Absolute Asymmetric Synthesis. III.[1,2] Hindered Rotation about Aryl–Ethylene Bonds in the Excited States of Diaryl Ethylenes. Structural Effects on the Asymmetric Synthesis of 2- and 4-Substituted Hexahelicenes

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Abstract: The optical yield in the asymmetric synthesis of 2- and 4-substituted hexahelicenes from irradiation of para- and ortho-substituted 1-phenyl-2-(2-benzo[*c*]phenanthryl)ethylenes (1-4 precursors) with circularly polarized light was found to be markedly dependent on the position and nature of the substituent. The optical yield in the asymmetric synthesis of heptahelicene from 1-(2-naphthyl)-2-(2-benzo[*c*]phenanthryl)ethylene (2-4) and 1,2-bis(3-phenanthryl)ethylene (3-3) were observed to be almost equal. The wavelength dependence of the optical yield of heptahelicene from the 2-4 precursor was examined. These results are in agreement with a mechanism in which the asymmetric synthesis of helicenes with circularly polarized light is due to selective excitation of the enantiomeric conformers of the *cis*-diarylethylene enantiomers, which stereospecifically lead to helicenes. The dependence of the optical yield on the substitution pattern in the 1-4 hexahelicene precursors is believed to be related to the rate of rotation about the phenyl–ethylene bond in their excited states.

In a previous paper[1a] we reported the asymmetric synthesis of hexa-, hepta-, octa-, and nonahelicene (VI–IX) from irradiation with circularly polarized light (CPL) of the corresponding diaryl olefins (I–IV, or 1-4 to 4-4) (Figure 1).[4a] The optical yield was shown to be dependent on the type of precursor used, *i.e.*, 1-4 *vs.* 2-3 etc., and on the wavelength of light employed. Also, it was unambiguously demonstrated that the induced optical activity could not be due to asymmetric destruction of the helicenes.

We have analyzed the various possibilities for inducing optical activity photochemically with circularly polarized light, and come to the conclusion that the asymmetric synthesis of helicene is due to selective excitation of the enantiomers of the parent olefins.[4b]

Furthermore, we are now able to assign absolute configurations to the enantiomeric forms of *cis*-1-phenyl-2-(2-benzo[*c*]phenanthryl)ethylene (Figure 2), which is the precursor of hexahelicene. Since Lightner, *et al.*,[5] have determined the absolute configuration of 2-bromohexahelicene and hexahelicene it can be seen that *cis*-1-phenyl-2-(2-benzo[*c*]phenanthryl)ethylene of right-handed helical (P)[6] configuration has a *positive* CD at 370 nm, as demonstrated by the fact that irradiation of the olefin at this wavelength with left circularly polarized light (LCL) gives a preponderance of (+)-hexahelicene. Since the latter has a right-handed helical configuration, the enantiomer of *cis*-Ia with a positive CD at 370 nm must have a similar configuration.

It appeared striking that irradiation of the 1-4 precursor (Ia) yields hexahelicene in a much lower optical yield than that found with the 2-3 precursor (Ib).[1a,2a,b] *A priori* this could be explained in two different ways.

(1) Rotation of the aryl–ethylene bonds in the lowest excited singlet (S_1) state of the diaryl olefin, from which the reaction presumably takes place, requires very little energy at the temperatures employed and is thus very rapid. Such rotation about the phenyl–ethylene bond in *cis*-1-4 interchanges its enantiomeric forms, whereas this is not the case for *cis*-2-3 (Figure 2).

(2) The difference in optical yields from 1-4 and 2-3 reflects the differences in the optical anisotropy factors (*g* values) of the precursors in the wavelength region employed for irradiation.

In order to distinguish between the two hypotheses we irradiated some ortho- and para-substituted derivatives of 1-4 (Ia) with CPL. With ortho-substituted 1-4 precursors, ~180° rotation about the phenyl–ethylene bond no longer racemizes the conformers of the helicene precursors (Figure 3).

By examining Figure 3 it is furthermore seen that (1) Closure to the helicene can only occur from the exo conformation.

(2) Rotation of ~180° around the phenyl–ethylene bond interchanges the M-endo form with the P-exo, and the P-endo form with the M-exo.

(3) Assuming that the substituent does not contribute significantly to the electronic structure of the molecule,

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[1] (a) For previous papers in this series, see W. J. Bernstein, M. Calvin, and O. Buchardt, *J. Amer. Chem. Soc.*, **94**, 494 (1972); (b) W. J. Bernstein, M. Calvin, and O. Buchardt, *Tetrahedron Lett.*, 2195 (1972).

