Circular Dichroism Spectra and Molecular Geometry of Six-Membered Ring Anhydrides and Imides

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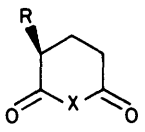
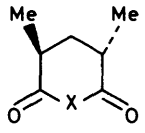
Several six-membered ring anhydrides and imides of known absolute configuration have been synthesized and their c.d. spectra measured. It has been established that the shape of the c.d. curves of anhydrides is generally similar to those of the corresponding imides. The Cotton effect sign of relatively rigid bicyclic compounds is correctly predicted by the octant rule. The c.d. spectra of substituted glutaric anhydrides and imides are discussed in terms of the conformational equilibria between half-boat and twist-boat conformers. The geometries and relative energies of these forms have been calculated by the molecular mechanics method.

In the preceding paper[1] chiroptical properties of substituted succinic anhydrides and imides have been discussed. It has been established that the two lowest energy electronic transitions are of n—π* character. The Cotton effects (C.e.s) corresponding to them should exhibit opposite signs owing to the opposite symmetry of the wave functions belonging to the excited states. The octant rule has been postulated for the correlation of molecular geometry with the c.d. signs.

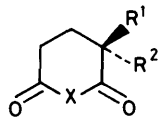
This study deals with the six-membered ring anhydrides and imides which present a greater variety of structures than the



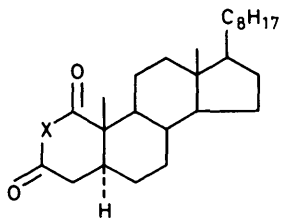
(**1a**) R = H, X = O
(**1b**) R = H, X = NH
(**2a**) R = Me, X = O
(**2b**) R = Me, X = NH
(**3a**) R = Bu^t, X = O
(**3b**) R = Bu^t, X = NH
(**4a**) R = Ph, X = O
(**4b**) R = Ph, X = NH
(**5**) R = OH, X = NH
(**6**) R = $NHCO_2CH_2Ph$, X = NH
(**7**) R = $^+NH_3$, X = NH
(**8**) R = $NHSO_2Me$, X = NH
(**9**) R = $N(Me)SO_2Me$, X = NH



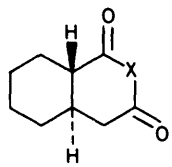
(**10a**) X = O
(**10b**) X = NH



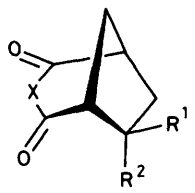
(**11**) $R^1 = R^2 = Me$, X = O
(**12**) $R^1 = Me$, $R^2 = Et$, X = NH
(**13**) $R^1 = Me$, $R^2 = Ph$, X = NH



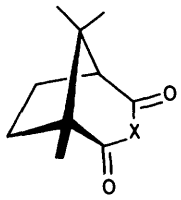
(**15a**) X = O
(**15b**) X = NH



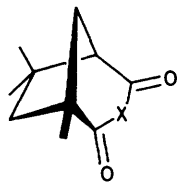
(**14a**) X = O
(**14b**) X = NH



(**16a**) $R^1 = Me$, $R^2 = H$, X = O
(**16b**) $R^1 = Me$, $R^2 = H$, X = NH
(**17a**) $R^1 = H$, $R^2 = Me$, X = O
(**17b**) $R^1 = H$, $R^2 = Me$, X = NH
(**18a**) $R^1 = R^2 = Me$, X = O
(**18b**) $R^1 = R^2 = Me$, X = NH
(**19**) $R^1 = R^2 = H$, X = O

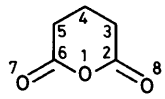


(**20a**) X = O
(**20b**) X = NH
(**20c**) X = NMe



(**21a**) X = O
(**21b**) X = NH

Table 1. Selected torsion angles ° of six-membered ring anhydrides calculated from MM2



