cyclohexane gave 96 mg of a solid having mp 118.0–121.5°; $[\alpha]^{25}_{578}$ +39.2°, $[\alpha]^{25}_{546}$ +45.3°, and $[\alpha]^{25}_{D}$ +37.4° (calcd) (*c* 1.07, methylene chloride). The remainder of the material was in the mother liquor. The residue had $[\alpha]^{25}_{578}$ −5.0°, $[\alpha]^{25}_{546}$ −5.9°, and $[\alpha]^{25}_{D}$ −4.7° (calcd) (*c* 2.8, methylene chloride).

Anal. Calcd for $C_{21}H_{27}Cl_2NPt$: C, 45.07; H, 4.86; Cl, 12.67; N, 2.50; Pt, 34.89. Found:[22] C, 45.13; H, 5.12; Cl, 12.79; N, 2.81; Pt, 34.54.

Liberation of the Olefin 1 from Partially Resolved Complex 8 with Sodium Cyanide. A solution of 88 mg (0.155 mmole) of partially resolved complex **8** having $[\alpha]^{25}_{578}$ +2.0°, $[\alpha]^{25}_{546}$ +2.3°, and $[\alpha]^{25}_{D}$ +1.9° (calcd) (*c* 1.76, methylene chloride) was shaken with a cold (0°) solution of 15% aqueous sodium cyanide.[3b] The product was worked up as described previously.[3b] The resulting olefin (29 mg, 104%) showed no optical activity in cyclohexane solution. Vpc analysis (10-ft × 0.25-in. 15% XF-1150, 160°) indicated the presence of a slight contamination of *cis*-olefin; the major component was identified as the *trans*-olefin **1** by vpc retention time, infrared spectrum, and mass spectrum.

Liberation of the Olefin 1 from Partially Resolved Complex with Triphenylphosphine. The apparatus used was that described previously.[3d] Partially resolved complex **8** (141 mg, 0.254 mmole) having $[\alpha]^{25}_{578}$ −1.2°, $[\alpha]^{25}_{546}$ −1.4°, and $[\alpha]^{25}_{D}$ −1.1° (calcd) (*c* 7.1, methylene chloride), was dissolved in 12.5 ml of acetic anhydride, and 152 mg (0.58 mmole) of triphenylphosphine was dissolved in 12.5 ml of acetic anhydride. The two solutions were added in equal quantities as described previously.[3d] The reaction mixture was filtered through Celite into a precooled flask and the pentane layer was washed as indicated.[3d] The rotation of the pentane layer was measured at −25.5°. There was no optical activity. Removal of the pentane at reduced pressure afforded 27 mg (65%) of the *trans*-olefin **1** which was identified by vpc retention time, infrared spectrum, and mass spectrum. Vpc analysis (10-ft × 0.25-in. 15% XF-1150, 160°) showed the presence of approximately 3% of *cis*-olefin.

Variable-Temperature Nuclear Magnetic Resonance Spectra of *trans*-Olefin 1. The nuclear magnetic resonance spectrum of *trans*-olefin **1** in carbon disulfide was measured at +47, +37, −13, −25, −37, and −58°. The nuclear magnetic resonance spectrum of olefin **1** in carbon tetrachloride was measured at +107, +71, +56, and +34°. The nuclear magnetic resonance spectrum of olefin **1** in a 1:1 mixture of deuteriochloroform and acetaldehyde was measured at +14, −57, −66, and −87°. There was no change in these spectra except at the lowest temperatures where the lines become somewhat broadened. The samples were very viscous at the lowest temperatures.

(22) The sample used for elemental analysis had $[\alpha]^{25}_{D}$ +37.4°.

Optical Properties of Hexahelicene[1]

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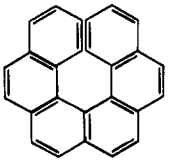
Abstract: The optical rotatory dispersion and circular dichroism spectra of (+)-hexahelicene were determined. Improvements in the synthesis are described.

