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OPTICAL ACTIVITY OF C_2 SYMMETRICAL 9,10-DIHYDRO-9,10-ETHANOANTHRACENES

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Abstract- Optically active C_2-symmetrical 9,10-dihydro-9,10-ethanoanthracene (DEA) derivatives have been prepared and their absolute configurations determined by kinetic resolution of phenylmethylcarbinol with optically active DEA-11,12-dicarboxylic acid chloride, spectroscopic studies and chemical correlations. The rotational strengths for the α- and the *p*-band regions calculated from the dipole-velocity procedure in the π-SCF approximation, rather than the point-dipole exciton treatment, are in good agreement with experiment. Although the rotational strengths are mainly produced from coupling of local excitations, the charge-transfer configurations cause inversion of the sequence of the transition energy of the A and B combination in the excited configurations in certain cases. This is the most important factor in the inconsistence between experimental and calculated results based on the exciton approximation in which it is assumed that there is no electron exchange between the two chromophores.

WE PREVIOUSLY REPORTED a determination of the absolute configuration of bis-1,1′-spiroindane derivatives through an analysis of the CD spectrum based on the calculated rotational strength using the SCF-MO-CI method and the dipole velocity procedure.[1] This calculation is more complicated than a simple coupled oscillator model[2] based on the exciton theory of the optical rotatory power of dimeric systems, but the defects from both the use of the point dipole approximation and the neglect of the mixing of the transitions due to the influence of another aromatic chromophore are remedied. In practice, agreement between the observed CD curve and the calculated one, based on the absolute configuration determined by X-ray analysis on the dibromo compound, was much improved and seemed to be almost quantitative.

It is interesting to apply this calculation to other compounds which contain the same aromatic chromophores situated in different geometrical positions. In the C_2 symmetrical 9,10-dihydro-9,10-ethanoanthracene (DEA) derivatives, there are two carbon atoms which are directly bound to two aromatic chromophores and by which the two chromophores are held at 120° to each other. The degree of overlap and the electrostatic repulsion between orbitals on atoms of different aromatic chromophores of this molecule are of the same order as those in bis-1,1′-spiroindanes.

In addition, according to the exciton theory of optical rotatory power, C_2 symmetrical 1,5-disubstituted DEA would not show optical activity if the excitation moment of the aromatic chromophore generated by the absorption of radiation is a point electric dipole located at the centre of the benzene ring. Calculation by our method, however, predicts optical rotatory power even in such molecules. By the exciton theory the C_2 symmetrical 2,6-disubstituted and 1,2;5,6-dibenz-DEA should show a very strong CD spectrum. Therefore, it should be of great interest to compare the CD spectra of these compounds with those of 1,5-disubstituted derivatives, and further, to determine whether the optical rotatory power is produced mainly from

simple coupling between the same kind of transitions of the two aromatic chromophores or whether other factors contribute significantly to the optical activity. Changing the nature of the substituents at the 1,5- and 2,6-positions should also have a considerable effect on the CD spectra.

For the purpose of these investigations, we have prepared a series of optically active 1,5-, 2,6-disubstituted and 1,2;5,6-dibenz-DEA derivatives and determined their absolute configurations by the kinetic resolution method.[3, 16]

Synthesis and determination of the relative configuration

Adducts prepared by the Diels–Alder reaction of anthracene-1,5-dicarboxylic acid[4] and dimethyl fumarate were evidently a mixture of two isomers, 11(*endo*),12(*endo*)-dicarbomethoxy-DEA-1,5-dicarboxylic acid (**1**) and the 11(*exo*),12(*exo*)-isomer (**2**). These could be fractionally recrystallized with difficulty, so for the purposes of both separation and resolution they were converted to the brucine salt mixture. By several fractional recrystallizations from MeOH, two optically pure diastereomers were isolated, as prisms, $[\alpha]_D$ −33·3° (MeOH), and needles, $[\alpha]_D$ +50·2° (MeOH). The (−)-free acid was obtained by decomposition of the (−)-brucine salt and (+)-free acid from the (+)-salt. Their CD spectra, however, showed that they were not in an antipodal relationship (Fig 5 and 6).

The (−)-isomer was converted to the 1,5-dihydroxymethyl derivative ((−)-**5**) by selective hydrogenation of the carboxylic acid groups with diborane.[5] The relative configuration of the carbomethoxy groups in this (−)-dihydroxymethyl derivative ((−)-**5**) was assigned on the basis of the following evidence: (1) The IR spectrum of a highly dilute solution of the dihydroxy derivative ((−)-**5**) in CCl_4 (3·60 mg in 10 ml) showed two absorptions, at 3609 and 3525 cm^{-1}, attributable to intramolecular hydrogen bonding (Fig 1). The absorption at 3609 cm^{-1} was assigned to intramolecular hydrogen bonding of the hydroxy groups with the π-orbitals of the aromatic chromophore as observed in benzyl-alcohol.[6] While the absorption at 3525 cm^{-1} could be assigned to intramolecular hydrogen bonding between the carbomethoxy groups and the hydroxy groups. (2) Dreiding models show that the distance between the hydrogen atom in the hydroxy group and the oxygen atom in the carbomethoxy group is *ca.* 1·2 Å at the nearest position within a region allowable by the conformation of the *endo*-configuration* and for the *exo*-configuration the corresponding distances for the two nearest positions are *ca.* 3·4 and 3·5 Å. As these distances for the *exo*-configuration are too large to allow hydrogen bonding (it is thought that hydrogen bonding is impossible at over 3·2 Å) we concluded that the (−)-isomer ((−)-**5**) has an *endo*-configuration and hence the (+)-isomer ((+)-**2**) an *exo*-configuration.

The (+)-1,5-diamino compound ((+)-**9**) was obtained from (+)-**2** by applying the Curtius reaction and the (+)-diacylchloride ((+)-**6**), (+)-diacylazide ((+)-**7**) and (+)-diisocyanate derivative ((+)-**8**) were isolated in the course of this reaction. The (+)-dichloro derivative ((+)-**10**) and the nonsubstituted one ((+)-**11**) were then prepared from (+)-**9** by diazotization followed by replacement by chlorine and hydrogen, respectively.

* The prefixes *endo* and *exo* are used in the sense that substituents at C-11 and C-12 on the same side of the bicyclo[2.2.2]octadiene ring as the substituents at C-1 and C-5 respectively in the benzene rings are *endo*, those on the other side are *exo*.

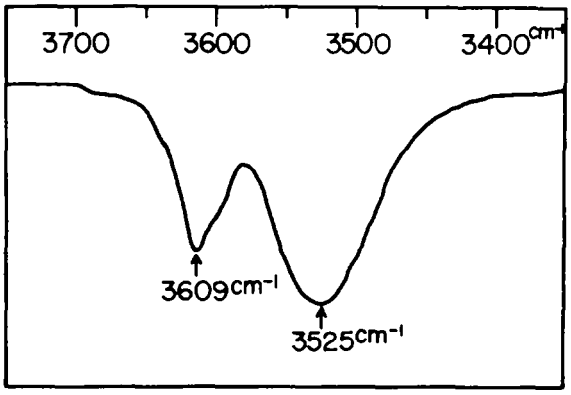


FIG 1. IR spectrum of (−)-**5** (3·60 mg) in CCl_4 solution (10 ml) using a 20 mm cell

(−)-1,5-Dichloro-DEA-11-carboxylic acid ((−)-**18**) constructed from the same DEA skeleton was also obtained by the Diels–Alder reaction of 1,5-dichloroanthracene with methylacrylate or acrylonitrile followed by hydrolysis and resolution with (−)-phenethylamine. This (−)-acid ((−)-**18**) was converted by the Curtius reaction to the (−)-amino derivative, isolated as a salt ((−)-**19**) (Chart I)*.

2,6-Disubstituted DEA was prepared from (+)-dimethyl-DEA-1,5-dicarboxylate ((+)-**21**), which was shown by CD comparison (Table 2) to have configuration at C-9 and C-10 identical with (+)-**4**. Nitration of (+)-**21** using two molar equivalents of HNO_3 gave two dinitro-compounds, ((+)-**22**, $[\alpha]_D$ +233°) and ((+)-**23**, $[\alpha]_D$ +160°), in the ratio 9/10, determined from the specific rotation of the mixture of the products ($[\alpha]_D$ +193°) (Chart II). The position of the nitro groups was determined by analysis of the NMR spectra. The product (+)-**23** showed AB-pattern (J = 2·5 Hz) at 1·65 and

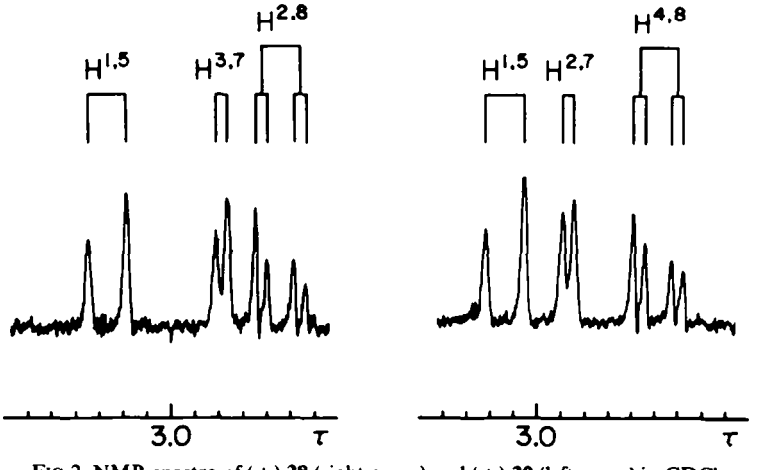


FIG 2. NMR spectra of (+)-**28** (right curve) and (+)-**30** (left curve) in $CDCl_3$

* After conversion of (−)-**9** to (−)-dimethyl amino N-oxide, pyrolysis was tried but 1,5-dichloroanthracene was obtained.

Chart 1

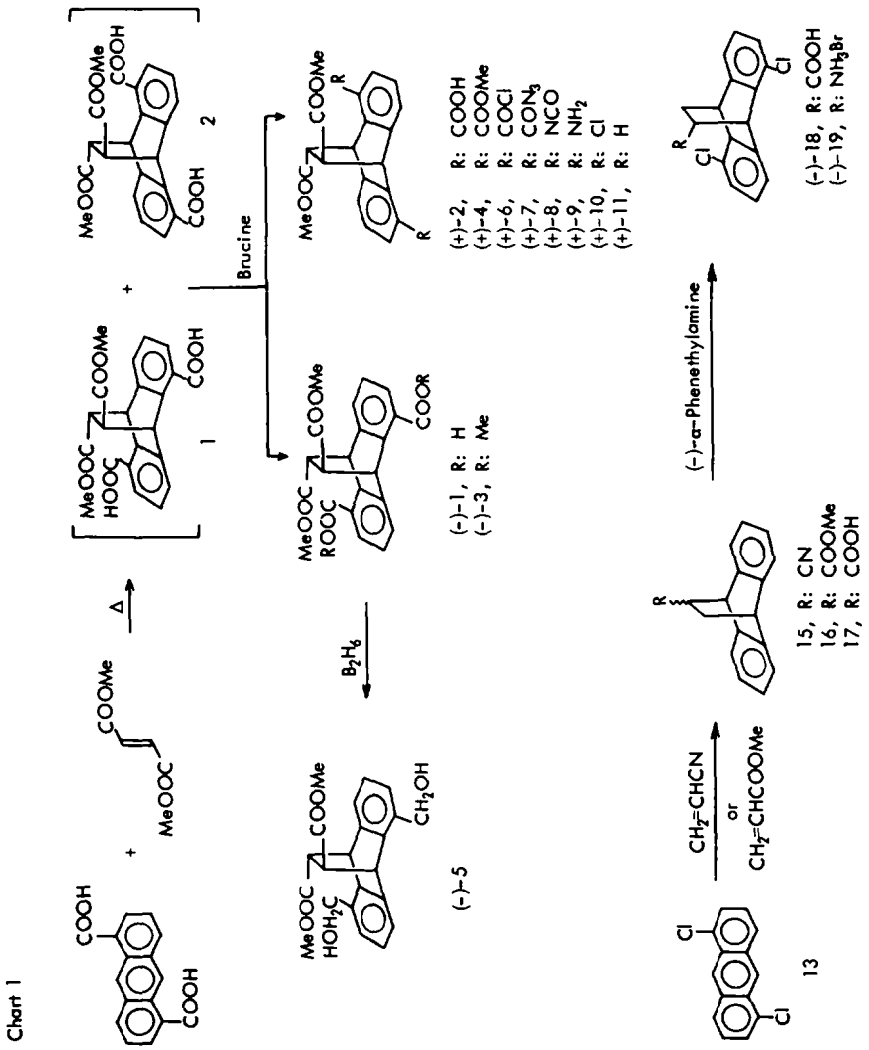
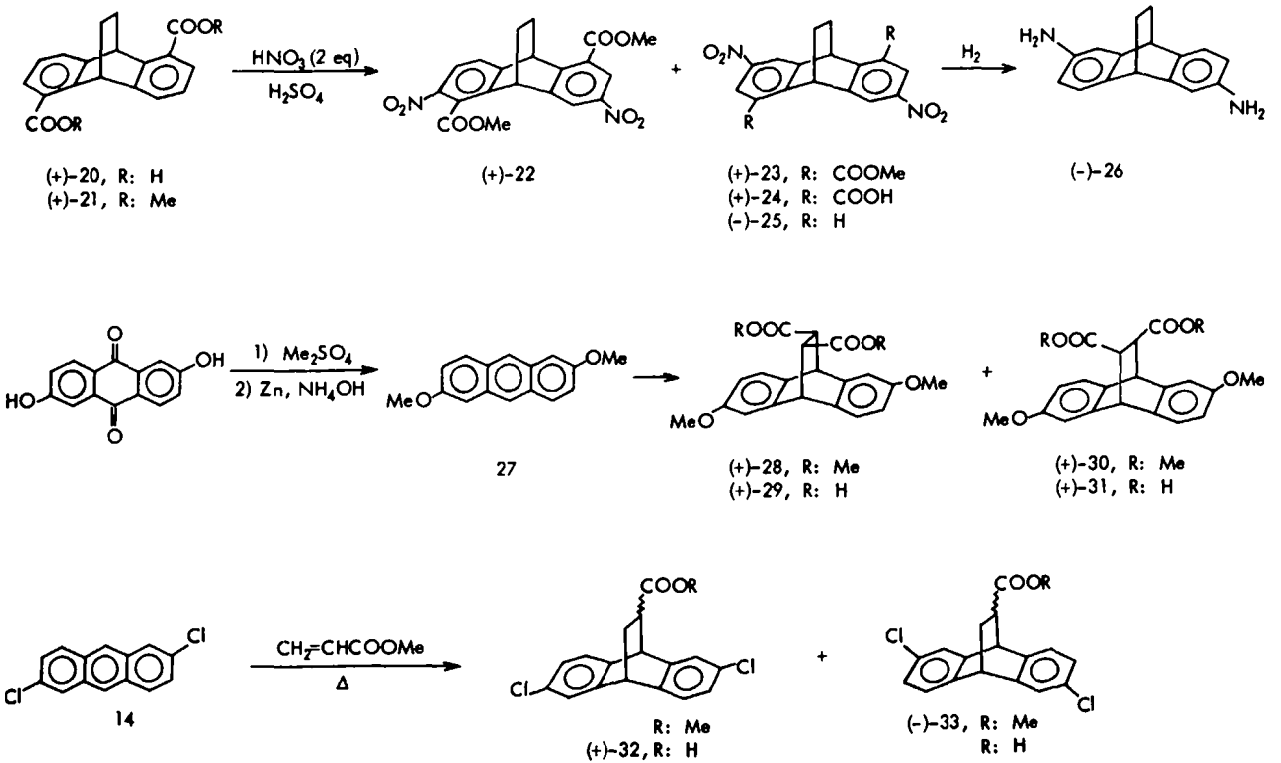

COOH
COOH
+
MeOOC
COOMe
Δ
MeOOC
HOOC
COOMe
COOH
1
+
MeOOC
COOMe
COOH
COOH
2
Brucine
MeOOC
ROOC
COOMe
COOR
(-)-1, R: H
(-)-3, R: Me
MeOOC
R
COOMe
R
(+)-2, R: COOH
(+)-4, R: COOMe
(+)-6, R: COCl
(+)-7, R: CON3
(+)-8, R: NCO
(+)-9, R: NH2
(+)-10, R: Cl
(+)-11, R: H
B2H6
MeOOC
HOH2C
COOMe
CH2OH
(-)-5
Cl
Cl
13
CH2=CHCN
or
CH2=CHCOOMe
R
(-)-α-Phenethylamine
15, R: CN
16, R: COOMe
17, R: COOH
R
Cl
Cl
(-)-18, R: COOH
(-)-19, R: NH3Br

Chart 2


COOR
COOR
HNO3 (2 eq)
H2SO4
COOMe
O2N
COOMe
NO2
+
O2N
R
R
NO2
H2
H2N
NH2
(+)-20, R: H
(+)-21, R: Me
(+)-22
(+)-23, R: COOMe
(+)-24, R: COOH
(-)-25, R: H
(-)-26
HO
OH
O
O
1) Me2SO4
2) Zn, NH4OH
MeO
OMe
27
ROOC
COOR
MeO
OMe
+
ROOC
COOR
MeO
OMe
(+)-28, R: Me
(+)-29, R: H
(+)-30, R: Me
(+)-31, R: H
Cl
Cl
14
CH2=CHCOOMe
Δ
COOR
Cl
R: Me
(+)-32, R: H
+
COOR
Cl
Cl
(-)-33, R: Me
R: H

1·35 τ and is therefore the 3,7-dinitro isomer. The product (+)-**22** had two kinds of AB-patterns, at 2·45 and 2·04 τ (J = 8·0 Hz) and at 1·72 and 2·33 τ (J = 2·5 Hz). The half-widths of the AB pattern at the higher τ values were unequal, due to interaction of the proton at C-4 with the bridge head proton. This shows that (+)-**22** is a 2,7-dinitro and not a 3,8-dinitro isomer.