[2] (a) See also A. Moradpour, J. F. Nicoud, G. Balavoine, H. Kagan, and G. Tsoucaris, *J. Amer. Chem. Soc.*, **93**, 2353 (1971); (b) G. Tsoucaris, G. Balavoine, A, Moradpour, J. F. Nicoud, and H. Kagan, *C. R. Acad. Sci., Ser. B*, **272**, 1271 (1971); (c) H. Kagan, A. Moradpour, J. F. Nicoud, G. Balavoine, R. H. Martin, and J. P. Cosyn, *Tetrahedron Lett.*, 2479 (1971).

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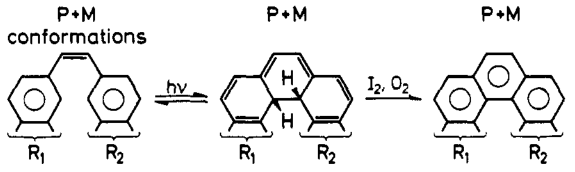
[4] (a) The first chemical step in all these helicene syntheses is formation of the dihydrohelicenes, which, however, are oxidized so fast under the reaction conditions that the reverse reaction can be neglected; *cf.* ref 13. (b) A mechanism involving "partial photoresolution" of the intermediate dihydrohelicenes was also discussed, but excluded.[1]

[5] D. A. Lightner, D. T. Helefinger, T. W. Powers, G. W. Frank, and K. N. Trueblood, *J. Amer. Chem. Soc.*, **94**, 3492 (1972).

[6] "P" and "M" denote right- and left-handed helical conformations, respectively; see R. S. Cahn, C. K. Ingold, and V. Prelog, *Angew. Chem., Int. Ed. Engl.*, **5**, 385 (1966).



diarylolefin	R_1	R_2	helicene
1-4 (Ia)	2H	3,4-phenanthrylene	hexa-
2-3 (Ib)	phenylene	1,2-naphthylene	hexa-
2-4 (IIa)	phenylene	3,4 phenanthrylene	hepta-
3-3 (IIb)	1,2-naphthylene	1,2-naphthylene	hepta-
3-4 (III)	1,2-naphthylene	3 4 phenanthrylene	octa-
4-4 (IV)	3,4-phenanthrylene	3,4-phenanthrylene	nona-

Figure 1.

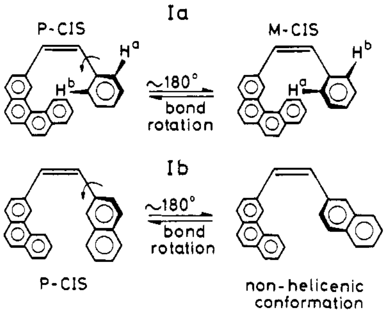


Figure 2.

it is seen that the endo and exo forms will have nearly the same circular dichroism and absorption spectra as those of the unsubstituted compound.

(4) The endo:exo ratio will be dependent upon the substitution, temperature, and solvent.

(5) If the helicene precursors exist only in the exo conformation in the ground state, rotation around the phenyl–ethylene bond in the excited state will no longer lead to a decrease in the optical yield for helicene formation. Thus, if the difference in optical yield[7] for hexahelicene formation from 1-4 (Ia) and 2-3 (Ib) is indeed due to rapid rotation around the phenyl–ethylene bond in 1-4, this difference should disappear upon ortho substitution in the phenyl group of 1-4. On the other hand, if the observed difference is due to a difference in CD between 1-4 and 2-3, substitution in the ortho position should have little or no effect.

(6) If conditions are such that the endo conformation predominates in the ground state it is seen that the excited molecule must rotate into the exo conformation of the opposite chirality before closure can occur. Thus, irradiation with circularly polarized light will induce long wavelength optical activity in *the opposite direction of that observed for compounds I–IV.*[1,2]

(7) Using the same argument, it is predicted that a 50:50 mixture of the endo and exo forms will lead upon irradiation with CPL to racemic helicene.[8]

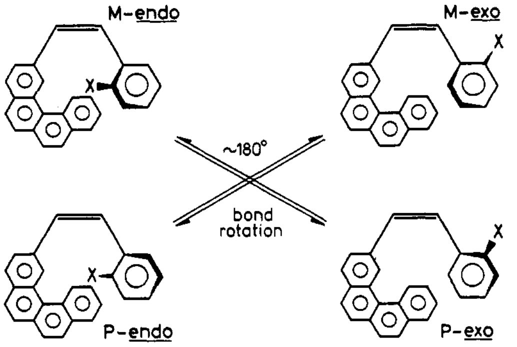


Figure 3.

(8) In order to reveal any electronic factors associated with such substitution, irradiations with CPL should also be performed on the corresponding para-substituted compound.

Thus, the discovery of optical yields for ortho-substituted derivatives of Ia that are significantly greater than the yield found for Ia would provide good evidence for the hypothesis of bond rotation in the excited state.

