when the substituent combinations are hydroxy–methyl and chloro–cyano this correlation breaks down. Since MCD measurements on the meta and para isomers of xylene and dichlorobenzene[16] do not show a difference in CD sign between these isomers we believe

Table II. Liquid Crystal Induced Circular Dichroism (LCICD) Spectral Data for Some Disubstituted Benzenes, XC_6H_4Y

X	Y	$[\theta]^a$	λ, nm	ϵ^b	λ_0^c
Chloro	*o*-Methoxy	−66,110	283	2400	636
		−72,591	276	2464	
		−52,931	270^d	1729	
Chloro	*m*-Methoxy	−43,063	283	2071	637
		−46,994	276	2160	
		−32,967	269^d	1446	
Chloro	*p*-Methoxy	+75,062	291	1687	643
		+76,222	284	1936	
		+45,501	278^d	1594	
Chloro	*o*-Methyl	−17,382	274	475	600
		−16,663	267	475	
		−7,253	261	210	
Chloro	*m*-Methyl	−19,798	276	405	600
		−19,972	268	410	
		−9,986	261	197	
Chloro	*p*-Methyl	+4,117	278	201	630
		+3,572	272	182	
		+2,542	264	151	
Methoxy	*m*-Methoxy	−632,983	281	4785	603
		−670,774	274	5054	
		−510,166	270^d	4015	
Methoxy	*p*-Methoxy	+141,093	300^d	2642	609
		+181,737	290	3302	
Methoxy	*o*-Methyl	−85,214	279	2524	612
		−93,628	273	2693	
		−66,090	265^d	2012	
Methoxy	*m*-Methyl	−70,844	280	2435	599
		−72,660	274	2408	
		−46,321	266^d	1172	
Methoxy	*p*-Methyl	+35,375	287	1415	609
		+37,733	280	1538	
		+30,186	277	1415	
		+18,866	272	1160	
Hydroxy	*o*-Methyl	−107,809	281	2142	658
		−112,108	274	2334	
Hydroxy	*m*-Methyl	−88,267	281	1654	646
		−95,236	274	1822	
Hydroxy	*p*-Methyl	−10,286	290	2012	622
		−9,363	283	2441	
Chloro	*o*-Cyano	$-5,883^e$	288	1440	634
			279	1391	
			272	884	
Chloro	*m*-Cyano	+10,542	288	1010	630
		+8,167	280	1002	
		+3,341	273	705	
		+1,485	265	497	
Chloro	*p*-Cyano	+3,542	282	138	635
		+13,045	278	194	
		−23,671	270	290	
		−11,490	262	271	
Chloro	*m*-Chloro	−11,923	278	375	723
		−13,333	271	387	
		−8,157	263	280	
		−3,414	257	196	
Chloro	*p*-Chloro	+2,795	282	447	800
		+3,303	274	535	
		+2,910	266	407	
		+2,033	260	279	
		+2,056	253	210	
Methyl	*m*-Methyl	−5,777	273	317	651
		−3,278	269	276	
		−5,374	265	352	
		−2,866	259	276	
Methyl	*p*-Methyl	+3,099	275	633	637
		+2,095	269	558	
		+2,511	268	450	
		+1,765	266	517	
		+1,105	261	408	

[a] Molecular ellipticity [θ] is a function of wavelength, sample, solvent (matrix), temperature, pitch, and texture. [b] Molar absorptivities. [c] Reflective wavelength of the cholesteric matrix ($\lambda_0 = 2np$, where n = refractive index, p = pitch). [d] Shoulder. [e] Circular dichroism spectrum does not match absorption spectrum.

---

(15) Only the meta and para isomers were studied.

(16) D. J. Shieh, S. H. Lin, and H. Eyring, *J. Phys. Chem.*, 77, 1031 (1973).

the para effect is the result of a conformational variation between the para and ortho,meta isomers and not a spectroscopic one. From the previously proposed quadrant rule,[3] the orientation of the ^1L_b transition moment in the para isomers that exhibit the above effect is expected to lie perpendicular to the long molecular axis of the cholesteryl molecules, while the average direction of the ^1L_b transition in the ortho and meta isomers, on the other hand, is expected to lie parallel with the long molecular axis of the solvent molecules.

In general, large rotational strengths are again associated with the intensity of the transition and unusually high intensity LCICD is associated with the presence of methoxy groups.

Conclusion

LCICD studies on benzene and some of its substituted derivatives show both spectroscopic and conformational effects as a function of aromatic ring substitution. The signs of the CD within the ^1L_b electronic transition in monosubstituted benzenes show variations which depend on the electronic behavior (ortho-, para-, or meta-directing properties) of the substituent, similar to that found in MCD studies.[9] We have concluded that the change in LCICD sign as a function of aromatic ring substituent is a result of a spectroscopic change within the benzene electronic transitions and not a result of a conformational variation, as a function of substituent, in the liquid crystal.