Holleman reported that nitration of ethyl benzoate gave the *ortho*-, *meta*- and *para*-nitro isomers in the proportions 28·3, 68·4 and 3·3%, respectively.[7] As the products ratio (+)-**22**/(+)-**23** calculated on the basis of these values is 45·3/54·7 and the same as the experimental value, the effect of interaction of two aromatic groups cannot be appreciated.

(−)-2,6-Dinitro-DEA((−)-**25**) was prepared by a decarboxylation of the dicarboxylic acid derivative ((+)-**24**) and subsequent conversion to (−)-2,6-diamino-DEA((−)-**26**) isolated as a salt.

2,6-Dimethoxy anthracene, prepared from treatment of anthraflavic acid with dimethyl sulphate followed by reduction with Zn dust and NH_4OH, was treated with dimethyl fumarate at 150° (bath temp.) to give a mixture of adducts (**28** and **30**). The mixture was hydrolyzed and separated into two dicarboxylic acid derivatives (**29** and **31**) by fractional recrystallization from EtOAc. The relative configuration at C-11 and C-12 was suggested by comparison of the NMR spectra of the dimethyl ester derivatives (**28** and **30**), in which the three kinds of protons in the benzene rings have different chemical shifts as depicted in Fig 3. C-3 and C-7 protons have similar chemical shifts in both **28** and **30** (3·39 and 3·42 τ), but C-1 and C-5 protons in **28** have higher shifts than those in **30** (3·18 and 3·11 τ) while C-4 and C-8 protons shifts in **28** are lower than those in **30** (2·79 and 2·88 τ). These facts lead to the conclusion that **28** has an *exo*-configuration and **30** an *endo*-configuration,* in consideration of the shielding effect of the carbomethoxy groups at C-11 and C-12.

The resolution of the dicarboxylic acid (**29**) was readily achieved by the fractional

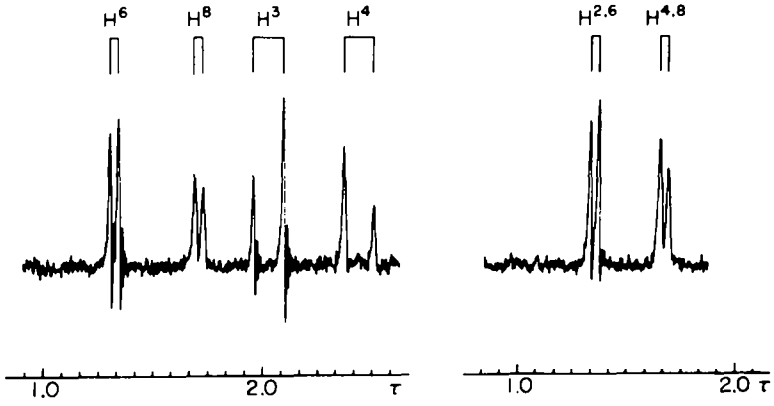
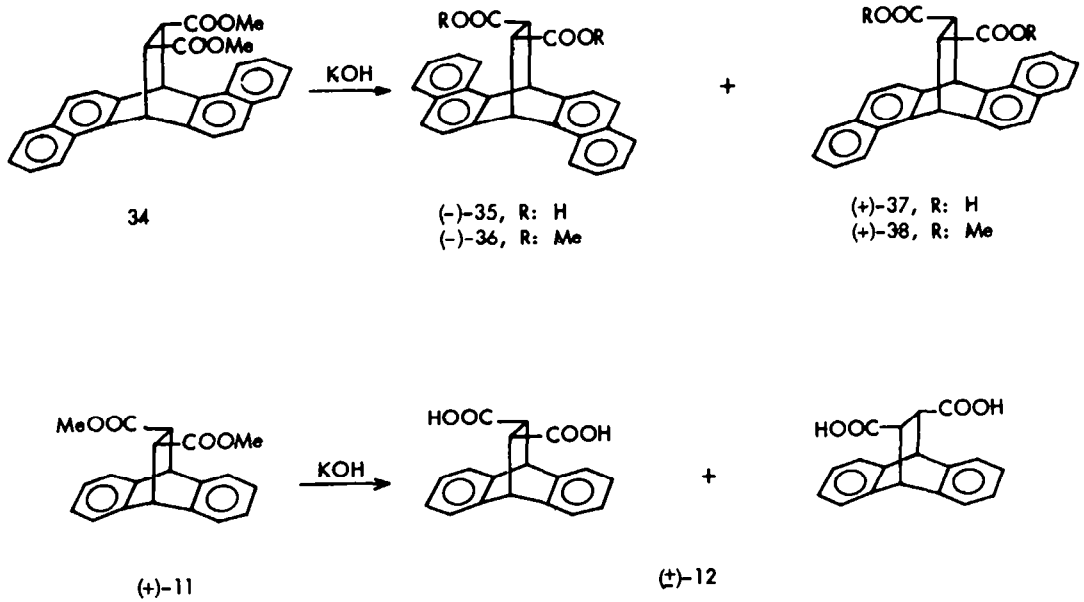


FIG 3. NMR spectra of (+)-**22** (left) and (+)-**23** (right in $CDCl_3$

* The prefixes *endo* and *exo* are used in the sense that substituents at C-11 and C-12 on the same side of the bicyclo[2.2.2]octadiene ring as the substituents at C-2 and C-6 respectively in the benzene rings are *endo*, those on the other side are *exo*.

Chart 3


COOMe
COOMe
KOH
ROOC
COOR
+
ROOC
COOR
34
(-)-35, R: H
(-)-36, R: Me
(+)-37, R: H
(+)-38, R: Me
MeOOC
COOMe
KOH
HOOC
COOH
+
HOOC
COOH
(+)-11
(±)-12

recrystallization of the brucine salt but the other dicarboxylic acid (**31**) was only partially resolved by this method. The optically pure dicarboxylic acid ((+)-**31**) was obtained by fractional recrystallization of the cinchonidine salt and then the quinine salt.

2,6-Dichloro-9,10-dihydro-9,10-ethanoanthracene-11(*endo*) and (*exo*)-carboxylic acids (**32**) were also prepared by reaction of 2,6-dichloroanthracene and methyl-acrylate in a sealed tube followed by hydrolysis. Separation of the two epimers by fractional recrystallization failed but both separation and resolution were accomplished by fractional recrystallization of their cinchonidine or (+)-phenethylamine salt. The (+)-acid ((+)-**32**) obtained from the (+)-phenethylamine salt was purified by recrystallization from MeOH–H_2O; the (−)-acid, from the cinchonidine salt, was purified after first being converted to its methylester ((−)-**33**). These two isomers are antipodal in the 2,6-dichloro DEA skeleton but have the same configuration at C-11.

A mixture of isomers 1,2;5,6-dibenzo-DEA-11,12-*trans*-dicarboxylic acids (**35** and **37**) was prepared from the *cis*-ester[8] by hydrolysis with KOH. The conversion from the *cis*-diester to two *trans*-diacids is observed in general[9] and also the conversion of *trans*-diester to two *trans*-diacids was possible by base catalysed hydrolysis. This phenomenon was observed in conversion of (+)-*trans*-diester ((+)-**11**) to (±)-*trans*-diacid ((±)-**12**).

Separation and resolution were accomplished by fractional recrystallization of the cinchonidine salts of the mixture of **35** and **37**. The (+)-salt, obtained by recrystallization from MeOH gave the (+)-acid ((+)-**37**) and the (−)-salt from acetone gave the (−)-acid ((−)-**35**). Determination of the configurations at C-11 and C-12 was achieved by analysis of the NMR spectra of their dimethyl esters ((−)-**36** and (+)-**38**); the ester Me groups showed a higher chemical shift in the *endo*-configuration (6·57 τ) than in the *exo*- (6·37 τ), owing to shielding by the aromatic groups.

Determination of absolute configuration

Kinetic resolution of the carboxylic acid anhydride or acid chloride by means of optically active secondary alcohols has been used to determine the absolute configuration of the alcohols.[3] We considered that if an optically active carboxylic acid chloride or anhydride bearing an asymmetric centre at the α-position and a racemic secondary alcohol were used under the same esterification conditions, the closely related topology of the environment in the diastereomer would enable us to determine the absolute configuration of the carboxylic acid.

By this method, the kinetic resolution of phenyl methyl carbinol[10] was achieved with (+)-(1S,2S)-bicyclo[2.2.2]octane-1,2-dicarboxylic acid chloride ((+)-**42**,[11] (−)-(1S,4R,9S,10S)-6-bromobenzobicyclo[2.2.2]oct-2-one-9,10-dicarboxylic acid chloride ((−)-**43**),[9] which have similar skeletons to DEA dicarboxylic acid chloride (**13**), and (+)-0,0-dimethyl tartaric acid anhydride ((+)-**41**). The absolute configurations of compounds (+)-**41**, (+)-**42** and (−)-**43** were already known.

The results for these molecules, summarized in Table 1, showed that the Cram–Prelog's rule can be applied to these esterification reactions* and that this method is

* To compounds (+)-**39** and (−)-**40**, the sequence of bulkinesses of the groups is considered to be following from the larger one, the bridge head group, the group having the other carboxylic acid group and hydrogen. Compound (+)-**41** is considered to proceed through the analogous transition state proposed by H. Brockmann, Jr. and J. Bode.[12]

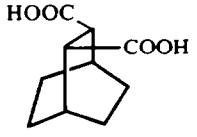
TABLE 1. RESULTS OF KINETIC RESOLUTION

Acid chloride of	Molar ratio acid (chloride/alcohol)	Optical purity of recovered alcohol (%)[b]	Sign and configuration of recovered alcohol	Configuration of acid
(+)-**12**	1:4	16·8	(+)-R	11R, 12R
(+)-**39**	1:4	0·6	(+)-R	1R, 2R
(−)-**40**	1:4	7·3	(−)-S	9S, 10S
(−)-**18**	1:2	1·7	(−)-S	11R
(−)-**35**	1:4	8·4	(+)-R	11R, 12R
(+)-**41**[a]	1:2	1·7	(+)-R	2R, 3R

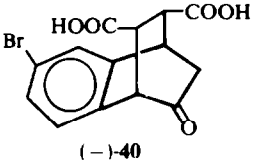
[a] Acid anhydride.

[b] These values were calculated from the observed specific rotation without consideration of the yield of the esterification.

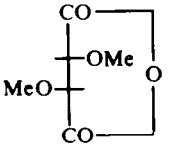
useful for the determination of the absolute configuration of asymmetric carboxylic acid derivatives.



(+)-**39**



(−)-**40**



(+)-**41**

This technique was also applied to compound (+)-**12**. The plus sign and the high optical yield of the recovered carbinol revealed that (+)-**12** has the 11R,12R configuration and therefore led us to establish the R configuration at both C-9 and C-10 of a series of (+)-1,5-disubstituted DEA, shown above to be of *exo*-configuration.

When the CD spectra of compounds (+)-**10**, (−)-**18** and (−)-**19** were compared, it is seen that (−)-**18** and (−)-**19** are of opposite sign but almost the same magnitude as (+)-**10** (Fig 4). It seems that groups such as carbomethoxy or ammonium on C-11 and C-12 contribute only slightly to the CD spectrum. Therefore compounds (−)-**18** and (−)-**19** are antipodal to (+)-**10** in their 1,5-dichloro-DEA skeletal configuration.

As compound (−)-**18** is somewhat different from the other dicarboxylic acid derivatives in the environment of its groups, though of similar bulkiness, the configuration at C-11 may be assigned as R by the kinetic resolution technique (Table 1).

Comparison of the CD spectrum of (+)-**21** with that of (+)-**4** (Table 2) indicates that (+)-**21** has the R configuration at both C-9 and C-10, the *exo*-carbomethoxy groups at C-11 and C-12 contributing only slightly to the CD in the α- and *p*-band regions as observed with compounds (+)-**10**, (−)-**18** and (−)-**19**. Therefore, compounds (−)-**25** and (−)-**26**, which were prepared from (+)-**21**, have the S configuration at both C-9 and C-10. Compound (−)-**26** shows a negative Cotton effect in the α-band

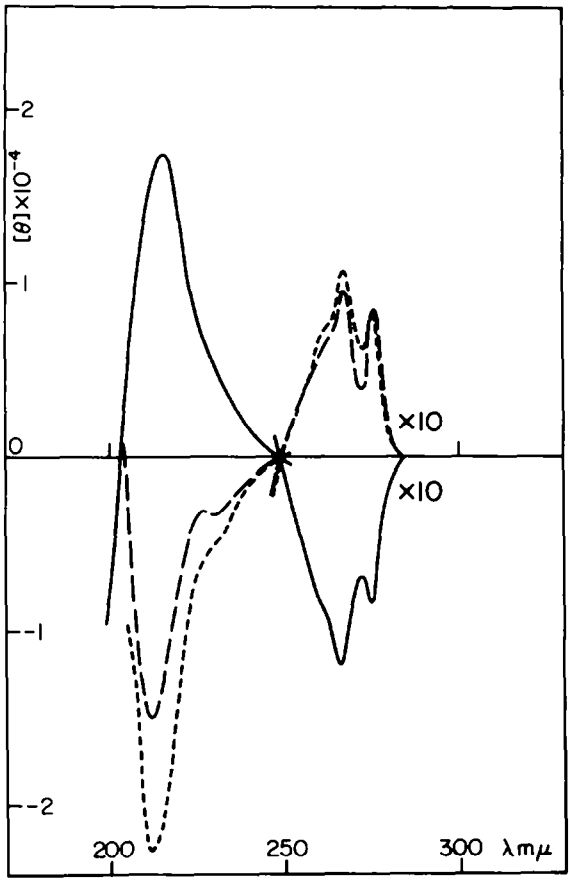


FIG 4. CD spectra of (+)-**10** (———), (−)-**18** (– – – –) and (−)-**19** (· · · · · ·) in MeOH

region and positively and then negatively signed Cotton effects in the lower wavelength of the *p*-band region. This pattern is opposite to that of compounds (+)-**29** and (+)-**32**, but similar to that of compound (−)-**33** (Table 3). Therefore, it is concluded that compounds (+)-**29** and (+)-**32** have the R configuration and compound (−)-**33** the S configuration at C-9 and C-10, that is the (+) signed 2,6-disubstituted DEA has the R configuration and the (−) one the S configuration at C-9 and C-10.