The possibility that the difference in optical yield from the ring closure of the 1-4 (Ia) and 2-3 (Ib) hexahelicene precursors was due to a difference in their *g* values[9] could be tested further by obtaining optical yields for the production of heptahelicene from the 2-4 precursor (IIa) and the 3-3 precursor (IIb). The electronic relationship between IIa and IIb is similar to that between Ia and Ib, *i.e.*, IIb is more symmetric than IIa, just as Ib is more symmetric than Ia. Thus, the more symmetric of the two latter heptahelicene precursors would be expected to have a higher circular dichroism.[10]

Results and Discussion

The 1-4 hexahelicene precursors substituted with F, Cl, Br, and methyl in the 2- and 4-positions of the phenyl ring were synthesized by the Siegrist[11] and Wittig[1a] methods from the appropriately substituted benzaldehydes.[12] The trans isomers were used for irradiation.

Dihydrohelicene formation can only take place from the cis forms of the diaryl ethylenes and, by analogy with the results from the stilbenes,[13] from the first singlet excited state (cis S_1). However, intersystem crossing from either cis S_1 or trans S_1 to the first triplet state (T_1) also takes place. The triplet relaxes to a mixture of the cis and the trans ground states.[14] In the simple stilbenes as well as in our experiments, in the absence of added triplet quenchers, cis–trans photo-

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(7) The optical yield is defined as

$$([\alpha]_{\text{product}}/[\alpha]_{\text{pure enantiomer}}) \times 100\%$$

D. R. Boyd and M. A. McKorvey, *Quart. Rev. Chem. Soc.*, 95 (1968).

(8) In fact compound Ia presents such a situation, where the ortho substituent is hydrogen, and the exo and endo conformations are present in equal amounts. However, ring closure may take place from both the "*endo*" and "*exo*" forms in this case.

(9) The anisotropy factor $g = \Delta\epsilon/\epsilon$, *i.e.*, for the *d* form $g = [\epsilon_L(d) - \epsilon_R(d)]/\{[\epsilon_L(d) + \epsilon_R(d)]/2\}$, where $\Delta\epsilon$ is the usual measure of CD and, *e.g.*, $\epsilon_L(d)$ is the extinction coefficient of a *d* enantiomer for LCL, etc. Since $\epsilon_R(d) = \epsilon_L(l)$, $g = [\epsilon_L(d) - \epsilon_L(l)]/\{[\epsilon_L(d) + \epsilon_L(l)]/2\}$. Consequently *g* is the fraction of one enantiomer which will be excited more than the other.

(10) In the S_1 state of the diaryl olefins, the degree of interaction between the two aryl groups will increase as the gap between their individual S_1 energies decreases. Such an increase in interaction between the chirally oriented groups will result in a more "chiral" $S_0 \rightarrow S_1$ transition, producing a higher CD.

(11) A. E. Siegrist, P. Liechti, M. R. Mezer, and E. Weber, *Helv. Chim. Acta*, **52**, 2521 (1969).

(12) The compounds are called, *e.g.*, 1-(2-fluorophenyl)-2-(2-benzo[c]phenanthryl)ethylene = *o*-F-Ia, etc., or for the 4-fluorophenyl isomer, *p*-F-Ia.

(13) K. A. Muszkat and E. Fischer, *J. Chem. Soc. B*, 662 (1967).

(14) G. S. Hammond, J. Saltiel, A. A. Lamola, N. J. Turro, J. S. Bradshaw, D. O. Cowan, R. C. Counsell, V. Vogt, and C. Dalton, *J. Amer. Chem. Soc.*, **86**, 3197 (1964).

Table I

mg of starting material[a]	Product hexahelicene	$[\alpha]^{20}_{436}$, deg, in $CHCl_3$ with LCL (concn)[b]	RCL (concn)[b]	Optical yield,[c] %	Irradiation period,[d] hr
7.5 Ia	Unsubst	7.6 ± 0.9 (0.566)	−8.0 ± 0.8 (0.591)	0.06	24
7.5 *p*-F-Ia	2-Fluoro-	10.7 ± 0.9 (0.535)	−10.5 ± 0.9 (0.554)	0.08	24
7.5 *p*-Cl-Ia	2-Chloro-	15.8 ± 0.8 (0.653)	−16.4 ± 0.8 (0.660)	0.12	24
6.0 *p*-Br-Ia	2-Bromo-	23.2 ± 0.9 (0.590)	−23.8 ± 0.9 (0.585)	0.17	24
7.5 *p*-Me-Ia	2-Methyl-	37.5 ± 1.1 (0.468)	−36.4 ± 1.0 (0.503)	0.26	36
7.5 *o*-F-Ia	4-Fluoro-	34.0 ± 1.3 (0.382)	−31.5 ± 1.2 (0.410)	0.23	36
7.5 *o*-Cl-Ia	4-Chloro-	46.9 ± 2.0 (0.255)	−45.8 ± 1.4 (0.367)	0.33	72
6.0 *o*-Br-Ia	4-Bromo-	34.2 ± 2.4 (0.211)	−38.7 ± 1.4 (0.349)	0.26	68
7.5 *o*-Me-Ia	4-Methyl-	35.9 ± 1.1 (0.442)	−35.6 ± 1.0 (0.508)	0.26	24