Hexahelicene[3] (I) represents a classical example of an inherently dissymmetric chromophore, hence the optical properties of the resolved hexahelicene molecule can provide the basis for comparison of different theoretical treatments. To date, these analyses have restricted themselves to consideration of the sign and magnitude of the long-wavelength rotation.[4-6] However, the complexity of the problem is such that



I

these workers have not been able to agree on the chirality of (+)-hexahelicene. Since the preliminary optical rotatary dispersion measurement[7] we have further extended these measurements to shorter wavelengths and the determination of the circular dichroism. We wish to report these results and hope they will be of value for further theoretical analysis.

The ORD spectra have been determined in chloroform in order to allow comparison with earlier data and in methanol in order to extend the measurements to 210 mμ (Figure 1, Table II). The present chloroform curve is in good agreement with that obtained previously.[7] In the region above 250 mμ, except for small solvent shifts, the bands in both solvents are essentially identical; however, the strong negative Cotton effect associated with the 245-mμ band is clearly displayed in methanol solution. The CD and electronic absorption spectra in methanol are shown in Figure 2. The various bands in the CD can be correlated with absorption bands between 360 and 210 mμ. Interestingly of the CD bands, only the ones at 325 and 244 mμ follow approximately the CD–ORD relationship[8] derived for single transition

$$a = 0.0122 \times [\theta]$$

where a is the molecular amplitude of the ORD curve and $[\theta]$ is the molecular ellipticity of the CD curve (see Table I).

(1) The synthesis of a large amount of hexahelicene and its resolution was supported by a grant from the Petroleum Research Foundation.

(2) Author to whom inquiries may be addressed at The Ohio State University.

(3) A. Moscowitz, *Tetrahedron*, **13**, 48 (1961).

(4) D. D. Fitts and J. G. Kirkwood, *J. Am. Chem. Soc.*, 77, 4940 (1955).

(5) I. Tinoco and R. W. Woody, *J. Chem. Phys.*, **40**, 160 (1964).

(6) O. E. Weigang, Jr., J. A. Turner, and P. A. Trouard, *J. Chem. Phys.*, **45**, 1126 (1966).

(7) These data were referred to by Moscowitz in ref 3.

(8) P. Crabbe, "Optical Rotatory Dispersion and Circular Dichroism in Organic Chemistry," Holden-Day, Inc., San Francisco, Calif., 1965, p 19.

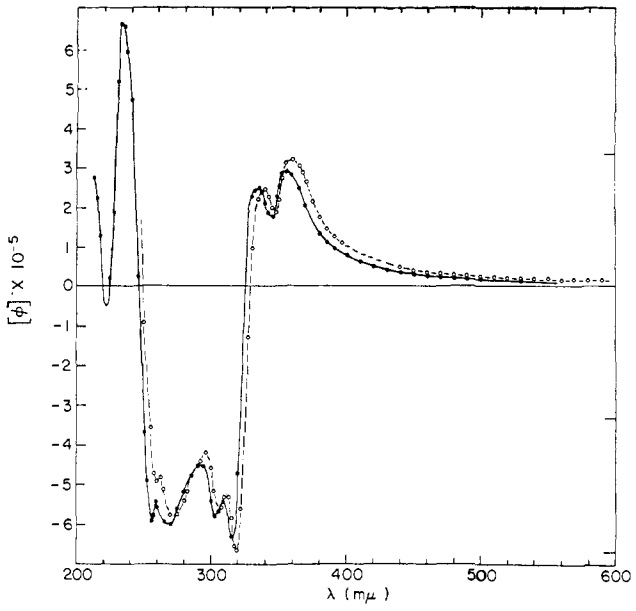


Figure 1. ORD of (+)-hexahelicene in chloroform, O, and in methanol, ●.