As the (+) alcohol was recovered in high optical yield by esterification of compound (−)-**35** which had been shown to have *endo*-configuration, (−)-**35** was concluded to be R at C-11 and C-12 and therefore to be S at both C-9 and C-10.

CD and UV spectra

As the experimental results summarized in Table 2 show, Cotton effects of large magnitude are observed in an accessible absorption region in a series of 1,5-disubstituted DEA derivatives, (+)-**2**, (+)-**4** ~ (+)-**10**, (−)-**18** and (−)-**19**, and their Cotton effects are not influenced by the substituents at C-11 and C-12. Except for the α-band of compounds (+)-**8** and (+)-**9** and the *p*-band of compound (+)-**5** they do not show couplets[2] in the α- and *p*-band regions. Therefore, dipole coupling between the

TABLE 2. CD AND UV SPECTRA OF 1,5-DISUBSTITUTED DEA

Compd	Solv.	UV λ, mμ (ε, $\times 10^{-3}$)	CD λ, mμ ($\Delta\varepsilon$)
(−)-**3**	M[a]	288 (4·23), 225[s] (22·2), 205! (47·7)	289 (−6·54), 248 (+2·75), 215 (−15·7)
(+)-**4**	M	290 (4·40), 227 (22·7), 205! (47·7)	290 (+6·76), 231 (+26·6), 205 (−13·2)
(+)-**21**	M	291 (5·16), 229 (21·1), 206·5[s] (40·7), 197! (52·1)	292 (+9·68), 232 (+20·5), 224 (+21·4), 210 (+27·3), 197! (−34·5)
(−)-**5**	M	276 (1·00), 269 (0·89), 212 (14·0), 203! (15·9)	276 (+1·76), 267 (+1·01), 233 (−11·5), 220 (−15·2), 213 (−15·4), 203! (+25·3)
(+)-**6**	O[b]	290 (5·31), 254[s] (18·7), 247 (21·4), 209 (25·8)	308 (+9·91), 247 (+17·6), 227 (−5·73), 212 (−23·8)
(+)-**7**	M	297 (4·70), 254 (24·9), 207! (41·0)	297 (+9.41), 258 (+20·9), 246 (+19·6), 205! (+28·2)
(+)-**8**	D[c]	305[s] (0·06), 282 (0·78), 272 (1·04) 265 (1·04), 215 (42·7)	287 (+0·17), 281 (−0·57), 271 (−1·21), 228 (+43·7), 222 (+43·7), 208! (0)
(+)-**9**	M	292 (4·29), 230[s] (19·3), 208[s] (40·3)	297 (+8·96), 276 (−2·20), 237 (+34·6), 214 (+27·6), 202 (−70·1)
(+)-**9**·HCl	M·HCl	271 (0·60), 262 (0·67), 254[s] (0·61), 205 (37·8)	271 (−2·14), 264 (−1·63), 230 (+9·48), 208 (+18·4)
(+)-**12**	M	273 (1·17), 266 (0·99), 259 (0·67), 207 (35·5)	272 (+0·32), 265 (+0·22), 260 (+0·12), 241 (−0·31), 216 (+5·90)
(−)-**18**	M	275[s] (0·33), 266 (0·47), 212 (35·5)	275·5 (+2·66), 267 (+2·94), 230 (−10·2), 212 (−46·5)
(−)-**19**	A[d]	273[s] (0·32), 265 (0·47), 258[s] (0·39), 210 (45·6), 190 (68·9)	275 (−2·51), 267 (−3·58), 225[s] (+19·5), 212 (+62·9)

[a] MeOH.
[b] *i*-Octane.
[c] Dioxane.
[d] MeCN. s = shoulder. ! = Lowest recorded value, not a maximum.

same electronic transitions of the two chromophores does not play a major part in the development of the Cotton effects for the compounds having spherically symmetric substituents, though substituents of non-spherical symmetry, such as acid chloride and isocyanate in compounds (+)-**8** and (+)-**9**, would change the orientation of the electronic transition dipole and consequently produce optical activity.

The absolute configuration of compound (−)-**3** has been determined to be 9S, 10S, 11R, 12R and compound (+)-**4** to be 9R, 10R, 11R, 12R, the two compounds being antipodal in the DEA skeleton. When their CD spectra are compared, the Cotton effects are equal in magnitude and opposite in sign at around 290 mμ, but in compound (−)-**3**, a positively signed CD band is observed at 248 mμ which is not observed in (+)-**4**. The sodium salt of compound (−)-**1** shows a large oppositely signed Cotton effect at around 230 mμ not found in the free acid, although change of polarity of the solvent does not give any substantial change in CD curves (i.e. in MeOH and in *i*-octane, Table 4). More interestingly, the Cotton effect for compound (−)-**3** in EPA, which had a positive value ($\Delta\varepsilon$ +2·33) at 251 mμ at 23°, was decreased in value at −68° and at −190° had changed to a large negative value ($\Delta\varepsilon$ −11·2) at 246 mμ (Fig 5 and Table 4). On the contrary, the CD curve for (+)-**4** at −190° showed a slight increase in both α- and *p*-band regions over that at 23°. Likewise the sodium salt of (+)-**2** did not show such a remarkable change in the CD spectrum as (+)-**1** (Fig 6 and Table 4).

These phenomena are interesting; the contribution from the electronic transition

TABLE 3. CD AND UV SPECTRA OF 2.6-DISUBSTITUTED AND 1,2;5,6-DIBENZ DEA

Compd	Solv.	UV λ, mμ (ε, × 10^{-3})	CD λ, mμ (Δε)
(−)-**25**	D[a]	345 (0·78), 280 (19·9), 222 (14·9), 206! (21·5)	327 (−0·58), 293 (−8·58), 258 (−4·06), 234 (−8·12), 208 (−46·4)
(−)-**26**	M·S[b]	293 (4·91), 234 (20·7), 203 (76·5)	294 (−9·71), 253 (+32·0), 232 (−35·8), 210 (−64·7)
(−)-**26**·HCl	M·HCl[c]	272 (2·05), 266 (1·55), 258[s] (1·08), 207[s] (37·5), 196! (40·2)	273 (−4·06), 266 (−2·86), 233 (+3·06), 217 (−7·71), 206! (+9·37)
(−)-**26**·HCl	M[d]		293 (−0·36), 272 (−3·91), 266 (−2·37), 247[s] (+0·71), 234 (+1·76), 217 (−8·93), 206! (+8·71)[h]
(+)-**31**	D	288 (5·90), 282 (5·09), 240[s] (8·46), 228 (23·6), 207! (46·1)	290[s] (+0·72), 274 (+4·98), 245 (−45·1), 226 (+64·1), 208! (+54·5)
(+)-**32**	A[e]	279·5 (2·36), 272 (1·81), 265[s] (1·02), 257[s] (0·72), 221 (27·2), 197 (61·3)	279 (+8·99), 272 (+6·22), 265[s] (+2·48), 237 (−35·5), 219 (+88·8), 205! (+52·0)
(−)-**33**	H[f]	280 (2·57), 221 (23·9), 198 (46·4)	280 (−9·99), 273 (−6·58), 267[s] (−2·98), 237 (+36·3), 220 (−91·0), 205! (−29·5)
(+)-**37**	A	324 (2·07), 315 (1·95), 308[s] (3·15), 300[s] (5·06), 283 (12·2), 274[s] (10·0), 232 (95·2), 221 (81·7), 190! (8·17)	330 (+0·30), 326 (−0·13), 319[s] (+6·25), 304 (+28·6), 282 (−41·8), 236 (+306), 222 (−195), 206 (−126)
Na salt of (+)-**37**	S[g]	324 (2·77), 314 (2·50), 307[s] (1·17), 284 (11·7), 275[s] (9·94), 230 (81·6), 208! (33·0)	329 (+0·62), 320[s] (+8·65), 304 (+24·2), 283 (−35·2), 237 (+222), 223 (−49·4), 210! (0)

[a] Dioxane.
[b] MeOH–MeONa.
[c] MeOH–HCl.
[d] MeOH.
[e] MeCN.
[f] *n*-Heptane.
[g] 0·1N NaOH.
[h] In MeOH, there exists an equilibrium between salt and free acid. These data were obtained from the 1·814 × 10^{-3} mole/l solution.

of the carbomethoxy groups at C-11 and C-12 must be small in the α- and *p*-band regions, because of the similarity in the CD spectra of compounds (+)-**4** and (+)-**23**. The difference in the population of rotational isomers existing in the form depicted in Fig 7 must be considered. Though the sodium salts of (−)-**1** and (+)-**2** do not have such differences in population, their CD spectra are not antipodal in the 230 mμ region. Therefore other stronger factors must be operative. The population of the rotational isomer having both C-1 and C-5 carbomethoxy groups in the plane of the benzene ring is reduced by the steric interaction between the carbomethoxy substituent and the bridgehead hydrogen. This interaction is considered to be operative in both compounds (−)-**3** and (+)-**4**. But in the *endo*-isomer, (−)-**3**, the substituents at C-11 and C-12 interact also with those at C-1 and C-5 thus changing the population of the right or left handedly rotated isomer*. Thus we deduced that the difference in

* Compounds (−)-**3** and (+)-**4** show dipole moments of μ = 2·88 and 2·90 Debye respectively at 25° in benzene. However, as there are many orientations of four carbomethoxy groups, this similarity of dipole moment does not deny the above estimation.

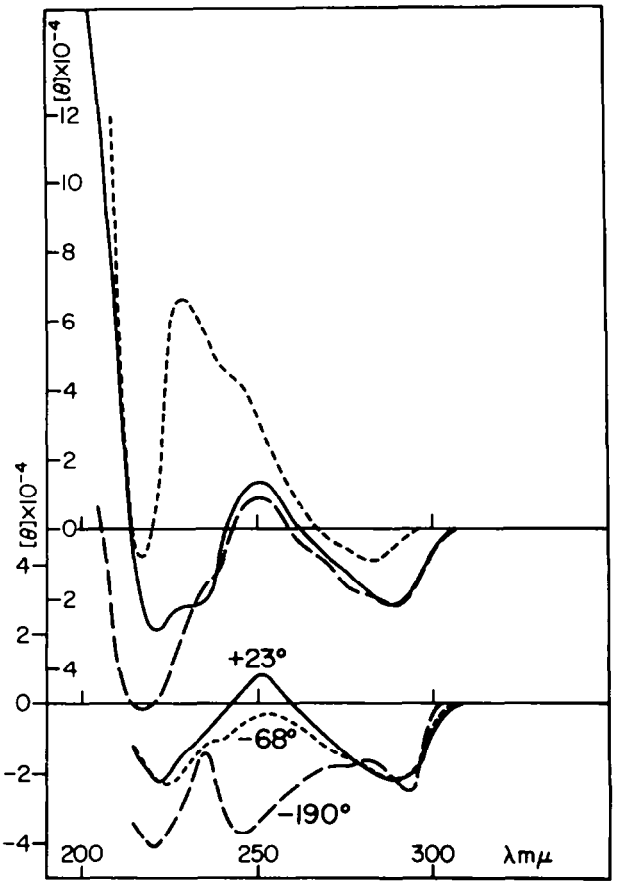


FIG 5. CD spectra (upper curves) of (−)-**1** in MeOH (———), (−)-**3** in iso-octane (- - - - -) and the sodium salt of (−)-**1** in 0·1N NaOH (· · · · · · ·), and CD spectra (lower curves) of (−)-**3** in EPA solution at +23° (———), −68° (· · · · · · ·) and −190° (- - - - -)

population of these rotomers made the long-axis transition inherently dissymmetric thereby producing optical activity.

The *exo*-1,5-disubstituted DEA is free from such an effect and therefore the temperature dependence and the change in the salt cannot be observed*.

2,6-Disubstituted DEA showed a couplet in the *p*-band region, as expected by the coupling theory,[2] but not in the α-band region, except for compound (−)-**25** and the CD curve in this compound was too complex to analyse owing to mixing of the n–π* transitions of the nitro groups.

The UV and CD spectra of the hydrogen chloride salt of compound (−)-**26** change with concentration and apparently show the existence of the dissociation equilibrium between the salt and the free amine (Table 3). The values of the Cotton effects of the free amine and the salt were measured in NaOMe–MeOH solution and in HCl–MeOH

* The UV spectrum of compound (+)-**4** shows a maximum at 226 mμ but that of (−)-**3** has a shoulder at 225 mμ. This reveals the difference in population of the rotomers in compounds (−)-**3** and (+)-**4**.

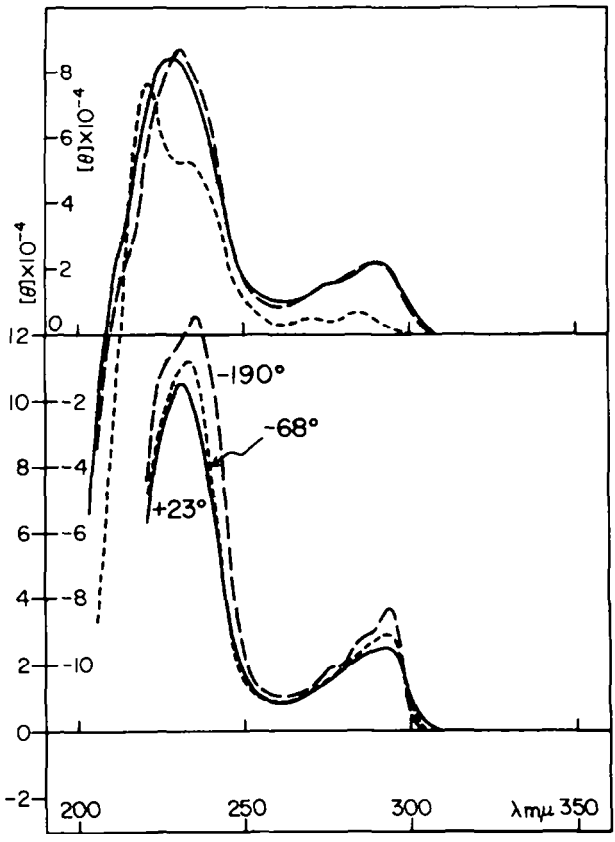


FIG 6. CD spectra (upper curves) of (+)-2 in MeOH (———), (+)-4 in iso-octane (- - - - -) and the sodium salt of (+)-2 in 0·1N NaOH (·····), and CD spectra (lower curves) of (+)-4 in EPA solution at +23° (———), −68° (·····) and −190° (- - - - -)

solution, and the *pKa'* value was determined to be 5·3 at 24° from the values obtained. This value is similar to that of 3,4-dimethylaniline (5·17 ± 0·02 at 25°).[13] The CD spectrum offers a very convenient method to determine the *pKa'* value in the case where one isomer shows a Cotton effect in a region where the other does not.

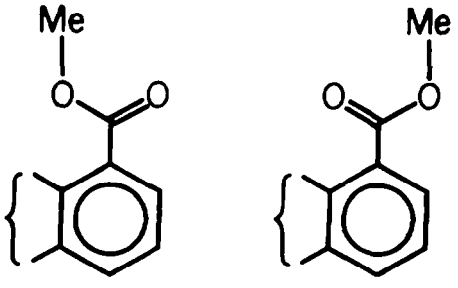


FIG 7. Two possible orientations of the carbomethoxy group

TABLE 4. TEMPERATURE AND SOLVENT EFFECTS OF 1,5-DICARBOXYL DERIVATIVES

Compd	Solv.	Temp. (°C)	CD λ, mμ ($\Delta\varepsilon$)
(−)-1	M[a]	rt	289 (−0·69), 250 (+3·86), 235[s] (−6·75), 221 (−9·25), 200! (+51·4)
Na salt of (−)-1	A[b]	rt	282 (−3·15), 243 (+12·8), 228 (+20·0), 217 (−2·90), 205! (+87·0)
(−)-3	O[c]	rt	290 (−7·33), 251 (+2·23), 223 (−14·7), 200! (+17·1)
(−)-3	EPA[d]	23	289 (−6·64), 251 (+2·23), 232 (−3·60), 222 (−6·75)
(−)-3	EPA	−68	290 (−6·69), 241 (−3·15), 227 (−7·08)
(−)-3	EPA	−190	293 (−7·60), 275 (−5·57), 246 (−11·2), 220 (−12·6)
(+)-2	M	rt	290 (+6·75), 230 (+25·7), 205! (−17·3)
Na salt of (+)-2	A	rt	285 (+1·91), 272 (+1·38), 232 (+15·8), 221 (+23·0), 204! (−29·0)
(+)-4	EPA	23	294 (+7·86), 232 (+32·1), 210! (0)
(+)-4	EPA	−68	294 (+9·07), 234 (+34·1), 210! (0)
(+)-4	EPA	−190	294 (+11·2), 236 (+38·2), 210! (0)

[a] MeOH.
[b] 1N-NaOH.
[c] *i*-Octane.
[d] Ether: Pentane: Alcohol. ! = Lowest recorded value, not a maximum. s = shoulder.