[a] The starting material in each case consisted of the pure trans olefin. [b] In g/100 ml. [c] Rotations of the substituted hexahelicenes assumed equal to hexahelicene; *cf.* ref 5. [d] 89% circularly polarized light.

equilibration is a much faster process than ring closure.[13] Thus, it does not matter whether the starting material is the cis or trans olefin, or a mixture of the two.

Preparative irradiations with unpolarized light of the substituted precursors were undertaken in order to obtain the 2- and 4-substituted hexahelicenes in sufficient amounts for identification (Tables V and VI).

The hexahelicene precursors and the substituted hexahelicenes were identified on the basis of single and double focusing mass spectrometry and uv spectroscopy (Tables III–VI). The uv spectra of all of the substituted hexahelicenes are virtually identical to the spectrum of hexahelicene itself. The method of preparation, taken together with the asymmetric synthesis described below, is regarded as unambiguous structural proof.

None of the new hexahelicenes except 2-bromohexahelicene has yet been totally resolved. However it was, *a priori*, expected that they would have nearly the same uv, ORD, and CD spectra as hexahelicene itself. Substituents such as those employed should affect the electronic structures of the ground state and the low-lying excited states to only a small extent as seen from their almost identical uv spectra (Table VI). Since the asymmetry is almost entirely due to the inherently dissymmetric helicene chromophore, it is similarly reasonable to expect a likeness in ORD and CD. Indeed Lightner, *et al.*, have found that partially resolved 2-bromohexahelicene with $[\alpha]^{20}_{589}$ −444° is converted to hexahelicene with $[\alpha]^{20}_{589}$ −420° by reduction with butyllithium in hexane.[5]

The irradiation of the hexahelicene and heptahelicene precursors was undertaken with both RCL and LCL at 370 nm. Furthermore, the heptahelicene precursor was irradiated with LCL and RCL at 310, 335, and 400 nm (Figure 4) (total dispersion = 12.2 nm). Toluene was used as solvent in all irradiations, and small amounts of iodine were added as oxidizer for the helicene generation step. The analysis for optical activity of the hexahelicenes was done with polarimetry, that of heptahelicene with CD. These results are presented in Tables I and II.

From Table I it is seen that *o*-F-Ia gives a much higher yield than *p*-F-Ia and Ia itself. This is in excellent correspondence with the proposed model according to which the 1-4-hexahelicene precursors (Ia) are able to undergo rotation around the aryl–ethylene bond in the excited state.

All of the ortho-substituted 1-4-hexahelicene precursors give *ca.* five times larger optical yields than the unsubstituted 1-4 precursor.[15] It is also seen that as the size of the *p*-phenyl substituent increases, an increasing optical yield is observed, indicating an increased hindrance to rotation about the phenyl–ethylene bond in the excited state. Examination of molecular models of para-substituted 1-4 shows steric interaction between the hydrogen atom in the 11 position of the benzo[c]phenanthryl group and the para substituent of the phenyl group in the transition state for racemization (see Figure 4).

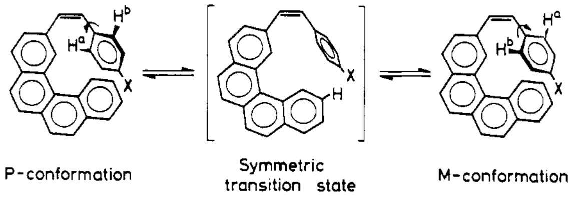

Figure 4.

Table II

Starting material	Time irradiated, hr	Wavelength irradiated,[b] nm	Relative optical yield[a] of heptahelicene with LCL, ±0.06%	RCL, ±0.06%
IIa	24	400	1.26	−1.29
IIa	4	370	0.76	−0.74
IIa	24	335	0.47	−0.47
IIa	12	310	0.11	−0.11
IIb	24	370	0.62	−0.57

[a] Based on $g = \Delta\epsilon/\epsilon = 0.01$ in the long wavelength ($\lambda > 370$ nm) region for fully resolved heptahelicene. [b] 89% circularly polarized light.

Table II and Figure 5 describe our results with the two heptahelicene precursors. From the table it is seen that the optical yield from the 3-3 precursor (IIb) is smaller than that from the 2-4 precursor (IIa). Thus a more symmetric precursor does not necessarily give the corresponding helicene in higher optical yield than a less symmetrical one.[16]

(15) We cannot at the present time offer any explanation for the slightly higher yield observed in the case of the 4-chlorohexahelicene.