The CD spectrum in chloroform between 370 and 450 mμ (Figure 3) is interesting in that the bands at 413 and 397 mμ are opposite in sign. This suggests that these two bands are most likely part of two distinct electronic transitions. Although the 397-mμ band may be part of the succeeding transition that has a minimum at 325 mμ, it does not seem likely because

Table I

λ	*a*	[θ] calcd	[θ] obsd
325 mμ	$+8.621 \times 10^3$	$+7.07 \times 10^5$	$+6.47 \times 10^5$
244 mμ	-12.41×10^3	-1.016×10^6	-7.124×10^5

the separations between successive peaks surrounding the 325-mμ peaks (*viz.*, 348, 325, 305, and 293 mμ) are of the order of 1400–2000 wave numbers whereas the separation between the peaks at 397 and 348 mμ is about 3500 wave numbers. This observation casts some doubt as to the correctness of the previous assignments of these bands.[6]

Experimental Section

Hexahelicene was prepared essentially as described[3] except for the improvement in certain steps as described below. The Roman numerals used in the original article[3] are used here also.

The conversion of the dimesyl derivative of 2,2-di-1-naphthyl-1,3-propanediol (IV) to 3-[di-(1-naphthyl)methyl]glutaronitrile on a large scale was accomplished as follows. A solution of 200 g of the dimesyl derivative in 1.5 l. of dimethylformamide was added during 2 hr to a solution of 150 g of potassium cyanide and 5 g of potassium iodide in 1 l. of water held at 80°. After 1 hr more at 80° the solution was cooled to 25° and poured into 8 l. of water. The pale brown solid was collected and recrystallized from benzene–Skellysolve B (petroleum ether, bp 65–70°) to yield 124.5 g (86%) of dinitrile, mp 156–158°.

Anal. Calcd for $C_{26}H_{20}N_2$: C, 86.6; H, 5.6; N, 7.8. Found: C, 86.9; H, 5.7; N, 7.8.

On hydrolysis essentially as described[3] this nitrile was converted into the diacid VI in high yield.

1,2,3,4-Tetrahydro-4-(1-naphthyl)-1-oxo-3-phenanthreneacetic Acid (VII). To 30 g (0.075 mole) of 3-[di-(1-naphthyl)methyl]-glutaric acid was added 150 ml of anhydrous hydrogen fluoride.

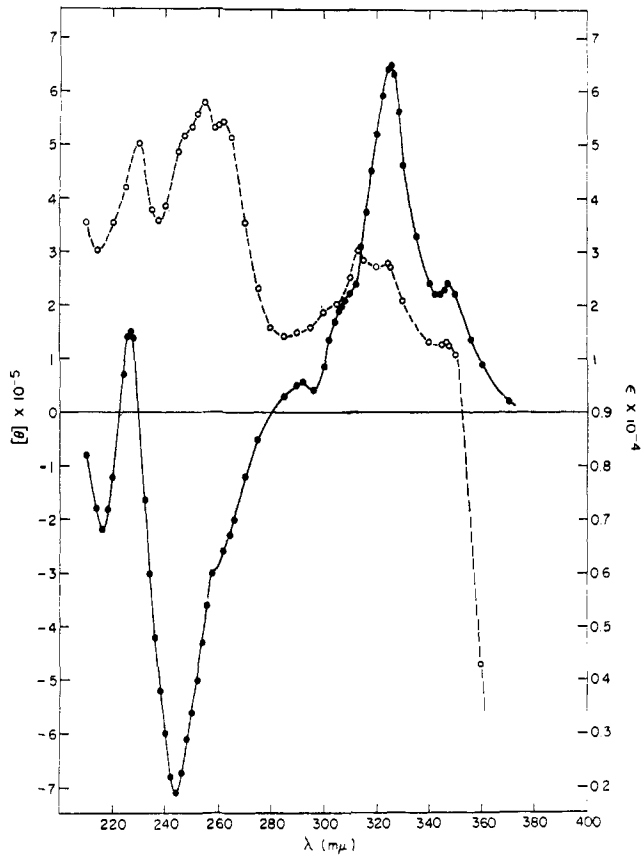


Figure 2. CD, ●, and ultraviolet, O, spectra of (+)-hexahelicene in methanol.