THEORETICAL

The exciton treatment has been used to explain the couplet pattern of CD spectra and UV spectra for 2,6-disubstituted derivatives, in which substituents have large spectroscopic moments,[14] such as amino and methoxy groups, or for compounds in which the direction of the transition dipole moment is known as in naphthalene.[15] As shown in Tables 5 and 6, the order of the sign of the CD band and dipole strength do not always agree with experimental values for a chemically determined configuration. The treatment also fails to explain 1,5-disubstituted derivatives. Therefore, this method was found to be inapplicable to the molecules studied here.

A. Method of calculation

The DEA derivatives are constructed from two aromatic chromophores joined by the sp^3 hybridized carbon atoms. Although σ–π interaction may play an important role in these bicyclic systems, only the π-electrons were considered in this calculation. The two chromophores are initially considered to be very far apart and a fairly well established molecular orbital method, such as the SCF-MO-CI, is applied for the separate subsystems. As MO, for these subsystems we adopted the molecular orbitals obtained by Nishimoto and Forster.[16] When the two aromatic chromophores are joined together in the atomic co-ordinate of the DEA skeleton, the molecular orbitals of the DEA derivatives are described in terms of the linear combination of singly excited configurations. In the calculation using the composite system,[17] the two centre repulsion integrals (γ_{ij}) should be estimated from the angular-dependency of the

TABLE 5. EXPERIMENTAL AND CALCULATED ROTATIONAL AND DIPOLE STRENGTHS USING DIPOLE COUPLING TREATMENT

Compd	Found				Sym.	Calcd			
	UV		CD						
	λ (mμ)	D ($\times 10^{-36}$ cgs)	λ (mμ)	R ($\times 10^{-40}$ cgs)		λ (mμ)	D ($\times 10^{-36}$ cgs)	R ($\times 10^{-40}$ cgs)	ν (cm^{-1})
(+)-37			330	+0·14	B	320	0·25	+1·28	+4·3
	324	0·27	326	−0·02	A		0·02	−1·28	
	283	4·2	304	+45·1	B	290	18·0	−226	+101
	274	18·0	282	−61·1	A		4·2	+226	
	232	149	236	+356	B	220	149	−1089	+2600
	221	10·0	222	−215	A		10·0	+1089	

The value of the dipole strengths D_A and D_B, the rotational strengths R_A and R_B and the separation between the two transition energies $\nu_A - \nu_B$ were calculated by the following equations:

$$D_A = 2\rho^2 \cos^2 v$$

$$D_B = 2\rho^2(\cos^2 t + \cos^2 r)$$

$$R_A = -R_B = \pi\nu d\rho^2 \cos v \cdot \cos t$$

$$\nu_A - \nu_B = 2\rho^2(\cos^2 v - \cos^2 t + 2\cos^2 r)/hcd^3$$

where d: the distance between the centres of the naphthalene rings,: the transition dipole moment of naphthalene, v: the wavenumber of the transition, r, t and v: the cosines of the radial, tangential and vertical angles, respectively, between the exciton dipole and the local Cartesian axes, h: Planck's constant, c: the velocity of light.

repulsion between a pair of electrons in two 2pπ orbitals. However, as the angular-dependency would not be effective over the distances involved here, the Nishimoto–Mataga method was used.[18]

The resonance integrals (β) between two aromatic chromophores separated by an sp^3 hybridized carbon atom have been estimated variously,[19, 20] and values in the literature range from a low of $-0{\cdot}4$ eV[20] to a high of $-1{\cdot}25$ eV. In general, the β value can be approximated by the following equation:

$$\beta = \beta_0\{S/(1 + S)\}/\{(S_0/(1 + S_0)\}$$

where S represents the overlap integral and subscript 0 indicates the value for benzene ($-2{\cdot}37$ eV).

We obtained the molecular orbitals using the following resonance integrals for the nearest π-orbitals of intergroup; $\beta = 0$, $-0{\cdot}4$, $-0{\cdot}65$, $-0{\cdot}916$ and $-1{\cdot}251$ eV. The value, $-0{\cdot}916$ eV, was obtained from the above equations.

In 1928, Rosenfeld[21] derived the quantum-mechanical theory of optical activity. The rotational strength R_i is defined as the imaginary part of the scalar product of the transition electric dipole moment and transition magnetic dipole moment:

$$R_i = Im\langle\psi_0|\varepsilon|\psi_i\rangle \cdot \langle\psi_i|m|\psi_0\rangle \tag{1}$$

where

$$\varepsilon = e\sum_k r_k \quad \text{and} \quad m = \frac{eh}{4\pi imc}\sum_k r_k \times \nabla_k$$

Evaluation of the matrix of the transition electric dipole moment could be carried out through use of the dipole length expression. However, it has been shown that the rotational strength so calculated is origin dependent.[22] The equation of motion allows a transformation of the following type for the exact wave functions.[23]

$$\langle\psi_0|r|\psi_i\rangle = \frac{h}{4\pi^2 m\nu_{i0}}\langle\psi_0|\nabla|\psi_i\rangle \tag{2}$$

where

$$h\nu_{i0} = E_i - E_0$$

It has been shown[22] that rotational strengths evaluated from the dipole velocity formalisms are origin independent. However, even for quite good wave functions there can be considerable disagreement between the values of the transition electric dipole moment evaluated from the dipole velocity and dipole length formalisms,[24] though it has been reported that the dipole strengths evaluated with the dipole velocity formalism give good agreement with the data in the absence of configuration interaction with doubly excited states in π-electron wave functions.[25]

The wave functions obtained above can be written in a following form:

$$\psi_i = \sum_j C_j^i\psi_j^M + \sum_k C_k^i\psi_k^{CT} \tag{3}$$

where ψ_j^M and ψ_k^{CT} represent the jth wave function of the monomer chromophores and the kth wave function of the charge-transfer transition, respectively. The lowest

four charge-transfer transitions were only considered. The monomer wave function can be rewritten as a linear combination of configurations:

$$\psi_i^M = \sum_l \sum_m C_{lm}^i (\phi_l^{-1} \phi_m) \tag{4}$$

Then, the electric dipole and magnetic dipole moments of the monomer are approximated as follows:

$$\langle \psi_0^M | \nabla | \psi_i^M \rangle \doteqdot \sqrt{2}\, C_{00}^0 \sum_l \sum_m C_{lm}^i \langle \phi_l | \nabla | \phi_m \rangle \tag{5}$$

$$\langle \psi_i^M | m | \psi_0^M \rangle \doteqdot \frac{eh}{4\pi imc} \cdot \sqrt{2}\, C_{00}^0 \sum_l \sum_m C_{ml}^i \langle \phi_m | \boldsymbol{r} \times \nabla | \phi_l \rangle \tag{6}$$

where $\boldsymbol{r}$ is the radius vector to the electron under consideration. Expanding into a linear combination of atomic orbitals

$$\phi_1 = \sum_\alpha C_\alpha^1 \chi_\alpha \tag{7}$$

there results

$$\langle \phi_l | \nabla | \phi_m \rangle = \sum_{\text{all bond}} C_{\alpha\beta}^{lm} \langle \chi_\alpha | \nabla | \chi_\beta \rangle \tag{8}$$

with $C_{\alpha\beta}^{lm} \equiv C_\alpha^l C_\beta^m - C_\beta^l C_\alpha^m$ called the transitional bond order.[26] Non-nearest neighbour contributions are small and assumed zero in deriving (8). Also, the 2pπ orbitals only are considered.

Similarly

$$\langle \phi_m | \boldsymbol{r} \times \nabla | \phi_l \rangle = \sum_{\text{all bond}} C_{\alpha\beta}^{lm} \boldsymbol{r}_{\alpha\beta} \times \langle \chi_\beta | \nabla | \chi_\alpha \rangle \tag{9}$$

where $\boldsymbol{r}_{\alpha\beta}$ is the radius vector to the midpoint of the π bonds. 2pπ Slater orbitals were used as the atomic orbitals. Therefore, from the skew Hermitian properties of the integrals

$$\langle \chi_\alpha | \nabla | \chi_\beta \rangle = -\langle \chi_\beta | \nabla | \chi_\alpha \rangle \tag{10}$$

which property is easily seen by an integration by parts.

In our calculation, only two centre integrals are considered between 2pπ orbitals and are easily evaluated through the use of the Slater orbitals. The following values are adopted: 4·2255, 3·8731 and 3·4793 in 10^7 cm^{-1} unit for an aromatic carbon–carbon bond of length 1·395 Å, for a nitrogen–carbon bond of length 1·36 Å and for an oxygen–carbon bond of length 1·38 Å, respectively.

B. Results and discussion

The calculated results are summarized in Table 6 together with the experimental results with compound (−)-**26**. The relation between the order of the transition energies and the values of the resonance integrals is depicted in Fig 8 for the lower four transition states.

The first two excited states are largely made up of the A and B combination of the lowest energy excited configuration of the two aniline chromophores. The A- and B-symmetrical properties of the first two transitions are reversed with the change of the 1,3-resonance energies from $\beta = -0{\cdot}4$ to $-0{\cdot}65$ eV.

TABLE 6. EXPERIMENTAL AND CALCULATED ROTATIONAL (R) AND DIPOLE (D) STRENGTHS OF (−)-**26** USING VARIOUS RESONANCE ENERGIES

Found (MeOH) UV λ (mμ)	UV D (× 10^{-36} cgs)	CD λ (mμ)	CD R (× 10^{-40} cgs)	Sym.[b]	Calc. (Excition treatment)[a] D (× 10^{-36} cgs)	R (× 10^{-40} cgs)	$\nu_A - \nu_B$ (cm^{-1})	Sym.	Calc. (β = 0 eV) λ (mμ)	R (× 10^{-40} cgs)	D (× 10^{-36} cgs)	Sym.	Calc. (β = −0·4 eV) λ (mμ)	R (× 10^{-40} cgs)	D (× 10^{-36} cgs)
293	4·37	294	−20·1	A	0·27	−22·2	−81·8	A	282·3	−2·24	0·09	A	281·8	−1·83	0·09
				B	4·10	+22·2		B	281·6	−0·56	1·81	B	281·6	−0·32	1·83
234	28·8	253	+59·4	B	23·4	−184	+1840	B	230·5	−109·4	16·0	B	230·0	−118·4	15·9
		232	−56·4	A	5·4	+184		A	227·9	+195·3	2·01	A	228·4	+84·0	2·00
												B	208·4	−1·99	0·25
												A	207·6	+7·59	0·12
203	45·0	210	−119·0									A	199·5	−21·4	0·17
												B	198·5	+4·89	0·65
								A	195·1	−80·2	0·36	A	193·4	−57·2	0·27
								B	193·8	+105·0	15·9	B	193·1	+101·2	14·3
								B	188·6	−218·6	22·9	B	187·8	−232·0	24·5
								A	183·0	+239·7	5·87	A	182·3	+223·7	6·65

Sym.	Calc. (β = −0·65 eV) λ (mμ)	R (× 10^{-40} cgs)	D (× 10^{-36} cgs)	Sym.	Calc. (β = −0·916 eV) λ (mμ)	R (× 10^{-40} cgs)	D (× 10^{-36} cgs)	Sym.	Calc. (β = −1·251 eV) λ (mμ)	R (× 10^{-40} cgs)	D (× 10^{-36} cgs)
B	281·5	−0·56	1·79	B	281·5	−0·89	1·72	B	281·4	−1·46	1·62
A	281·1	−1·85	0·08	A	280·0	−1·89	0·08	A	278·1	−1·97	0·08
B	229·6	−120·3	16·2	A	230·8	+73·9	1·62	A	232·7	+68·2	1·39
A	229·4	+79·1	1·81	B	228·9	−123·2	16·7	B	227·8	−128·1	17·5
B	208·2	−4·70	0·60	B	207·9	−78·6	1·01	B	207·3	−11·1	1·46
A	206·5	+17·8	0·22	A	205·4	+25·1	0·19	A	204·7	+17·3	0·05
A	199·9	−36·0	0·40	A	199·6	−43·8	0·84	A	197·6	−33·5	1·59
B	198·1	+11·6	1·58	B	197·5	+19·8	2·81	B	196·4	+29·6	4·49
B	192·4	+96·0	13·2	B	191·4	+88·9	11·9	B	189·0	+78·8	10·1
A	191·7	−51·6	0·27	A	189·7	−50·5	0·32	A	187·0	−50·3	0·46
B	187·2	−226·7	23·6	B	186·1	−218·3	22·4	B	184·4	−203·8	20·5
A	182·0	+228·3	6·37	A	181·3	+235·1	5·97	A	179·9	+242·2	5·31

[a] Calculated by the procedure cited in Table 5.
[b] Symmetry of the upper state in the group C_2.

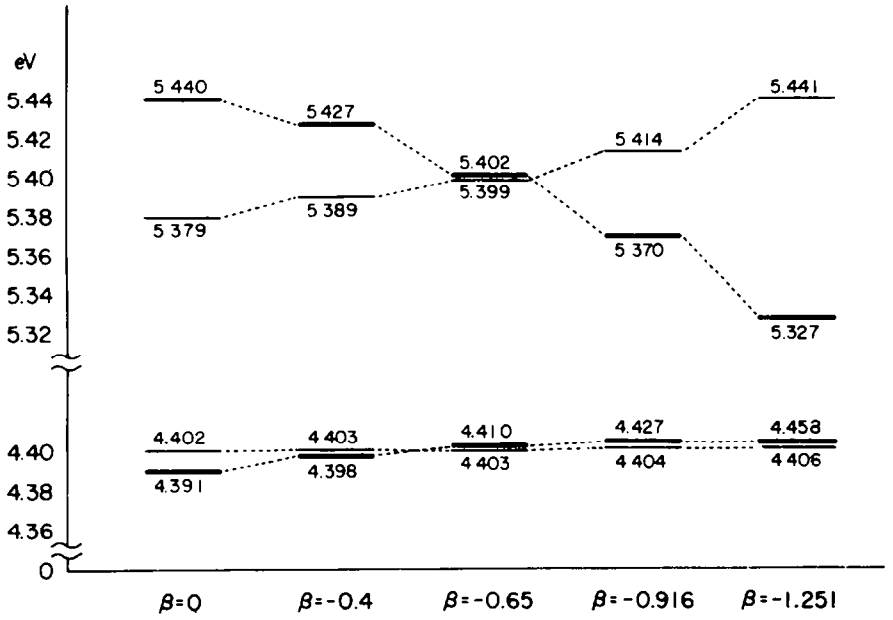


FIG 8. Sequence of the first four excitation energies in (−)-**26**. The narrow and the bold lines show the A and the B combinations of the C_2 symmetry, respectively

The second pair of excited states of (−)-**26** largely represent the A and B combination of the next lowest energy localized excitation of the two aniline groups. Inversion is also observed in these transitions with change of the 1,3-resonance energies from $\beta = -0{\cdot}65$ to $-0{\cdot}916$ eV.

In the higher energy regions, excitations involving lone pair and σ-orbitals doubtless contribute to the molecular orbitals and this contribution is beyond the scope of the π-SCF method.