(16) It may be argued that the optical yield from IIb could be much larger at other wavelengths. However, the wavelength studies on both IIa and III show that the highest optical yields are obtained with light in the long wavelength region of the absorption spectra of the *cis*-diarylethylenes (Figure 6). Since IIb, like IIa and III, could not be converted to the helicene at wavelengths longer than 400 nm, it would be expected to show the same wavelength dependence. Unfortunately, the excessively slow rate of photoclosure of IIb prevented wavelength studies of this compound with the present experimental setup.

Table III

Product olefin	Method used	Wt, and aldehyde used	Plc no. of developments, solvent system	Recrystallization solvent	Yield, mg (%)	Mp, °C
trans-p-Br-Ia	A	159 mg, 4-bromobenzaldehyde		C_6H_6–pet ether	84 (24)	160–160.5
trans-o-Br-Ia	B	159 mg, 2-bromobenzaldehyde	7 times, pet ether	2 times, EtOH–H_2O	60 (17)	108–110
trans-p-Cl-Ia	B	120 mg, 4-chlorobenzaldehyde	5 times, 9:1 pet ether:benzene	EtOH–H_2O	65 (21)	143–144
trans-o-Cl-Ia	B	120 mg, 2-chlorobenzaldehyde	5 times, pet ether	EtOH–H_2O	49 (16)	102–104
trans-p-F-Ia	C	4-fluorobenzaldehyde	3 times, 9:1 pet ether:benzene	EtOH–H_2O	88 (31)	136–137
trans-o-F-Ia	C	2-fluorobenzaldehyde	3 times, 9:1 pet ether:benzene	EtOH–H_2O	85 (30)	101–102
cis-o-F-Ia	A	106 mg, 2-fluorobenzaldehyde		Pet ether	43 (14)	75–76
trans-o-F-Ia	A			EtOH–H_2O	60 (20)	101–102
trans-p-Me-Ia	B	103 mg, 4-methylbenzaldehyde	5 times, pet ether	EtOH–H_2O	52 (18)	114–116
trans-o-Me-Ia	B	103 mg, 2-methylbenzaldehyde	12 times, pet ether	EtOH–H_2O	55 (19)	86.5–88

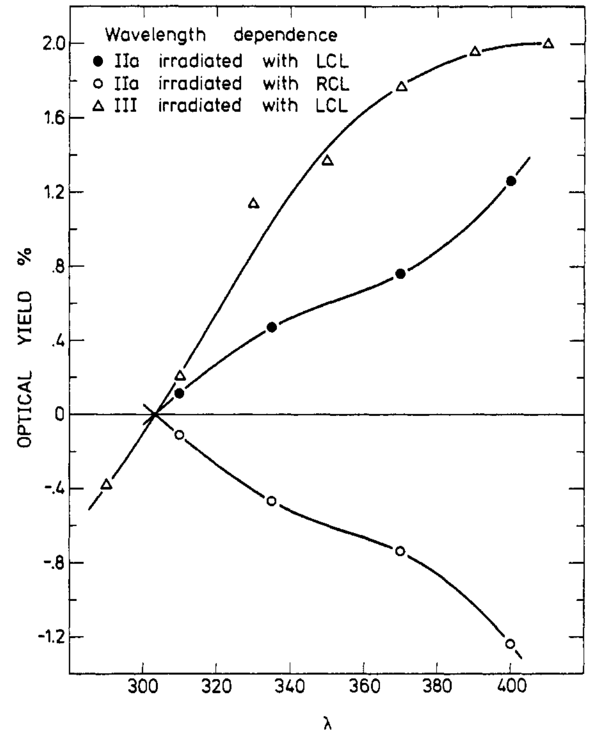

Figure 5. Optical yields as a function of wavelength using 370-nm light.

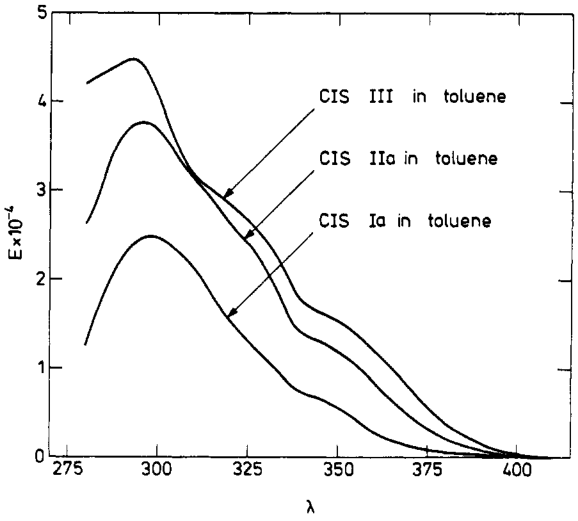

Figure 6. Uv spectra of cis helicene precursors.