The LCICD behaviors of some ortho-, meta-, and para-disubstituted benzene derivatives show an interesting trend where the para isomer possesses oppositely signed CD bands from the less symmetrical ortho and meta derivatives. We believe the latter phenomena to be a result of conformational variation between the isomers in a cholesteric mesophase of a single chirality.

Acknowledgment. Stimulating discussions with Drs. W. H. H. Gunther, G. Johnson, J. E. Kuder, H. Scheraga, and H. Erying are gratefully acknowledged.

D-Nor Steroids. VI. Stereochemical Effects on Carbonium Ion Reactions of C/D Cis D-Nor Steroids[1]

J. Meinwald* and A. J. Taggi

Contribution from the Department of Chemistry, Cornell University, Ithaca, New York 14850.
Received July 19, 1973

Abstract: An improved synthesis of 16-diazo-17-keto steroids, used for the preparation of C/D cis 16α- and 16β-substituted D-nor steroids, is described. The results of deamination and solvolysis reactions of these D-nor steroids in both the 16α and 16β series are presented. Product and rate studies indicate that *both* series behave as if the 16 substituent occupies a pseudoequatorial conformation. While this is expected for the 16α compounds, it can be rationalized for the 16β cases only by assuming that these compounds exist in an unusual conformation, in which ring C occurs as a boat. Severe nonbonded repulsions between a 16β substituent and nearby axial protons in the normal steroid conformation make this assumption plausible, and it is confirmed by X-ray crystallographic analysis. In this way, the anomalous behavior of these C/D cis D-nor steroids can be readily explained.

Carbonium ion reactions of cyclobutanes have been the subject of much investigation.[2] The C/D trans-fused D-nor steroids provide a series of compounds which have been especially appropriate for the examination of carbonium ion reactions of cyclobutanes of defined conformation.[3] In the present work, we describe the preparation, characterization, and chemical behavior of the corresponding C/D cis D-nor steroids, in which unanticipated conformational effects come into play.

Syntheses. The requisite 16-substituted C/D cis D-nor steroids were prepared *via* photochemical Wolff rearrangement[4,5] of the appropriate 16-diazo-17-keto steroid (**5**, Chart I), for which an improved preparation has been developed. Photochemical equilibration of dehydroisoandrosterone (**1**)[6] affords the C/D cis starting material **2**, from which the desired diazo ketone **5** was prepared. The usual route to such diazo ketones has been the chloramine oxidation of the corresponding oximino ketone,[5] and this sequence has been applied to **2** itself.[7] In our hands, however, only a low yield (*ca.* 25%) of **5** could be obtained, and in view of the difficulty in preparing the cis-fused starting material, a more efficient synthesis involving the "diazo transfer" technique[8,9] was developed. Formylation of **2** with sodium hydride and ethyl formate in dimethylformamide gave the 16-formyl-17-keto steroid, which exists largely as the enol **3**. Treatment of **3** with diethylamine in refluxing ethanol gave the enamine **4**, which reacted

---

(1) The partial support of this research by grants from the National Science Foundation and the Petroleum Research Fund, administered by the American Chemical Society, is acknowledged with pleasure.

(2) For a leading reference, see P. v. R. Schleyer and V. Buss, *J. Amer. Chem. Soc.*, **91**, 5880 (1969).

(3) J. Meinwald and T. N. Wheeler, *J. Amer. Chem. Soc.*, **92**, 1009 (1970).

(4) P. A. S. Smith, "Molecular Rearrangements," Vol. 1, P. DeMayo, Ed., Interscience, New York, N. Y., 1963.

(5) J. C. Mateos and O. Chao, *Bol. Inst. Quim. Univ. Nac. Auton. Mex.*, **13**, 3 (1961); M. P. Cava and E. Moroz, *J. Amer. Chem. Soc.*, **84**, 115 (1962); J. Meinwald, G. G. Curtis, and P. G. Gassman, *ibid.*, **84**, 116 (1962).

(6) A. Butenandt, A. Wolff, and P. Karlson, *Ber. Deut. Chem. Ges. B*, 74, 1308 (1941); A. Butenandt and L. Poshmann, *ibid.*, 77, 394 (1944).

(7) G. Muller, C. Huynh, and J. Mathieu, *Bull. Soc. Chim. Fr.*, 296 (1962).

(8) W. von E. Doering and C. DePuy, *J. Amer. Chem. Soc.*, **75**, 5955 (1953); M. Regitz, *Angew. Chem., Int. Ed. Engl.*, **6**, 733 (1967); M. Rosenberger, P. Yates, J. B. Hendrickson, and W. Wolf, *Tetrahedron Lett.*, 2285 (1964).

(9) J. B. Hendrickson and W. Wolf, *J. Org. Chem.*, **33**, 3610 (1968).