The calculated energies and the rotational strengths of these transitions were converted into a theoretical CD spectrum on the assumption that the spectrum represented a sum of Gaussian bands.[1]

$$[\theta]_\lambda = \frac{1}{1{\cdot}233 \times 10^{-42}} \sum_i R_i \frac{\lambda_i}{\Delta_i} \exp\left[-\frac{\lambda - \lambda_i}{\Delta_i}\right]^2$$

Where λ_i is the wavelength corresponding to the maximum ellipticity and Δ_i is the half-width and is approximated to 10 mμ in all transitions whose values were deduced from the experimental UV curves. Using this equation and the values, we plotted the theoretical CD curves in the case of the $\beta = 0$ and $-1{\cdot}251$ eV in Fig 9.

The theoretical CD spectra obtained using $\beta = -0{\cdot}916$ and $-1{\cdot}251$ eV agrees better with the experimental one than those using other β values, although the experimental spectra still show lower energies owing to the direct use of the local excitation energies from the calculated molecular orbital of aniline instead of the benzobicyclic derivative.

For the α-band region, the maximum of the CD curve is coincident with that of the absorption curve. The calculated rotational strengths for the first two transitions are not opposite in sign and are identical with the experimental values. The calculation

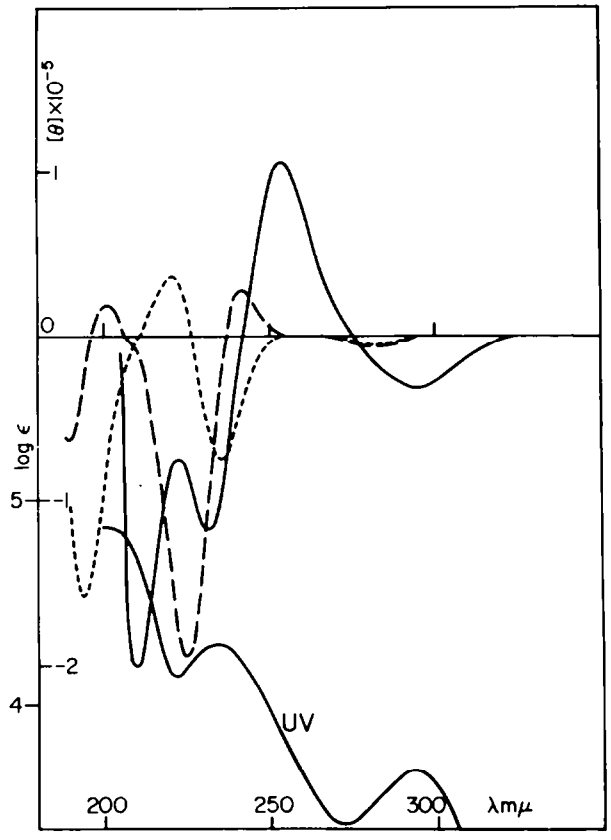


FIG 9. CD spectra of (−)-**26**. The experimental spectrum (——) refers to EtOH solution and the theoretical spectra to calculations based on consideration of the value of the resonance integral (β = −1·251 eV) (– – – –) and without the resonance integral (· · · · · ·)

using $\beta = 0$ is the same as that using simple dipole coupling in the adoption of only the electrostatic repulsion term, but different in the radius vector to the electron (r). By comparison of both results (Table 5 and Table 6), the point dipole approximation in the simple dipole coupling would seem to be unsuitable in this case. The magnetic dipole transition moment directed perpendicularly to the benzene plane[27] and other factors must work to produce the Cotton effect.

For the p-band region, the maximum of the longer wavelength in the CD curve corresponds to the shoulder of the absorption bands and maximum of the shorter wavelength in the CD band to the maximum of the absorption bands. Thus, the two split CD bands are the same in magnitude but the dipole strength of the longer wavelength is smaller than that of the shorter one. The sequence of the calculated CD and absorption bands using the resonance integrals β = −0·916 and −1·251 eV agrees with experiment. But in other cases, the calculated and the experimental CD and absorption band sequences are opposite to each other (Fig 9). This change of the sequence would be caused by the appropriate mixing of the charge-transfer transition mentioned above. Therefore, the charge-transfer transition must be estimated precisely in the DEA derivatives.

TABLE 7. ROTATIONAL (R) AND DIPOLE (D) STRENGTHS OF (+)-**31** AND (+)-**9**

(+)-**31**

Found UV λ (mμ)	Found UV D (× 10 ^{36} cgs)	Found CD λ (mμ)	Found CD R (× 10^{-40} cgs)	Sym.	Calc. (Exciton treatment) D (× 10^{-36} cgs)	Calc. (Exciton treatment) R (× 10^{-40} cgs)	$\nu_A - \nu_B$ (cm^{-1})	Sym.	Calc. (β = −0·916 eV) λ (mμ)	Calc. (β = −0·916 eV) R (× 10^{-40} cgs)	Calc. (β = −0·916 eV) D (× 10^{-36} cgs)
285	2·26	280	~0	A	0·17	+14·7	−51·7	B	268·5	−1·04	1·00
266	0·49	274	+8·10	B	2·58	−14·7		A	266·2	+2·27	0·06
239	1·93	242	−61·0	B	8·27	+65·0	+647	A	219·7	−25·3	0·97
227	8·25	224	+74·0	A	1·91	−65·0		B	211·7	+70·4	9·36
199	57·1							B	199·0	+53·0	5·88
								A	196·4	+10·4	0·81
								A	192·0	+39·3	0·06
								B	188·7	−25·0	4·12
								B	185·8	−2·03	19·4
								A	181·9	−48·3	0·17

(+)-**9**

Found UV λ (mμ)	Found UV D (× 10 ^{36} cgs)	Found CD λ (mμ)	Found CD R (× 10^{-40} cgs)	Sym.	Calc. (β = −0·916 eV) λ (mμ)	Calc. (β = −0·916 eV) R (× 10^{-40} cgs)	Calc. (β = −0·916 eV) D (× 10^{-36} cgs)
292	4·55	297	+17·2	B	283·0	+23·7	1·84
		276	−3·24	A	278·5	−13·3	0·42
				A	229·6	−1·73	~0
236	16·6	237	+81·8	B	225·5	+19·0	12·3
		214	+36·7	A	215·0	+24·2	0·11
				B	214·4	+12·6	1·69
208·5	31·0	202	−77·6	A	202·4	+27·9	0·06
				B	201·8	−1·48	0·82
				A	200·7	−9·80	0·01
				B	199·7	+1·00	10·9
				A	190·3	−73·3	3·61
				B	184·6	+20·8	18·8

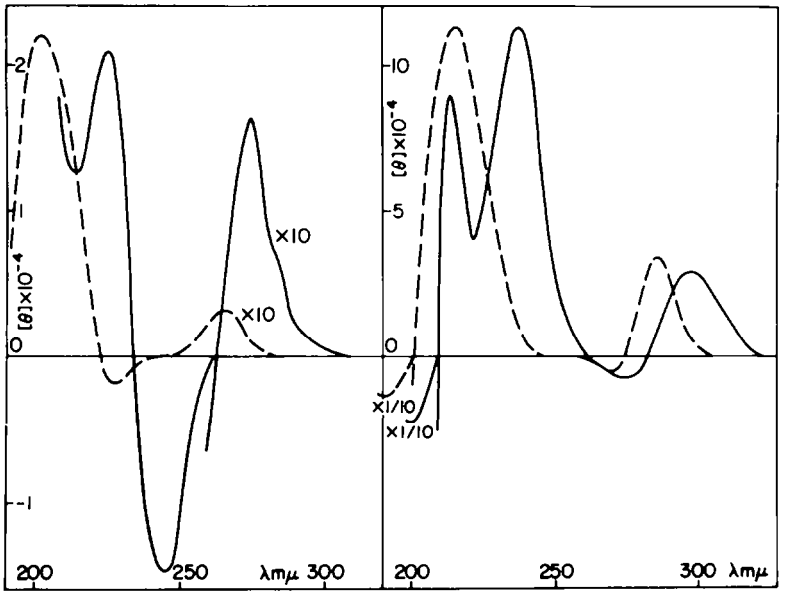


FIG 10. CD spectra of (+)-**9** (right curves) and (+)-**31** (left curves). The experimental spectra (———) refer to MeOH and dioxane solution to (+)-**9** and (+)-**31**, respectively and the theoretical spectra to calculations using the resonance integral (β = −0·916 eV) (– – – –)

We obtained the theoretical CD spectra for compounds (+)-**9** and (+)-**31** by the same method and in these calculations, the exchange integral was estimated with the aid of the relation between exchange and overlap integrals cited above.[20] The results are shown in Table 7 and Fig 10 and the agreement between the calculated and experimental result is almost quantitative.

Compound (+)-**37** shows couplets in all three absorption regions accessible by the apparatus and in the first and the second absorption regions from longer wavelength, the CD maximum of the longer wavelength in the couplet corresponds to the shoulders of the absorption bands and that of shorter ones to the maxima (Fig 11 and Table 3). The calculated sequence of the sign in the CD spectrum using the point-dipole exciton treatment agrees with the experimental in the region of the long axis polarization of naphthalene (about 320 and 220 mμ region), but is opposite in the short axis transition region (about 290 mμ) (Table 5). As the magnitude of the dipole strength shows an opposite pattern between experimental and calculated values in the short axis excitation region, it is deduced that the neglect of the charge-transfer transition leads to the incorrect sequence of the excitation energies, as was discussed for compound (−)-**26**.

CONCLUSION

The optical activity of DEA compounds may be deduced by consideration of the following factors: (1) the substituents at the benzene rings; the point electronic transition dipoles are not located at the centre of benzene rings and thus dipole

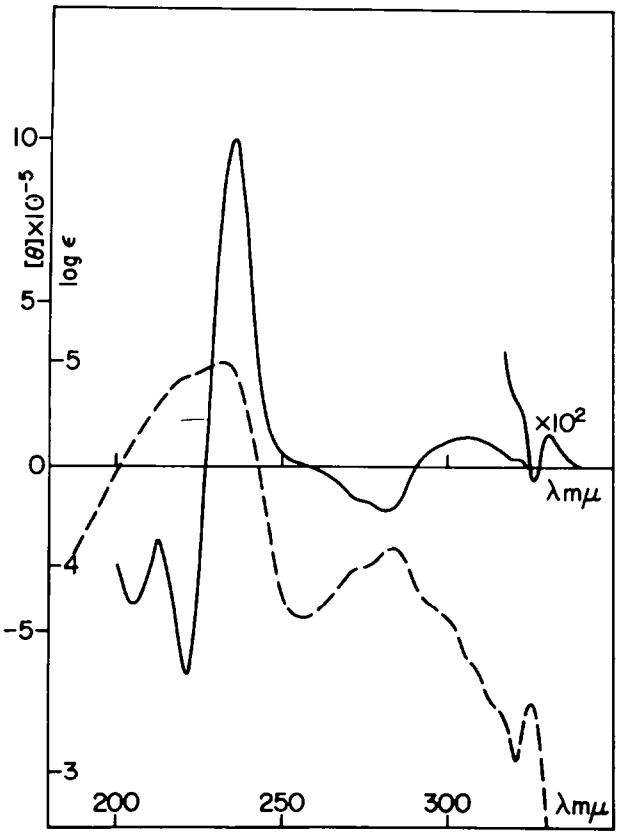


FIG 11. CD (———) and UV (- - - -) spectra of (+)-37

coupling plays an important role in optical activity; even in 1,5-disubstituted DEA. (2) The dipole moments of the transitions responsible for the α- and *p*-bands of the local chromophores are orthogonal and they do not mix, but in the DEA derivatives the transitions of the same symmetry derived from different aromatic chromophore excitations interact and the rotational strength is to some extent redistributed between the different band systems. (3) Also in substituted benzene chromophores, a magnetic moment is produced perpendicular to the benzene plane in the α-band.[27] (4) The charge-transfer transition between two aromatic chromophores is possible in these compounds through space interaction of two aromatic π-bonds and through bond interaction, and in addition to the direct contribution of the charge-transfer transition to the optical activity, the order of the A and B combination, in the group C_2, of the localized excitation energies of the two aromatic chromophores may be different from the one obtained from the simple exciton treatment.

If the first factor plays an important role in the optical activity, the CD curve should show a couplet pattern. Experimentally, a coupling pattern could not be observed in the 1,5-disubstituted DEA derivatives. The calculated results suggest that the first factor is smaller than the second. Furthermore the calculated results suggest that though the magnetic moment cited as the third factor is not large it cannot be

ignored in the α-band region, as rotational strengths of only small magnitudes are observed in this region. This was especially shown in the α-band region of the 2,6-disubstituted DEA, which was expected to show a couplet. As observed in the *p*-band region of the 2,6-disubstituted DEA, the last factor must be considered to play an important part, in the prediction of the absolute configuration of DEA derivatives, because the simple exciton coupling treatment give the incorrect order of the A and B combination of the coupling mode.

Therefore these four factors, expecially the last, must be examined to analyse the CD and UV spectra of molecules having homo-conjugated chromophores.

EXPERIMENTAL

M.ps are uncorrected. IR spectra were carried out using a JASCO Model DS 402G doublemonochromatic spectrophotometer. Optical rotations were measured on a Perkin–Elmer polarimeter Model 141 using a 1-dm cell. CD spectra were taken with a JASCO Model ORD/UV-6. NMR spectra were measured with a Varian A-60 spectrometer in $CDCl_3$ using TMS as internal standard. UV spectra were measured with a Hitachi Model EPS-3T spectrometer.

Dimethyl-DEA-11(endo),12(endo)- and 11(exo),12(exo)-*dicarboxylate*-1,5-*dicarboxylic acid* (**1** and **2**). 1,5-Anthracene dicarboxylic acid[4] (5·0 g), dimethyl fumarate (25 g) and dioxane (100 ml) were heated under reflux for 54 hr. Dioxane was distilled under reduced pressure and $CHCl_3$ (100 ml) added. The recovered dicarboxylic acid (95 mg) was removed by filtration. The adducts were extracted with $NaHCO_3$ aq and then acidified with dil. HCl. The crystals were collected, washed with water and dried *in vacuo* to give a powder (4·72 g, 75·7%), m.p. >300°. Attempts at fractional recrystallization from several solvents failed. (Found: C, 64·32; H, 4·89. $C_{24}H_{18}O_4$ requires: C, 64·39; H, 4·42%).

Resolution and isolation of **1** *and* **2**. The mixture of the acids (**1** and **2**, 17·6 g), brucine dihydrate (32·5 g) and MeOH (500 ml) were heated under reflux for 30 min and allowed to stand at room temp. overnight. Crystals were filtered and recrystallized from MeOH three times to give one diastereomer in prisms (10·6 g). $[\alpha]_D$ −33·3° (MeOH, *c* 0·195).

The mother liquor from the first recrystallization was concentrated to 200 ml and the crystals were collected by filtration and recrystallized three times from MeOH to give the other diastereomer as needles (2·5 g), $[\alpha]_D$ +50·2° (MeOH, *c* 0·233).

The (−)-salt (10·6 g) was suspended in EtOAc and dil. HCl was added. The mixture was shaken for 30 min. The organic layer was separated and the aqueous layer extracted with EtOAc. The combined EtOAc layer was washed with water and dried (Na_2SO_4). Solvent was distilled under reduced pressure and the residue recrystallized from MeOH to give prisms (**1**, 3·08 g), m.p. >300°. $[\alpha]_D$ −70·3° (MeOH, *c* 0·266); IR ν_{max}^{Nujol} cm^{-1}: 1730, 1695. (Found: C, 64·21; H, 4·62. $C_{22}H_{18}O_4$ requires: C, 64·39; H, 4·42%).

The (+)-salt (2·5 g) was treated in a similar manner and the product recrystallized from EtOAc to give a powder (**2**, 679 mg), m.p. >300°. $[\alpha]_D$ +256·1° (MeOH, *c* 0·123); IR ν_{max}^{Nujol} cm^{-1}: 1740, 1692. (Found: C, 64·58; H, 4·47. $C_{22}H_{18}O_4$ requires: C, 64·39; H, 4·42%).