Conclusion

The above results strongly corroborate the hypothesis that the asymmetric synthesis of helicene with CPL is due to the selective excitation of enantiomeric conformations of the *cis*-diarylethylene substrates, and that rotation around the phenyl–ethylene bond of *cis*-1-4 in the excited state takes place approximately five times as fast as ring closure. Furthermore, the data indicate that this rotation may be hindered by substitution in the para position of the phenyl group.

Finally, it should be noted that the absolute configurations of the hexahelicene precursors can now be assigned.

Experimental Section

Absorption spectra were obtained with a Cary 14, a Unicam SP 1800 or a Unicam SP 800 spectrophotometer. Optical rotations were measured with a Perkin-Elmer 141 polarimeter. CD spectra were obtained with a Roussel–Jouan Model CD 185 dichrograph. Mass spectra were recorded on an A. E. I. Model M.S. 9.

The starting materials for synthesis were all "reagent" quality. Solvents for all irradiations, uv spectroscopy, and measurements of optical activity were all "spectrograde" quality. Melting points are uncorrected.

Diary Ethylenes. The new hexahelicene precursors were prepared by one of the following three methods. The method used, melting points, and yields are summarized in Table III, and the double focusing mass spectral data and uv data are recorded in Table IV.

Method A. 2-Benzo[*c*]phenanthrylmethyltriphenylphosphonium bromide[1a] (500 mg, 0.86 mmol) and an equimolar amount of the appropriately substituted benzaldehyde were mixed with 1 *N* lithium methoxide in methanol (4.0 ml), and the mixture left for 12 hr at room temperature. The residue was isolated and dissolved in benzene (5 ml). This solution was chromatographed on a short column of neutral aluminum oxide. The chromatography was followed by uv spectrophotometry. Elution with petroleum ether gave 2-methylbenzo[*c*]phenanthrene. This was followed by elution with mixtures of petroleum ether–benzene, gradually increasing the amount of benzene. The next fraction contained the cis olefin and the final fraction the trans olefin.

Table IV

Olefin	m/e, parent molecular ion (by double focus MS) Found	Calcd	Uv λ_{max} (nm), log ϵ ($HCCl_3$)
trans-p- Br-Ia	408.0522 410.0475	408.0514 410.0494	365, 4.42; 350, 4.50; 315, 4.60; 275, 4.54
trans-p- Br-Ia	408.0522 410.0556	408.0514 410.0494	349, 4.35; 312, 4.53; 273, 4.44
trans-p- Cl-Ia	364.1008 366.0991	364.1029 366.0989	363, 4.41; 348, 4.49; 313, 4.60; 274, 4.54
trans-o- Cl-Ia	364.1008 366.0991	364.1029 366.0989	349, 4.40; 313, 4.58; 273, 4.49
trans-p- F-Ia	348.1250	348.1236	360, 4.36; 344, 4.41; 312, 4.58; 271, 4.48
trans-o- F-Ia	348.1250	348.1236	359, 4.35; 345, 4.42; 314, 4.57; 271, 4.48
cis-o- F-Ia	348.1250	348.1236	299, 4.58
trans-p- Me-Ia	344.1580	344.1565	364, 4.39; 348, 4.47; 315, 4.58; 274, 4.48
trans-o- Me-Ia	344.1571	344.1565	348, 4.30; 312, 4.70; 273, 4.59
trans-Ia			360, 4.56; 344, 4.63; 312, 4.78; 272, 4.70
cis-Ia			299, 4.39

Method B. The synthesis procedure was identical to that of method A except that the residue was dissolved in 3 ml of benzene and separated by preparative layer chromatography on 20 × 100 cm plates coated with a 2.5-mm layer of silica gel (Merck $Pl_{254+377}$). The plates were developed with petroleum ether or petroleum ether–benzene mixtures. Two bands appeared, but only the one with the shorter rf was scraped off and extracted in a Soxhlet apparatus to give the pure trans isomer.

Method C.[11] The appropriately substituted benzaldehyde (~100 mg) and excess aniline in ethanol were mixed and kept at room temperature for 2 hr. After this the solvent and excess aniline were removed *in vacuo*. The residue (200 mg), 2-methylbenzo[*c*]-phenanthrene[1a] (200 mg), and freshly prepared potassium *tert*-butoxide (200 mg) in dimethylformamide (5 ml) were stirred at 90° for 1 hr. After this benzene (100 ml) was added and the solution was washed twice with 100-ml 2 *N* hydrochloric acid, reduced in volume to *ca.* 2 ml by evaporation, and chromatographed as in method B.

Substituted Hexahelicenes. These were synthesized as described below for 2-bromohexahelicene.