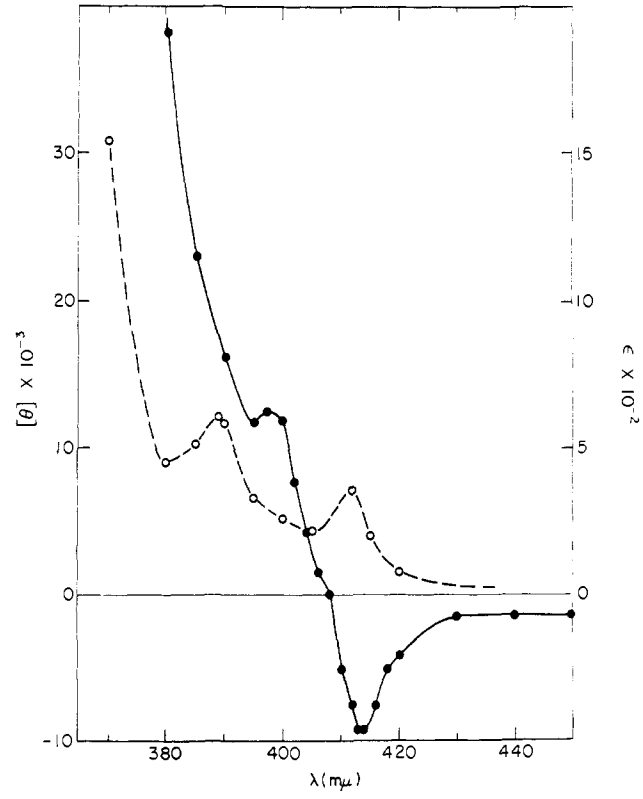


Figure 3. CD, ●, and absorption, O, spectra of (+)-hexahelicene in chloroform.

The homogeneous solution was allowed to stand overnight with gradual evaporation of hydrogen fluoride. The dark brown solid was dissolved in 1 l. of 5% potassium hydroxide. This solution

was extracted several times with an ether–benzene mixture to remove the neutral fraction. The alkaline solution was acidified to yield acid which was recrystallized from benzene–Skellysolve B to yield pure VII, mp 265–267°, in 83% yield.

7,8,8a,9,10,16c-Hexahydro-7-oxohexahelicene (IX). To 1 l. of dry benzene were added 50 g (0.137 mole) of 1,2,3,4-tetrahydro-4-(1-naphthyl)-3-phenanthreneacetic acid (VIII) and 30 g (0.144 mole) of phosphorus pentachloride. The mixture was refluxed for 1 hr followed by removal of benzene and phosphorus oxychloride under reduced pressure. The light yellow solid was taken up in 600 ml of dry *o*-dichlorobenzene followed by the addition of 32 ml (0.275 mole) of stannic chloride while the temperature was maintained near zero. The solution was heated to 60° for 0.5 hr and then poured into dilute hydrochloric acid. The reaction mixture was worked up in the usual manner.

Acidification of the alkaline washes yielded 6.1 g of the starting acid. The neutral extracts, after steam distillation, yielded upon recrystallization from benzene–Skellysolve B 40.4 g (85%) of IX, mp 216–220°.

Hexahelicene (I). A solution of 20.6 g (0.0615 mole) of hexahydrohexahelicene (X) in 300 ml of thiophene-free benzene in the presence of 25 g of 5% rhodium on alumina and under nitrogen was heated to 300° in a Pyrex-lined, high-pressure cylinder for 12 hr. Filtration followed by washing the spent catalyst several times with benzene resulted in about 1 l. of a dark greenish black solution. The benzene was removed under reduced pressure and the solid was recrystallized from benzene–Skellysolve B to give a brown-yellow solid. Purification was achieved by chromatography on alumina to yield 15.9 g (79%) of hexahelicene, mp 225–226°. Further purification over alumina gave a sample that melted at 238–240°.