(−)-*Dimethyl*-1,5-*dihydroxymethyl*-DEA-11(endo),12(endo)-*dicarboxylate* ((−)-**5**). A solution of diborane[5] in THF (50 ml), prepared by the addition of $NaBH_4$ (1·8 g) in diglyme to BF_3 etherate (25 g), was added to a suspension of (−)-diacid (**1**, 5·6 g) in THF (250 ml) at room temp. with vigorous stirring under N_2. The mixture was stirred for 48 hr at room temp. and decomposed with dil. HCl (50 ml). THF was distilled under reduced pressure and the residue extracted with $CHCl_3$. The organic solution was washed with $NaHCO_3$ aq and water and then dried (Na_2SO_4). The solvent was removed by distillation and the residue crystallized from benzene–$CHCl_3$ to give a powder (3·73 g, 71·5%), m.p. 141–143°. $[\alpha]_D$ −17·7° (MeOH, *c* 0·305); IR ν_{max}^{Nujol} cm^{-1}: 3609, 3525 (3·60 mg in 10 ml). (Found: C, 69·11; H, 5·79. $C_{22}H_{22}O_6$ requires: C, 69·10; H, 5·80%).

(−)-*Tetramethyl*-DEA-1,5,11(endo),12(endo)-*tetracarboxylate* ((−)-**3**). (−)-Diacid ((−)-**1**, 30 mg) in ether (2 ml) was treated with a solution of excess CH_2N_2 in ether. Ether and excess CH_2N_2 were distilled and the residue crystallized from CCl_4 *n*-hexane to give prisms (23 mg), m.p. 125–126°. $[\alpha]_D$ −82·2° (dioxane, *c* 0·255). Dipole moment μ = 2·88 Debye (benzene). NMR τ: 6·63 (2H, dd, *J* = 2·0, 1·5 Hz), 6·41 (6H, s), 6·06 (6H, s), 4·00 (2H, bs), 2·82 (2H, t, *J* = 7·0 Hz), 2·42 (2H, dd, *J* = 7·5, 2·0 Hz), 2·27 (2H, dd, *J* = 7·5, 1·5 Hz). IR ν_{max}^{Nujol} cm^{-1}: 1730, 1725. (Found: C, 65·31; H, 5·05. $C_{24}H_{22}O_8$ requires: C, 65·75; H, 5·06%).

(+)-*Tetramethyl*-DEA-1,5,11(exo),12(exo)-*tetracarboxylate* ((+)-**4**). (+)-Dicarboxylic acid (**2**, 530 mg) was

treated as described in the preparation of compound (−)-**3**. Recrystallization from benzene-*n*-hexane gave a powder (486 mg), m.p. 156–158°. $[\alpha]_D$ +239·3° (dioxane, *c* 0·234); IR ν_{max}^{Nujol} cm^{-1}: 1738, 1730; NMR τ: 6·60 (2H, d, *J* = 1·0 Hz), 6·38 (6H, s), 6·06 (6H, s), 3·88 (2H, bs), 2·86 (2H, t, *J* = 8·0 Hz), 2·52 (2H, dd, *J* = 7·0, 2·0 Hz), 2·22 (2H, dd, *J* = 7·0, 1·8 Hz). Dipole moment μ = 2·90 Debye (benzene). (Found: C, 66·46; H, 5·17. $C_{24}H_{22}O_4$ requires: C, 65·75; H, 5·06%).

(+)-11(exo),12(exo)-*Dicarbomethoxy*-DEA-1,5-*dicarboxylic acid chloride* ((+)-**6**). (+)-Dicarboxylic acid (**2**, 1·48 g) and $SOCl_2$ (4·0 g) were warmed at 60° (bath temp.) for 1 hr. Excess $SOCl_2$ was distilled under reduced pressure and the residue recrystallized from benzene-*n*-hexane to give a powder (1·45 g, 89·8%), m.p. 211–215°. $[\alpha]_D$ +285·8° (dioxane, *c* 0·219); IR ν_{max}^{Nujol} cm^{-1}: 1758, 1728. (Found: C, 58·98; H, 3·89; Cl, 15·29. $C_{22}H_{16}O_6Cl_2$ requires: C, 59·08; H, 3·61; Cl, 15·85%).

(+)-11(exo),12(exo)-*Dicarbomethoxy*-DEA-1,5-*dicarboxylic acid azide* ((+)-**7**). A solution of NaN_3 (443 mg) in water (5 ml) was added to a solution of (+)-acid chloride ((+)-**6**, 1·44 g) in acetone (60 ml) in one portion under cooling in ice. The mixture was stirred for 15 min at 0° and poured on ice (100 ml). Crystals were filtered, washed with ice water and dried *in vacuo* to give a powder (1·41 g, 95·4%), m.p. 116–117° (dec). $[\alpha]_D$ +395·3° (dioxane, *c* 0·149); IR ν_{max}^{Nujol} cm^{-1}: 2150. (Found: C, 57·19; H, 3·32; N, 18·08. $C_{22}H_{16}O_6N_6$ requires: C, 57·39; H, 3·50; N, 18·26%).

(+)-11(exo),12(exo)-*Carbomethoxy*-DEA-1,5-*diisocyanate* ((+)-**8**). A solution of acid azide ((+)-**7**, 1·41 g) in benzene (25 ml) was heated under reflux for 6 hr. The solution was concentrated to *ca.* 5 ml and pentane added drop by drop. The crystals were collected by filtration and washed with benzene–pentane to give a powder (1·046 g), m.p. 114–118°. $[\alpha]_D$ +241·0° (dioxane, *c* 0·266); IR ν_{max}^{Nujol} cm^{-1}: 2260, 1740.

(+)-*Dimethyl*-1,5-*diamino*-DEA-11(exo),12(exo)-*dicarboxylate* ((+)-**9**. A mixture of (+)-diisocyanate ((+)-**8**, (1·03 g) and conc. HCl (30 ml) was heated under reflux for 4 hr and concentrated to *ca.* 10 ml. Crystals were collected by filtration and dried *in vacuo* (955 mg). The IR ν_{max}^{Nujol} cm^{-1}: 1732, 1695, 3200–2400, showed a mixture of carboxylic acid and ester. Therefore, a mixture of this crude product with conc. H_2SO_4 (1 ml) and abs. MeOH (20 ml) was heated under reflux for 6 hr and poured into 6N NH_4OH (50 ml) under cooling in ice. The mixture was extracted with $CHCl_3$ and the organic solution washed with water and dried (Na_2SO_4). $CHCl_3$ was removed under reduced pressure and the residue crystallized from MeOH–water. Recrystallization from MeOH gave needles (501 mg), m.p. 143–146°. $[\alpha]_D$ +189·2° (MeOH, *c* 0·379); IR ν_{max}^{Nujol} cm^{-1}: 3340, 1732. (Found: C, 66·89; H, 6·03; N, 7·64. $C_{20}H_{20}N_2O_4$ requires: C, 68·17; H, 5·72; N, 7·95%).

(+)-*Dimethyl*-1,5-*dichloro*-DEA-11(exo),12(exo)-*dicarboxylate* ((+)-**10**). A solution of $NaNO_2$ (80 mg) in water (2 ml) was dropped into a solution of (+)-diamine ((+)-**9**, 200 mg) in conc. HCl (3 ml) and water (1 ml) at 0° with stirring. Stirring was continued for one hr at 0°. This solution was added to freshly prepared CuCl[34] at 70° with stirring. After five min conc. HCl (3 ml) was added in one portion and the mixture allowed to stand at room temp. overnight. The precipitate was collected, washed with water and dried *in vacuo*. This crude product was chromatographed on alumina (4 g, Woelm Co., act. II) in benzene (200 ml). The elute was concentrated and crystallized from CCl_4-*n*-hexane to give a powder (13·8 mg, 6·2%), m.p. 148·5–150°. $[\alpha]_D$ +164·3° (MeOH, *c* 0·227); IR ν_{max}^{Nujol} cm^{-1}: 1733, 791. (Found: C, 61·63; H, 4·20; Cl, 18·29. $C_{20}H_{16}O_4Cl_2$ requires: C, 61·39; H, 4·12; Cl, 18·12%).

(+)-*Dimethyl*-DEA-11,12(trans)-*dicarboxylate* ((+)-**11**). (+)-Diamino derivative ((+)-**9**, 245 mg) was diazotized according to the procedure described for the synthesis of compound (+)-**10**. This diazonium salt was poured onto 30% pyrophosphite (3 ml) and allowed to stand at room temp. for 4 hr. The solid was collected, washed with water and chromatographed on alumina (Act. II, Woelm Co., 10 g) in benzene. The crystals were purified by recrystallization from *n*-hexane (51 mg), m.p. 91–92°. $[\alpha]_D$ +20·3° (MeOH, *c* 0·290). (Found: C, 73·69; H, 5·53. $C_{20}H_{18}O_4$ requires: C, 74·52; H, 5·63%).

Resolution of DEA-11,12-trans-*dicarboxylic acid* ((+)-**12**). DEA-11,12-*trans*-dicarboxylic acid[29] and cinchonidine (4·0 g) were dissolved in warm MeOH (70 ml). Solvent was evaporated to dryness, acetone (100 ml) added to the residue and the mixture allowed to stand overnight. Crystals were collected and recrystallized from methanolic acetone (1 : 1) three times to give a pure diastereomer (1·174 g), $[\alpha]_D$ −79·7° (MeOH, *c* 0·402). This salt was suspended in ether and 6N HCl (20 ml) was added. The mixture was shaken for 10 min and the ether layer separated, washed with water and dried (Na_2SO_4). Ether was stripped off and the residue crystallized from benzene to give a powder (325 mg), m.p. 226–227°. $[\alpha]_D$ +7·9° (MeOH, *c* 0·795).

(+)-*Dimethyl*-DEA-11,12-trans-*dicarboxylate* ((+)-**11**). (+)-Acid (**11**, 83 mg) was treated as described for the synthesis of compound (−)-**3**. The residue was crystallized from CCl_4-*n*-hexane to give prisms, m.p. 89–91°. $[\alpha]_D$ +21·7° (MeOH, *c* 0·1476). (Found: C, 74·56; H, 5·65. $C_{20}H_{18}O_4$ requires: C, 74·55; H, 5·63%).

Hydrolysis of (+)-*dimethyl*-DEA-11,12-trans-*dicarboxylate*. (+)-Dimethylester ((+)-**11**, 36 mg) and a

10% solution of KOH in MeOH (5 ml) were heated under reflux for 2 hr. The solution was cooled, 6N HCl (15 ml) added, and the mixture extracted with ether. The ether layer was washed with water and dried (Na_2SO_4). Ether was evaporated and the crystalline residue recrystallized from methanolic water. $[\alpha]_D$ 0° (MeOH, *c* 0·517).

2,6-*Dichloroanthracene* (**14**). 2,6-Dichloroanthraquinone[30] (33·0 g) was suspended in 28% NH_4OH (1·16 l) and Zn powder (50 g) was slowly added with stirring. The mixture was warmed for 12 hr, initially at 50° with the temperature being gradually raised to 90°. NH_4OH (200 ml) and Zn dust (10 g) were added little by little during this period. The colour of the mixture gradually changed from reddish wine to grey. Precipitate was filtered, washed and dried *in vacuo*. The organic product was continuously extracted with xylene and crystallized from xylene (7·5 g, 25·4%). A small portion of the product was sublimed at 200°/3 mm, m.p. 273–274°. IR ν_{max}^{Nujol} cm^{-1}: 901, 799. (Found: C, 67·98; H, 3·24; Cl, 28·62. $C_{14}H_8Cl_2$ requires: C, 68·04; H, 3·26; Cl, 28·74%).

1,5-*Dichloro*-11(endo *and* exo)-*cyano*-DEA (**15**). A mixture of 1,5-dichloroanthracene[31] (18·6 g), freshly distilled acrylonitrile (75 ml) and hydroquinone (0·3 g) in dry benzene (300 ml) was heated at 150° in a sealed tube for 12 hr. A small amount of insoluble solid was removed by filtration. The IR spectrum showed that it was polymeric material and was discarded. Solvent was evaporated from the mother liquor, and the residue crystallized from benzene–CCl_4 (3:10). Two recrystallizations from benzene gave colourless prisms (*endo*- or *exo*-**18**, 7·32 g, 32·4%), m.p. 227–228°. NMR τ: 8·07 (1H, td, J = 12·8, 5·5, 2·8 Hz), 7·68 (1H, dd, J = 12·8, 3·0 Hz), 6·83 (1H, d, J = 2·8 Hz), 5·08 (1H, t, J = 2·5 Hz), *ca.* 2·75 (6H, m). IR ν_{max}^{Nujol} cm^{-1}: 2238, 792, 784. (Found: C, 68·10; H, 3·74; Cl, 23·45; N, 4·48. $C_{17}H_{11}Cl_2N$ requires: C, 68·02; H, 3·69; Cl, 23·62; N, 4·67%).

All of the mother liquors were collected, the solvent evaporated, and the residue once recrystallized from CCl_4. Leaflets (*endo*- or *exo*-**18** 7·19 g, 31·8%) were obtained by two recrystallizations from 99° EtOH, m.p. 174–177°. NMR τ: 8·10 (1H, td, J = 13·0, 6·0, 2·6 Hz), 7·72 (1H, dd, J = 12·0, 3·0 Hz), 6·93 (1H, d, J = 2·5 Hz), 5·09 (1H, t, J = 2·5 Hz), *ca.* 2·8 (6H, m). IR ν_{max}^{Nujol} cm^{-1}: 2240, 792. (Found: C, 68·39; H, 3·69; Cl, 23·62; N, 4·67. $C_{17}H_{11}Cl_2N$ requires: C, 68·02; H, 3·69; Cl, 23·62; N, 4·67%).

Methyl-1,5-*dichloro*-DEA-11(endo *and* exo)-*carboxylate* (**16**). (a) Adduct **15** (m.p. 227–8°, 8·03 g) was suspended in a mixture of ether (250 ml) and MeOH (40 ml).

A stream of anhyd HCl was passed through the suspension under cooling for 15 min then the flask was stoppered and allowed to stand at room temp. for 2 days. The solvent was evaporated under reduced pressure and the residue crystallized from CCl_4–*n*-hexane. Hydrolysis to the methylester was accomplished by heating the salt under reflux for 2 hr with a mixture of MeOH (100 ml), conc HCl (25 ml), and water (25 ml). After cooling, solid was collected (6·16 g, 69%). Recrystallization from EtOH gave colourless needles (**16**), m.p. 166·5–168°. NMR τ: *ca.* 8·0 (2H, m), 7·14 (1H, td, J = 10·0, 5·0, 3·0 Hz), 6·38 (3H, s), 5·15 (1H, t, J = 3·0 Hz), 4·82 (1H, d, J = 2·5 Hz), *ca.* 2·9 (6H, m). IR ν_{max}^{Nujol} cm^{-1}: 1738, 792. (Found: C, 64·88; H, 4·37; Cl, 21·43. $C_{18}H_{14}Cl_2O_2$ requires: C, 64·88; H, 4·23; Cl, 21·28%).

(b) Adduct **15** (m.p. 174–7°, 6·07 g) was hydrolyzed to the methylester according to the above procedure. Recrystallization from MeOH gave colourless prisms (5·67 g, 84·2%) (**16**), m.p. 130–3°. NMR τ: *ca.* 8·0 (2H, m), 7·15 (1H, td, J = 10·0, 5·5, 2·5 Hz), 6·42 (3H, s), 5·15 (1H, t, J = 3·0 Hz), 4·82 (1H, d, J = 3·0 Hz), *ca.* 2·8 (6H, m). IR ν_{max}^{Nujol} cm^{-1}: 1734, 784. (Found: C, 65·02; H, 4·32; Cl, 20·69. $C_{18}H_{14}Cl_2O_2$ requires: C, 64·88; H, 4·23; Cl, 21·28%).