2-Bromohexahelicene.[5] Compound *p*-Br-Ia (15 mg) was dissolved in 60 ml of benzene and a trace of iodine was added. The solution was irradiated for 8 hr in a Rayonet reactor with RUL 3500-Å lamps. After this the solution was reduced to *ca.* 2 ml by evaporation *in vacuo* and chromatographed on a short column of aluminum oxide with benzene as eluent. The elution was followed by uv spectroscopy and the helicene was crystallized from petroleum ether at −40°. Mass spectral, absorption, yield, and mp data are presented in Tables V and VI.

Table V

Parent olefin	Hexa-helicene formed	Yield,[a] mg	m/e parent molecular ion (by double focus MS) Obsd	Calcd	Mp, °C
p-Br-Ia	2-Bromo-	3.5	408.0331	408.0338	246–248[b]
o-Br-Ia	4-Bromo-	2.5	408.0373	408.0338	230–232
p-Cl-Ia	2-Chloro-	5.4	364.0826	364.0833	245–246
o-Cl-Ia	4-Chloro-	3.8	364.0826	364.0833	218–220
p-F-Ia	2-Fluoro-	3.8	346.1101	346.1158	235–237
o-F-Ia	4-Fluoro-	2.5	346.1101	346.1158	209.5–210
p-Me-Ia	2-Methyl-	4.0	342.1411	342.1408	194–196
o-Me-Ia	4-Methyl-	3.0	342.1377	342.1408	286–287
Ia	Unsubst	4.5			230–232

[a] After recrystallization. [b] Lit.[5] mp 245–247°.

Table VI

Parent olefin	Hexa-helicene formed	Uv λ_{max} (nm), log ϵ ($HCCl_3$)
p-Br-Ia	2-Bromo-	414, 2.66; 392, 2.79; 352, 4.01; 330, 4.32; 318, 4.36; 268, 4.70; 260, 4.69
o-Br-Ia	4-Bromo-	414, 2.45; 392, 2.66; 350, 4.00; 330, 4.29; 318, 4.29; 270, 4.59; 257, 4.59
p-Cl-Ia	2-Chloro-	414, 2.71; 392, 2.82; 351, 4.05; 330, 4.36; 318, 4.39; 266, 4.72
o-Cl-Ia	4-Chloro-	414, 2.51; 392, 2.73; 351, 4.09; 330, 4.38; 318, 4.38; 270, 4.67; 258, 4.67
p-F-Ia	2-Fluoro-	414, 2.85; 392, 2.92; 349, 4.07; 328, 4.39; 317, 4.42; 259, 4.69
o-F-Ia	4-Fluoro-	414, 2.54; 392, 2.73; 348, 4.09; 329, 4.39; 317, 4.40; 267, 4.65; 252, 4.67
p-Me-Ia	2-Methyl-	414, 2.62; 392, 2.77; 350, 4.08; 330, 4.35; 318, 4.40; 265, 4.61; 258, 4.70
o-Me-Ia	4-Methyl-	414, 2.46; 392, 2.70; 350, 4.12; 330, 4.40; 318, 4.42; 270, 4.68; 258, 4.64
Ia	Unsubst	413, 2.52; 391, 2.73; 349, 4.11; 328, 4.44; 317 4.45; 265, 4.74; 258, 4.73

Asymmetric Synthesis

The procedure for obtaining CPL was previously described.[1a] In this study the method using an SP 200 lamp and Fresnel rhomb was employed. The light was ~90% circularly polarized. Samples of either 6.0 or 7.5 mg of the hexahelicene precursors were irradiated at 370 nm (total dispersion = 12.2 nm) in 27 ml of toluene–I_2 in a 10-cm quartz cell with both RCL and LCL. Due to their slow rates of reaction, *o*-F-Ia, *o*-Cl-Ia, and *o*-Br-Ia were irradiated to only approximately 80% completion. The helicene was then separated from the remaining cis olefin by chromatography on neutral aluminum oxide, using graded mixtures of benzene–petroleum ether as eluent. The other six hexahelicene precursors were irradiated to completion, and chromatographed on neutral aluminum oxide using benzene as eluent. In all cases the hexahelicene fractions were evaporated to dryness, dissolved in 1 ml of chloroform, and analyzed for optical activity in a 10-cm cell in a Perkin-Elmer 141 polarimeter. The samples were then diluted, and their concentrations determined by uv spectrophotometry. The results are presented in Table I.

Unfortunately, unlike VI, VIII, and IX, compound VII has a relatively high rate of photodestruction,[17,18] so that complete irradiation of IIa, and especially IIb, whose photoconversion to VII is quite slow, results in a significant degree of asymmetric destruction of the VII produced.[17] This will generate optical activity of opposite sign to that generated by the asymmetric synthesis, making it very difficult to determine the relative optical yield due to asymmetric synthesis alone.