A picrate of hexahelicene was made by adding a saturated solution of picric acid in chlorobenzene to a solution of hexahelicene in chlorobenzene. The resulting deep red solution was concentrated to two-thirds volume under reduced pressure and allowed to stand. Deep red crystals were obtained which were washed with ethanol and recrystallized three times from chlorobenzene. The picrate melted at 196–197° dec.

Anal. Calcd for $C_{32}H_{19}N_3O_7$: C, 68.9; H, 3.4; N, 7.53. Found: C, 68.9; H, 3.6; N, 7.5.

The resolution was accomplished as before.[3] The sample of (+)-hexahelicene used for the optical measurements had mp 270° and $[\alpha]^{25}D$ +3750 ± 200° (*c* 5.4 × 10^{-3}, chloroform).

The ORD, CD, and absorption spectra were obtained on Cary 60, Jasco, and Cary 14M spectrometer, respectively. The ORD and CD data are presented in Table II.

Table II. ORD and CD Data of (+)-Hexahelicene at 25–26°

ORD				CD	
$CHCl_3$, *c* 1.645 × 10^{-4} *M*		CH_3OH, *c* 1.645 × 10^{-5} *M*		CH_3OH, *c* 1.645 × 10^{-5} *M*	
λ, mμ	$[\phi] \times 10^{-4}$	λ, mμ	$[\phi] \times 10^{-4}$	λ, mμ	$[\theta] \times 10^{-4}$
359	31.36	355.5	28.40	413.5	−0.93[a]
347	18.16	345	17.46	406	0.15[a,b]
339.5	23.91	335	24.14	397	1.24[a]
318.5	−65.67	315	−62.38	395	1.18[a]
312	−51.50	309	−53.04	347	24.08
306	−55.90	302.5	−56.85	343	22.57
296	−41.71	293.5	−43.74	325	64.70
286.3	−46.60	...	...	312	24.08[b]
272	−57.15	270	−59.43	304	17.06[b]
262	−47.29	259.5	−53.92	296	4.01
259.8	−48.64	255.5	−58.46	292	5.52
247.5	17.01			262	−26.08[b]
		232.5	65.68	260	−29.09
		222.5	−4.86	244	−7.12
		212.5	26.77	227	15.05
				216	−22.07
				210	−8.02

[a] In $CHCl_3$, *c* 1.555 × 10^{-4} *M*. [b] Shoulder.

Acknowledgment. The authors are grateful to Dr. Elliot Charney for helpful discussion concerning the circular dichroism features.

Conformations of Cyclic Peptides. The Folding of Cyclic Dipeptides Containing an Aromatic Side Chain

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Abstract: Proton magnetic resonances of a number of cyclic dipeptides, with and without an aromatic amino acid residue, were measured; solutions in trifluoroacetic acid, dimethyl sulfoxide-d_6, and deuterium oxide were used. Resonances of the α and β protons of the nonaromatic residue in compounds containing an aromatic side chain were found to be shifted to higher field. This shift suggests that the preferred conformation of the arylmethyl side chain is one in which the aromatic ring faces the dipeptide (diketopiperazine) ring. In three cases the thermodynamic parameters of the aromatic–diketopiperazine interaction that stabilizes this folded conformation were obtained; these were found not to be significantly dependent on solvent. The folded form is favored over other possible conformations of the arylmethyl side chain by an enthalpy change averaging −3 kcal/mole; this results from a direct, rather than solvent-mediated, interaction between the two rings.

The folding of peptide chains is determined by nonbonded interactions among the side chains of amino acid residues and by the geometry of covalent and hydrogen bonds. In principle, peptide folding could be completely determined for each case by X-ray crystallographic analysis, but it is unlikely that this will or can be done for any peptide or protein that may chance to be of interest. It is valuable, then, to explore the nature and magnitude of the forces determining side-chain position in peptides, in order to enhance the probability that an *a priori* estimate of secondary or tertiary structure approximates actuality.

For oligopeptides, in which individual nonbonded interactions can be examined with least ambiguity, it is particularly important to examine conformation directly in solution. The environment of most of a small