(c) A mixture of 1,5-dichloroanthracene (25 g), freshly distilled methylacrylate, and hydroquinone (100 mg) in dry benzene (60 ml) was treated as described for the preparation of compound **15**. The polymeric product was removed by column chromatography on alumina (Woelm Co., act. III, 80 g) in CCl_4 (1·5 l). The two isomers were then separated by fractional recrystallization from MeOH. The ratio of the yield of the higher melting isomer (10·5 g, 31·1%) to the lower melting one (9·26 g, 27·5%) was almost 1:1.

1,5-*Dichloro*-DEA-11(endo *and* exo)-*carboxylic acid* (**17**). A mixture of the higher melting methyl ester (**16**, m.p. 166·5–8°, 7·39 g), KOH (14 g), and MeOH (140 ml) was heated under reflux for 2 hr. Half the EtOH was distilled off and the solution poured into ice water (500 ml). After treating with Norit, the solution was acidified with conc. HCl and crystals which formed were collected, washed with water and dried. Recrystallization from MeOH gave a colourless powder (6·64 g, 93·8%) which did not show a sharp melting point.

The lower melting methyl ester (**16**, m.p. 130–3°, 6·96 g) was hydrolyzed in a similar manner, but this product (6·06 g, 90·4%) also did not have a sharp m.p.

Both products were thought to be mixtures of the *endo*- and *exo*-carboxylic acid, but no separation was achieved by fractional recrystallization. The carboxylic acid (200 mg) obtained from the higher m.p. ester was esterified by heating under reflux with MeOH (6 ml) and two drops of conc. H_2SO_4 for 7 hr. The

solution was poured on ice-water (30 ml) and extracted with benzene. The benzene solution was washed with $NaHCO_3$ aq and water. After evaporation of benzene, the residue was fractionally recrystallized from MeOH to give two esters, needles (**16**, 13 mg), m.p. 166–168° and prisms (**16**, 118 mg), m.p. 130–132°.

Similarly, the carboxylic acid (199 mg) obtained from the ester of lower m.p. was esterified to give two isomers, needles (**16**, 83·9 mg) and prisms (**16**, 30·6 mg).

Resolution of the mixture of carboxylic acids ((−)-**18**). To the mixture of carboxylic acids (**17**, 8·57 g) dissolved in EtOAc (100 ml) and EtOH (100 ml), (−)-phenethylamine (3·35 g) in EtOAc (5 ml) was added in one portion. The solution was warmed at 60° for 1 hr and evaporated to *ca.* 40 ml. To this residue, EtOAc (150 ml) was added. The crystals, $[\alpha]_D$ −30·6° (MeOH, *c* 0·466), were collected and recrystallized from acetone (5×) to give the pure diastereomer (1·348 g), m.p. 218–223°. $[\alpha]_D$ −127·6° (MeOH, *c* 0·261). The mother liquors of the recrystallizations were collected and concentrated to dryness. The residue was recrystallized from acetone (5×) to give another product (1·20 g), m.p. 267–269°. $[\alpha]_D$ −1·9° (MeOH, *c* 0·467). The salt (1·34 g, $[\alpha]_D$ −127·6°) was suspended in ether (20 ml) and decomposed by addition of dil. HCl. After usual treatment, the product was recrystallized from methanolic water to give colourless plates (88·3 mg), m.p. 225–227°. $[\alpha]_D$ −159·1° (MeOH, *c* 0·132); IR ν_{max}^{Nujol} cm^{-1}: 1705, 788.

The other salt (1·20 g, $[\alpha]_D$ −1·9°) was treated in a similar manner, but the product (816 mg) did not show optical activity, m.p. 270–271°.

(−)-1,5-*Dichloro*-DEA-11-*ammonium bromide* ((−)-**19**). A mixture of (−)-acid ((−)-**18**, 845 mg) and $SOCl_2$ (2·0 g) in dry THF was heated under reflux for 1 hr. The solvent and excess $SOCl_2$ were distilled under reduced pressure and the residue crystallized from *n*-heptane to give the acyl chloride (798 mg), m.p. 107–120°. IR ν_{max}^{Nujol} cm^{-1}: 1788, which was used without further purification.

The acylchloride was treated with NaN_3 (384 mg) as described for the preparation of compound (+)-**7** to give the acylazide (784 mg), m.p. 85–90° (dec.). $[\alpha]_D$ −101·1° (MeOH, *c* 0·364); IR ν_{max}^{Nujol} cm^{-1}: 2130. The acylazide was dissolved in dry toluene (10 ml) and the solution heated under reflux for 2 hr. After cooling, a crystalline solid (88 mg) was removed by filtration. As its IR spectrum did not show absorption attributable to the isocyanate group, the solid was discarded. The filtrate was concentrated to dryness and the residue hydrolyzed by heating under reflux for 5 hr with a solution of KOH (1·0 g) in MeOH (10 ml). This solution was poured into water and extracted with ether. The ether solution was washed with water. Dil. HBr was added to the solution and the mixture shaken. The crystalline solid which formed was collected and recrystallized from MeOH–EtOAc to give needles (147 mg), m.p. 300°. $[\alpha]_D$ −173·5° (MeOH, *c* 0·113); IR ν_{max}^{Nujol} cm^{-1}: 1166, 781. (Found: C, 52·00; H, 3·78; Br, 20·92; Cl, 18·57; N, 3·82. $C_{16}H_{14}BrCl_2N$ requires: C, 51·78; H, 3·80; Br, 21·54; Cl, 19·11; N, 3·78%).

Dimethyl 11,12-*dichloro*-DEA-1,5-*dicarboxylate*. A mixture of dimethyl anthracene-1,5-dicarboxylate (13·3 g),[4] *trans*-dichloroethylene (50 g) and dioxane (40 ml) was heated in a sealed tube at 200° for 15 hr. Crystals were collected by filtration, washed with benzene and dried. From the solution of the reaction, volatile materials were evaporated and the residue chromatographed on alumina (100 g, act. II, Woelm Co.) in benzene (500 ml). The total yield was 13·1 g (66·0%). The NMR spectrum showed the product to be a mixture of two isomers, but no separation was accomplished by fractional recrystallization or chromatography. (Found: C, 61·12; H, 4·08; Cl, 18·29. $C_{20}H_{16}O_4Cl_2$ requires: C, 61·40; H, 4·12; Cl, 18·12%).

Dimethyl DEA-1,5-*dicarboxylate* (**21**). The mixture of two isomers of dimethyl-11,12-dichloro-DEA-1,5-dicarboxylate (8·28 g) was hydrolyzed as described for compound **17**. The precipitate obtained was collected by filtration, washed with water and dried (7·79 g), m.p. 302° (dec.). This dicarboxylic acid was suspended in NaOEt–EtOH solution (prepared from sodium (2·5 g) and 99% EtOH (100 ml)) and heated in a sealed tube at 120–130° for three days. After treating with charcoal, the solution was acidified with HCl. The solids were collected, washed with water and dried (5·7 g).

A mixture of this carboxylic acid (4·6 g), abs. MeOH (110 ml) and conc. H_2SO_4 (5 ml) was heated under reflux for 8·5 hr and allowed to stand overnight. Crystals were collected, washed with MeOH and dried. Recrystallization from EtOH several times gave colourless prisms (3·0 g), but it was difficult to remove the dichloro compound from the product considered to be dimethyl 11-chloro-9,10-dihydro-9,10-etheno-anthracene-1,5-dicarboxylate. Therefore, this crude product (2·75 g) was hydrogenated in a mixture of PtO (0·57 g), NaOAc (0·90 g) and AcOH (100 ml) under hydrogen at room temp. The catalyst was removed and the solvent distilled under reduced pressure. The crystalline residue was washed with water and recrystallized from EtOH to give colourless prisms (1·72 g), m.p. 133–135°. IR ν_{max}^{Nujol} cm^{-1}: 1712. (Found: C, 73·85; H, 5·60. $C_{20}H_{18}O_4$ requires: C, 74·52; H, 5·63%).

DEA-1,5-*dicarboxylic acid* (**20**). Diester **21** (1·69 g) was treated as described for the preparation of **17** (1·51 g), m.p. >330°. IR ν_{max}^{Nujol} cm^{-1}: 1693. (Found: C, 72·54; H, 4·73. $C_{18}H_{14}O_4$ requires: C, 73·45; H, 4·80%).

Resolution of DEA-1,5-*dicarboxylic acid*. To a suspension of dicarboxylic acid (+)-**20** (1·49 g) in MeOH, a solution of brucine tetrahydrate (5·18 g) in MeOH (25 ml) was added in one portion. The mixture was warmed for one hr at 70° (bath temp.). Solids were collected by filtration from the hot solution and recrystallized (3 ×) from $CHCl_3$ and MeOH (2·45 g), m.p. 185–186° (dec.). $[\alpha]_D$ +90·2° ($CHCl_3$, *c* 1·112).

The mother liquor of the mixture was allowed to stand overnight and crystals were collected, washed with MeOH and dried. Recrystallization from $CHCl_3$ and MeOH four times gave needles (1·25 g), m.p. 173–176°. $[\alpha]_D$ −152·4° ($CHCl_3$, *c* 0·681).

(+)-Salt (2·45 g) was shaken with dil. HCl (30 ml) at 50° for 20 min. The free acid was collected by filtration, washed with water and dried. Recrystallization from MeOH gave a colourless powder (0·617 g), m.p. 325° (dec.). $[\alpha]_D$ +340·0° (dioxane, *c* 0·861).

The (−)-salt (1·02 g) was similarly decomposed to give the (−)-isomer (277 mg).

(+)- *and* (−)-*Dimethyl* DEA-1,5-*dicarboxylate* ((+)- *and* (−)-**21**). (+)-Dicarboxylic acid **20** (0·61 g), abs. MeOH (25 ml) and conc. H_2SO_4 (1·0 ml) were heated under reflux for 8 hr and allowed to stand overnight. The solution was concentrated to *ca.* 10 ml and poured onto ice. Crystals were collected, washed with water, dried and recrystallized from MeOH (0·60 g), m.p. 118–119°. $[\alpha]_D$ +392·3° (MeOH, *c* 0·0887); IR ν_{max}^{Nujol} cm^{-1}: 1715. (Found: C, 74·43; H, 5·72. $C_{20}H_{18}O_4$ requires: C, 74·52; H, 5·63%).

The (−)-dicarboxylic ester ((−)-**21**) was also obtained in a similar manner.

Nitration of (+)-**21**. (1) A nitrating reagent was prepared by mixing HNO_3 (10·5 g, *d* 1·375 at 22°), conc. H_2SO_4 (180·0 g, *d* 1·835 at 22°) and water (160·0 g). Thus the concentration of H_2SO_4 in the reagent was 90%. This reagent (5 ml) was added dropwise with vigorous stirring to a solution of (+)-diester ((+)-**23**, 584 mg) in Ac_2O (10 ml). The temperature was kept at 0° throughout. After stirring for one hr, the contents were poured onto ice and extracted with $CHCl_3$. The organic layer was washed with water, dried (Na_2SO_4) and concentrated to dryness. The residue was crystallized from ether (497 mg). $[\alpha]_D$ +193° ($CHCl_3$, *c* 0·264). The product consisted of two isomers, and was therefore chromatographed in benzene on a 20 cm silica gel (Woelm Co., GF_{254}) thin layer plate (dried in air). These processes were repeated three times. The 3,7-dinitro derivative ((+)-**23**) was obtained from the fraction with the larger R_f value and was recrystallized from benzene and ether, m.p. 227–230°. $[\alpha]_D$ +160·0° (dioxane, *c* 0·1721); IR ν_{max}^{CHCl} cm^{-1}: 1728, 1535, 1346. NMR τ: 8·16 (4H, bs), 5·97 (6H, s), 3·05 (2H, bs), 1·65 (2H, d, J = 2·5 Hz), 1·35 (2H, d, J = 2·5 Hz). (Found: C, 57·40; H, 4·04; N, 7·14. $C_{20}H_{16}N_2O_8$ requires: C, 58·25; H, 3·91; N, 6·80%).

The 2,7-dinitro derivative ((+)-**22**) was obtained from the fraction with the smaller R_f value and was recrystallized from benzene and ether, m.p. 235–237°. $[\alpha]_D$ +233·3° (dioxane, *c* 0·084); IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 1735, 1537, 1348. NMR τ: 8·16 (4H, bs), 5·98 (3H, s), 5·95 (3H, s), 5·25 (1H, bs), 4·03 (1H, bs), 2·45 (1H, d, J = 8·0 Hz), 2·04 (1H, d, J = 8·0 Hz), 1·72 (1H, d, J = 2·5 Hz), 1·33 (1H, d, J = 2·5 Hz). (Found: C, 58·44; H, 4·03; N, 6·66. $C_{20}H_{16}N_2O_8$ requires: C, 58·25; H, 3·91; N, 6·80%).

(2) The nitrating reagent (0·45 ml, 1·0 molar eq.) was added dropwise to a solution of (−)-diester ((−)-**21**, 136 mg) as described in procedure (1). The products were chromatographed in benzene on a 20 cm silica gel (Woelm Co., GF_{254}) thin layer plate (dried in air). The chromatography was repeated three times. The reactant was isolated from the fraction with the highest R_f value. 3-Nitro derivative was isolated from the fraction with the next highest R_f value and recrystallized from ether and *n*-hexane (20 mg), m.p. 112–113°. $[\alpha]_D$ −261·8° (dioxane, *c* 0·1119); IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 1724, 1531, 1347. NMR τ: 8·24 (4H, bs), 6·04 (3H, s), 6·00 (3H, s), 4·20 (2H, m), 2·81 (1H, t, J = 7·0 Hz), 2·53 (1H, dd, J = 7·0, 2·0 Hz), 2·21 (1H, dd, J = 8·0, 1·5 Hz), 1·68 (1H, d, J = 2·0 Hz), 1·38 (1H, d, J = 2·0 Hz). (Found: C, 65·82; H, 4·62; N, 3·49. $C_{20}H_{17}NO_6$ requires: C, 65·39; H, 4·66; N, 3·81%).

From the third fraction, a mixture of 2-nitro- and 3,7-dinitro-compounds were obtained. The latter was removed by filtration of the ether solution and the former crystallized from ether and *n*-hexane (11·0 mg), m.p. 61–63°. $[\alpha]_D$ −271·9° (dioxane, *c* 0·0629); IR $\nu_{max}^{CHCl_3}$ cm^{-1}: 1735, 1718, 1533, 1347. NMR τ: 8·24 (4H, bs), 6·05 (3H, s), 5·98 (3H, s), 5·45 (1H, bs), 4·17 (1H, bs), 2·81 (1H, t, J = 7·0 Hz), 2·54 (1H, dd, J = 7·0, 2·0 Hz), 2·49 (1H, d, J = 8·0 Hz), 2·20 (1H, dd, J = 8·0, 2·0 Hz), 2·05 (1H, d, J = 8·0 Hz). (Found: C, 65·56; H, 5·45; N, 3·68. $C_{20}H_{17}NO_6$ requires: C, 65·39; H, 4·66; N, 3·81%).

From the last fraction, the (−)-2,7-dinitro-derivative was obtained (7·7 mg).

(+)-3,7-*Dinitro*-DEA-1,5-*dicarboxylic acid* ((+)-**24**). (+)-Ester ((+)-**23**, 102 mg) was treated as described for the preparation of **17**. Recrystallization from MeOH gave needles (82·8 mg), m.p. >320°. $[\alpha]_D$ +114·8° (MeOH, *c* 0·1068). (Found: C, 54·18; H, 3·69; N, 6·70. $C_{18}H_{12}N_2O_8$ requires: C, 53·74; H, 3·51; N, 6·96%).

(−)-2,6-*Dinitro*-DEA ((−)-**25**). A mixture of (+)-dinitro-dicarboxylic acid ((+)-**24**, 61·4 mg), copper-chromite (60 mg), and quinoline (3 ml, freshly redistilled from copper-chromite) was heated under reflux for 90 min. To the cooled mixture, $CHCl_3$ (30 ml) was added and the solid formed filtered off and washed

with $CHCl_3$. The filtrate was washed with dilute HCl, $NaHCO_3$ aq, and water and dried Na_2SO_4. After evaporation of solvent, the brown residue was chromatographed in benzene on a 20 cm thin layer of silica gel (Woelm Co., GF_{254}). The product was recrystallized from benzene and ether to give prisms (17·5 mg), m.p. 155–156°. $[\alpha]_D$ −205·5° (dioxane, *c* 0·1022); IR ν^{CHCl_3} cm^{-1}: 1524, 1355, 1345. (Found: C, 64·45; H, 4·12; N, 8·85. $C_{16}H_{12}N_2O_4$ requires: C, 64·86; H, 4·08; N, 9·46%).