1-(2-Benzo[*c*]phenanthryl)-2-(2-napthyl)ethylene (IIa) and 1,2-bis(3-phenanthryl)ethylene (IIb) were irradiated to low conversion (approximately 50% for IIa, 20% for IIb). The irradiations were performed at 1.0 mg/ml in a 2-cm quartz cell of capacity 6 ml in toluene–I_2 with

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(17) W. Bernstein, M. Calvin, and O. Buchardt, unpublished results.

(18) Professor R. H. Martin, personal communication.

both RCL and LCL. IIa was irradiated at 310, 335, 370, and 400 nm, and IIb at 370 nm. The samples were evaporated to dryness and refluxed for 2 hr in 10 ml of chloroform with 10 mg of 3-chloroperbenzoic acid, which was then shaken with 100 ml of aqueous 1 *N* NaOH. The solvent was evaporated and the residue was taken up in 2 ml of warm benzene, and chromatographed on neutral aluminum oxide with benzene as eluent. This procedure eliminated all of the remaining olefin, allowing for accurate determination of the helicene concentration.

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Asymmetric Synthesis of Loganin. Stereospecific Formation of (1*R*,2*R*)- and (1*S*,2*S*)-2-Methyl-3-cyclopenten-1-ol and (2*R*)- and (2*S*)-2-Methylcyclopentanone

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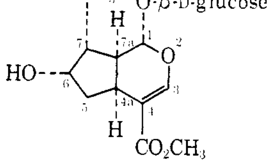
Abstract: A short asymmetrically induced synthesis of loganin pentaacetate (**6**) has been completed. 5-Methylcyclopentadiene (**7**) underwent a highly selective reaction with (+)-di-3-pinanylborane to yield (1*R*,2*R*)-2-methyl-3-cyclopenten-1-ol (**8a**) of 95% minimum optical purity. (−)-Di-3-pinanylborane gave (1*S*,2*S*)-2-methyl-3-cyclopenten-1-ol (**8b**) of equivalent optical purity. The absolute configurations of alcohols **8a** and **8b** were determined by their conversion into the previously unknown (2*R*)- and (2*S*)-2-methylcyclopentanones (**12a** and **12b**) and measuring the ORD and CD spectra of these ketones. The 1*R*,2*R* alcohol **8a** afforded the optically active methanesulfonate **10** which was converted into the 1*S*,2*R* acetate **2** with tetraethylammonium acetate. Irradiation of a 10:1 mixture of acetate **2** and methyl diformylacetate (**3**) gave the desired loganin aglucone derivative **5** regioselectively. Treatment of **5** with 2,3,4,6-tetra-*O*-acetyl-β-D-glucose and boron trifluoride afforded loganin pentaacetate (**6**) which has been converted to loganin (**1**).

The iridoid glucoside loganin (**1**) occupies a central position in the biosynthesis[1] of the *Corynanthe*,[2] *Aspidosperma*,[2] *Iboga*,[2] *Ipecacuanha*,[3] and *Cinchona*[4] groups of indole alkaloids. Evidence to date indicates that loganin becomes the "C_9–C_{10}" nontryptamine moiety incorporated into the skeleton of these alkaloids.[1] Tracer experiments also show that loganin is a biogenetic precursor of a growing number of iridoids,[5] alkaloid glucosides,[6] and monoterpene alkaloids.[7]



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Loganin was first isolated from the fruit pulp of *Strychnos nux vomica*.[8] It occurs in other *Strychnos* species as well as in the water plant *Menyanthes trifoliata* and in *Vinca rosea*.[2] More recently, loganin has been detected in various species of *Gentiana* (*Gentianaceae*),[5] *Hydrangea* (*Saxifragaceae*),[9] *Lonicera* (*Caprifoliaceae*),[9] *Mytragyna* (*Rubiaceae*),[10] and *Swertia* (*Gentianaceae*).[11] Thus, loganin appears to be an important building block in much of the plant world.

The structure and stereochemistry of loganin (**1**) have been the subject of many reports since its discovery in 1884 by Dunstan and Short.[8] The correct structure was postulated by Wolinsky[12] in 1961, but the structure and stereochemistry were not firmly established until 1968 when three groups[13] independently announced corroborating evidence for absolute structure **1**. This structure has since been confirmed by X-ray analysis,[14]

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(1) For recent reviews, see: O. Sticher, *Pharm. Acta Helv.*, **44**, 453 (1969); E. Leete, *Accounts Chem. Res.*, **2**, 59 (1969); A. I. Scott, *ibid.*, **3**, 151 (1970); A. R. Battersby in "The Alkaloids," Vol. 1, J. E. Saxton, Ed. (Specialist Periodical Reports), The Chemical Society, London, 1971, pp 31–47.

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