(−)-DEA-2,6-*diammonium hydrochloride* ((−)-**26**·2HCl). A mixture of a solution of (−)-dinitro derivative (−)-**25** (15·8 mg) in EtOAc (3 ml) and PtO_2 (8 mg) was shaken under H_2 at room temp. After removal of catalyst, EtOAc was distilled off. The residue was dissolved in dilute HCl, washed with $CHCl_3$ and concentrated to dryness. The crystalline residue was recrystallized from MeOH–benzene to give needles (2·9 mg), m.p. ~220° (dec.). $[\alpha]_{365}$ −361·8° (MeOH, *c* 0·0561). (Found: C, 61·89; H, 5·91; N, 8·84; Cl, 22·89. $C_{16}H_{18}N_2Cl_2$ requires: C, 62·14; H, 5·87; N, 9·06; Cl, 22·93%).

2,6-*Dimethoxy anthracene* (**27**). Dimethyl sulphate (10·3 ml) was dropped into a solution of anthraflavic acid (10 g) in 10% NaOH aq (50 ml) at 60–80° with vigorous stirring. More NaOH (50 ml) was added followed by dimethyl sulphate (8·5 ml). The mixture was heated under reflux for three hr with vigorous stirring. After cooling, a solid was collected by filtration, washed with dil. HCl, water, and dried *in vacuo*, (7·7 g). Recrystallization from AcOH gave needles, m.p. 253–6°.

This product was reduced according to the procedure described for the preparation of **14**, to give yellow plates (2·0 g), m.p. 267–9°. IR ν_{max}^{Nujol} cm^{-1}: 888, 802. (Found: C, 80·80; H, 5·95. $C_{16}H_{14}O_2$ requires: C, 80·65; H, 5·92%).

2,6-*Dimethoxy*-DEA-11(endo),12(endo)- *and* 11(exo),12(exo)-*dicarboxylic acid* (**29** *and* **31**). A mixture of 2,6-dimethoxy anthracene (7·5 g), dimethyl fumarate (45 g) and xylene (200 ml) was heated under reflux for 22 hr. Xylene was distilled and excess dimethylfumarate removed by sublimation. The residue was chromatographed on alumina (100 g, Woelm Co., act. II) in benzene, but with no isomer separation. The mixture of isomers was hydrolyzed by refluxing for 3 hr with KOH (6 g) and MeOH (60 ml) then acidified with 2N HCl. Solid was collected, washed with water and dried, (5·6 g). The two isomers were separated by fractional recrystallization from EtOAc. The m.p. of 11(*endo*),12(*endo*)-dicarboxylic acid (**33**) was 280–284°; 11(*exo*),12(*exo*)-dicarboxylic acid (**31**) was m.p. 224–225°. IR ν_{max}^{Nujol} cm^{-1}: 1712, 1255 (for **33**), 1712, 1250 (for **31**). (Found (for **33**): C, 67·80; H, 5·25. Found (for **31**): C, 67·68; H, 5·41. $C_{20}H_{18}O_6$ requires: C, 67·68; H, 5·12%).

Dimethyl-2,6-*dimethoxy*-DEA-11(endo),12(endo)-*dicarboxylate* (**30**). The *endo*-dicarboxylic acid (**31**, 100 mg), was esterified according to the procedure for the esterification of (+)-**20**. Recrystallization from MeOH gave prisms (41 mg), m.p. 107–108°. IR ν_{max}^{Nujol} cm^{-1}: 1734, 1029. NMR τ: 6·59 (2H, dd, *J* = 1·5, 1·0 Hz), 6·38 (6H, s), 6·28 (6H, s), 5·38 (2H, bs), 3·39 (2H, dd, *J* = 8·0, 2·5 Hz), 3·18 (2H, d, *J* = 2·5 Hz), 2·79 (2H, d, *J* = 7·5 Hz). (Found: C, 69·37; H, 5·80. $C_{22}H_{22}O_6$ requires: C, 69·10; H, 5·80%).

Dimethyl-2,6-*dimethoxy*-DEA-11(exo),12(exo)-*dicarboxylate* (**28**). The *exo*-dicarboxylic acid (**29**, 100 mg) was treated as described for the preparation of **30**. Recrystallization from MeOH gave prisms (33 mg), m.p. 113–115°. IR ν_{max}^{Nujol} cm^{-1}: 1732, 1033, 1022. NMR τ: 6·63 (2H, dd, *J* = 1·5, 1·0 Hz), 6·38 (6H, s), 6·28 (6H, s), 5·41 (2H, bs), 3·42 (2H, dd, *J* = 7·5, 2·5 Hz), 3·11 (2H, d, *J* = 2·5 Hz), 2·88 (2H, d, *J* = 8·0 Hz). (Found: C, 69·25; H, 5·58. $C_{22}H_{22}O_6$ requires: C, 69·10; H, 5·80%).

Resolution of endo-*dicarboxylic acid* (**31**). A mixture of *endo*-dicarboxylic acid (**30**, 942 mg), brucine tetrahydrate (2·29 g) and EtOAc (20 ml) was heated under reflux for two hr. After cooling, crystals were collected and recrystallized twice from MeOH (1·338 g). $[\alpha]_D$ −10·7° (MeOH, *c* 0·402). The salt was decomposed by shaking with dil. HCl for 30 min and free acid was filtered, washed with water and dried (621 mg). $[\alpha]_D$ +3·4° (dioxane, *c* 0·388).

A mixture of partially resolved *endo*-dicarboxylic acid, cinchonidine (1·031 g) and MeOH (10 ml) was warmed to 70° for 30 min. After cooling, crystals were collected and recrystallized twice from MeOH (372 mg). $[\alpha]_D$ −54·1° (MeOH, *c* 0·292). This salt was decomposed as described above and the free acid recrystallized from benzene (170 mg). $[\alpha]_D$ +35·3° (MeOH, *c* 0·317).

A mixture of this *endo*-dicarboxylic acid, quinine (220 mg) and 99% EtOH was warmed to 70° for 10 min and EtOH distilled to dryness. The residue was crystallized from acetone–EtOAc and then twice from acetone to give optically pure diastereomer (131 mg). $[\alpha]_D$ −113·5° (MeOH, *c* 0·349).

This pure salt was decomposed by adding dil. HCl to suspension in EtOAc. After the usual treatment, crude free acid was recrystallized from benzene to give optically pure acid (37 mg). $[\alpha]_D$ +39·0° (dioxane, *c* 0·331). (Found: C, 68·43; H, 5·24. $C_{20}H_{18}O_6$ requires: C, 67·78; H, 5·12%).

2,6-*Dichloro*-DEA-11(endo *and* exo)-*carboxylic acid* (**32**). 2,6-Dichloro anthracene (**14**, 7·6 g), freshly distilled methylacrylate (40 ml), and hydroquinone (0·2 g) in benzene (20 ml) were treated according to the

procedure (c) for the preparation of **16**. Crystallization of residue was unsuccessful, therefore the crude product was hydrolyzed by refluxing with a solution of KOH (10 g) and MeOH (100 ml) for 3 hr. The mixture was poured onto ice-water (500 ml) and acidified with conc. HCl. The solid was filtered, washed with water and dried *in vacuo* (8·35 g, 83·3%). Recrystallization from MeOH gave a powder, m.p. 249–253°. The product was a mixture of two isomers which could not be isolated in a pure form.

Resolution of 2,6-*dichloro*-9,10-*ethano anthracene* 11(endo *or* exo)-*carboxylic acid*. (a) A mixture of 2,6-dichloro acid **32** (2·6 g), cinchonidine (2·4 g) and MeOH (50 ml) was warmed to 70° (bath temp.). Crystals soon appeared and were recrystallized (10×) from MeOH to give pure diastereomer (1·079 g). $[\alpha]_D$ −116·8° (MeOH, *c* 0·155). This compound (1·66 g) was warmed for 15 min with 6N HCl (30 ml) and the crystals which formed were collected, washed with water, and dried *in vacuo* (0·842 g). Purification was unsuccessful, therefore the crude acid was esterified as for the preparation of (−)-**3**. Crystallization from MeOH gave the pure ester, m.p. 116–117°. $[\alpha]_D$ −91·6° (dioxane, *c* 0·297); IR ν_{max}^{Nujol} cm^{-1}: 1738. NMR τ: 8·02 (1H, dd, *J* = 5·5, 2·5 Hz), 7·88 (1H, dd, *J* = 2·5, 1·5 Hz), 7·16 (1H, td, *J* = 10·0, 5·5, 2·5 Hz), 6·39 (3H, s), 5·73 (1H, t, *J* = 2·5 Hz), 5·38 (1H, d, *J* = 2·5 Hz), 2·7 ~ 2·9 (6H, m). (Found: C, 65·20; H, 4·39; Cl, 22·29. $C_{18}H_{14}O_2Cl_2$ requires: C, 64·91; H, 4·23; Cl, 21·28%).

(b) Partially resolved (+)-acids (1·25 g), recovered from the mother liquor described above, (+)-phenethyl amine (494 mg), and acetone (20 ml) were mixed and allowed to stand at room temp. overnight. Crystals were collected and recrystallized (3×) from MeOH to give pure diastereomer (440 mg). $[\alpha]_D$ +78·7° (MeOH, *c* 0·313). The salt (440 mg) and dil. HCl (5 ml) were shaken at 70° for 10 min, solid was collected, washed with water, and dried *in vacuo*. Recrystallization from MeOH–H_2O gave the pure isomer (314 mg), m.p. 192–194°. $[\alpha]_D$ +92·3° (MeOH, *c* 0·116); IR ν_{max}^{Nujol} cm^{-1}: 1716, 822. (Found: C, 64·07; H, 3·80; Cl, 22·17. $C_{17}H_{12}Cl_2O_2$ requires: C, 63·97; H, 3·79; Cl, 22·22%). Though the (−)-acid was difficult to crystallize the (+)-acid was easy to purify and was esterified according to the above procedure, but crystallization failed. These two compounds have an epimeric relation to each other, one being 11(*endo*)- and the other 11(*exo*)-.

1,2:5,6-*Dibenz*-DEA-11(endo),12(endo)- *and* 11(exo),12(exo)-*dicarboxylic acid* (**35** *and* **37**). Dimethyl-1,2:5,6-dibenz-DEA-11(*endo*),12(*exo*)-carboxylate[11] (2·52 g) was hydrolyzed according to the procedure described for the hydrolysis of compound **16**. Recrystallization from AcOH gave a powder (2·31 g).

A small portion of the acid (663 mg) was esterified by heating under reflux with abs. MeOH (15 ml) and conc. H_2SO_4 (0·5 ml) for 5 hr. The mixture was poured onto ice-water (100 ml) and the crystals were collected, washed with water and dried *in vacuo*. Recrystallization from EtOH gave the ester (617 mg), m.p. 184–188°. The NMR spectrum of this ester showed two kinds of protons attributable to a Me group at 6·32 and 6·37 τ. As two isomers were considered to be formed, the conversion of the configuration occurs at the positions 11 and 12.

Resolution of **35** *and* **37**. A mixture of *trans*-diacids (**35** and **37**, 160 g), cinchonidine (2·38 g) and 99% EtOH (20 ml) were warmed at 70° (bath temp.) and allowed to stand for 1 hr. Alcohol was evaporated under reduced pressure and the residue dissolved in acetone and allowed to stand overnight. Crystals formed were recrystallized (4×) from MeOH to give pure diastereomer (422 mg), m.p. 248–249° (dec.). $[\alpha]_D$ −263·4° (MeOH, *c* 0·081).

Combined mother liquor was concentrated to dryness and the residue crystallized once from acetone and (4×) from MeOH–acetone to give another diastereomer (0·513 mg), m.p. 196–198° (dec.). $[\alpha]_D$ +205·7° (MeOH, *c* 0·122).

The (−)-salt (408 mg) was shaken with dil. HCl (10 ml) for 30 min at 50°. Slight yellow crystals were filtered, washed with water and dried *in vacuo*. Crude acid was recrystallized from AcOH–H_2O to give colourless needles (110 mg), m.p. 268–270°. $[\alpha]_D$ −437·0° (AcOH, *c* 0·127); IR ν_{max}^{Nujol} cm^{-1}: 1715, 819. (Found: C, 79·17; H, 4·60 $C_{26}H_{18}O_4$ requires: C, 79·04; H, 4·62%)

The (+)-salt (502 mg) treated similarly gave needles (280 mg), m.p. 267–268°. $[\alpha]_D$ +475·8° (AcOH, *c* 0·091); IR ν_{max}^{Nujol} cm^{-1}: 1710. (Found: C, 77·40; H, 4·75. $C_{26}H_{18}O_4 \cdot \frac{1}{2}H_2O$ requires: C, 77·41; H, 4·75%).

(+)-*Dimethyl*-1,2:5,6-*dibenz*-DEA-11(exo),12(exo)-*dicarboxylate* ((+)-**38**). (+)-Diacid (+)-**37** (59 mg) was esterified according to the preparation of (−)-**3**. Recrystallization from EtOAc–MeOH gave a colourless powder (51 mg, 87%), m.p. 266–267°. $[\alpha]_D$ +433·6° (dioxane, *c* 0·0602); IR ν_{max}^{Nujol} cm^{-1}: 1732, 1208, 810, 820, 743. NMR τ: 6·47 (2H, d, *J* = 1·2 Hz), 6·37 (6H, s), 4·26 (2H, bs), 2·1 ~ 2·8 (10H, m), 1·64 (2H, d, *J* = 7·5 Hz). (Found: C, 78·96; H, 5·29. $C_{28}H_{22}O_4$ requires: C, 79·60; H, 5·23%).

(−)-*Dimethyl*-1,2:5,6-*dibenz*-DEA-11(endo),12(endo)-*dicarboxylate* ((−)-**36**). (−)-Diacid (−)-**35** (63 mg) was treated as in the preparation of (−)-**3** to give colourless prisms (38·5 mg), m.p. 276°. $[\alpha]_D$ −335·6° (dioxane, *c* 0·239); IR ν_{max}^{Nujol} cm^{-1}: 1732, 1204, 824, 819. NMR τ: 6·57 (6H, s), 6·32 (2H, d, *J* = 1·5 Hz), 4·23

(2H, s), 2·1 ~ 2·8 (10H, m), 1·72 (2H, d, J = 7·2 Hz). (Found: C, 79·42; H, 5·33. $C_{28}H_{22}O_4$ requires: C, 79·60; H, 5·23%).

Kinetic resolution of phenyl methylcarbinol. Kinetic resolution was achieved under the conditions described in Table 1. As an example, we describe the procedure for (+)-bicyclo[2.2.2]octane-1,2-dicarboxylic acid ((+)-**39**.[14] Compound (+)-**39** (433 mg, $[\alpha]_D$ +35·5 ±3·7° (CF_3CH_2OH, *c* 0·1181)) and $SOCl_2$ (3·0 g) were warmed together at 60° (bath temp.) for 1 hr. $SOCl_2$ was evaporated under reduced pressure and the oily residue distilled at 100°/2 mmHg (428 mg). IR ν_{max}^{Film} cm^{-1}: 1785. This acid chloride was added to an ice cold solution of (±)-phenyl methylcarbinol (884 mg) in pyridine (20 ml). The mixture was stoppered, allowed to stand at room temperature for 20 hr then poured onto ice-water and ether. The organic layer was washed with dil. HCl, with water and dried (Na_2SO_4). After evaporation of solvent the residue was distilled twice through a 10 cm column, 72°/2 mmHg (309 mg). $[\alpha]_D^{25}$ +0·24 ± 0·03° (MeOH, *c* 30·846). (Found: C, 78·60; H, 8·39. $C_8H_{10}O$ requires: C, 78·65; H, 8·25%).

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