Compound[a]	(1—2—3—4)	(1—6—5—4)	(2—1—6—5)	(3—2—1—6)	(2—1—6—7)	(6—1—2—8)	(1—2—3—X)[b]	Energy kJ mol^{-1}
(1a)—s	−30.6	30.6	−2.0	2.0	178.6	−178.6		0
(1a)—tw	56.5	56.5	−28.0	153.2	153.2	153.2		8.8
(2a)—eq	36.4	−26.7	1.8	−7.0	−178.8	172.4	160.5	0
(2a)—ax	−28.1	28.5	−0.7	0.6	179.8	179.9	99.0	7.5
(2a)—tw	58.0	56.1	−27.5	−29.3	153.7	152.2	−175.8	7.5
(3a)—eq	−7.3	−43.2	−3.9	30.8	175.8	−149.0	124.4	0
(3a)—ax	−41.7	7.8	7.8	10.5	−171.9	−168.9	94.2	9.3
(3a)—tw	58.5	56.8	−23.2	−34.6	158.8	147.1	−169.0	3.3
(4a)—eq	8.6	−38.7	−1.8	17.7	177.6	−162.2	133.5	0
(4a)—ax	−29.3	26.5	2.4	−0.8	−177.1	179.3	98.0	2.8
(4a)—tw	56.9	55.8	−29.4	−26.5	152.1	155.9	−175.0	10.6
(10a)—ae	39.7	−15.8	5.8	6.9	−172.7	−172.6	−163.3	1.4
(10a)—tw	57.4	57.4	−28.7	−28.7	152.7	152.7	−176.3	0
(11a)—ae	42.6	−14.6	−3.9	−11.4	175.7	167.5	161.3	0
(11a)—tw	55.3	56.6	−20.0	−36.7	161.1	142.8	176.7	6.6
(14a)—eq	33.9	−28.6	−2.0	4.9	178.6	−174.3	158.0	0
(14a)—tw	54.7	17.3	−22.4	−14.5	158.0	166.4	177.9	5.7
(16a)	−42.4	36.4	−0.5	3.6	179.2	−176.1	71.9	
(17a)	−40.5	40.6	−4.3	4.3	175.6	−175.3	73.4	
(18a)	−43.6	33.9	2.7	2.4	−177.9	−176.8	71.6	
(19)	−39.3	39.6	−2.1	2.2	177.7	−177.5	74.6	
(20a)	−43.6	43.5	−10.8	10.3	168.4	−169.6	71.2	
(20a)[c]	(−42.0 ±0.3)	(44.3 ±0.3)	(−13.1 ±0.4)	(11.2 ±0.4)	(169.3 ±0.3)	(−171.0 ±0.3)	(71.2 ±0.3)	
(21a)	−43.3	37.9	6.0	−3.2	175.3	−173.7	71.7	

[a] s, sofa; ax, eq, ae, axial, equatorial, and axial-equatorial sofa respectively; tw, twist-boat. [b] X, α-substituent. [c] The experimental values[18] in parentheses.

former compounds and they may serve as a basis for testing sector rules.[1,2] Several model compounds (**1**)—(**21**) have been synthesized and their spectra examined.

Molecular Geometries.—Since knowledge of preferred conformations is a decisive factor in the interpretation of chiroptical spectra molecular mechanics (MM), calculations have been performed for model compounds. The results (selected torsion angles) obtained with the extended Allinger MM2 force field[1,3] are presented in Table 1. The development of parametrization for such polar compounds as imides would be difficult and for this reason calculations were restricted to anhydrides. However, owing to close geometrical relationships between both classes of compounds the conformational behaviour of imides is expected to be similar to those of anhydrides.

An inspection of the data in Table 1 shows that the simplest member of the class, glutaric anhydride (**1a**), prefers the so-called 'sofa' (half-boat)[4] conformation with the β-carbon atom out of the plane of the other ring atoms. Although the crystal structure of (**1a**) is unknown, symmetrically substituted 1-oxacyclohexane-4-spirocyclopentane-2,4-dione,[5] β-chloroglutaric,[6] and *cis*-α,α′-dimethylglutaric[7] anhydrides exhibit very similar geometries to that calculated for (**1a**). The reported *X*-ray geometry of glutarimide (**1b**)[8] is, as expected, very close to that of (**1a**). The MM2 method predicts a second energy minimum for glutaric anhydride, a twist boat[4] conformer, which shows a strong twisting of the ring and the chromophore C_{2v} symmetry. Since its energy is 8.8 kJ mol^{-1} higher than the sofa form it is negligible in the conformational equilibrium (Figure 1). Three energy minima: the sofa conformer with a bulky substituent in the equatorial position, sofa with an axial substituent, and a twist-boat conformer were calculated for

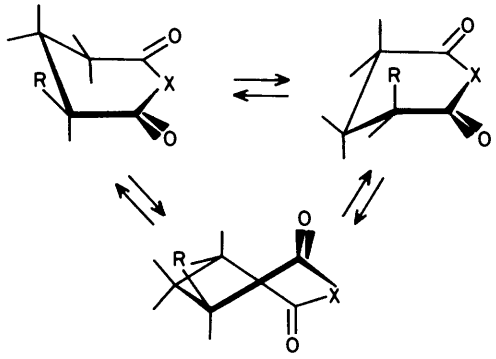


Figure 1.

α-substituted glutaric anhydrides. Substitution causes distortion of the sofa form of the ring from C_s symmetry which appears in the inequality of the O(1)–C(2)–C(3)–C(4) and O(1)–C(6)–C(5)–C(4) torsional angles. In most cases the sofa conformer is preferred with the bulky substituent in the equatorial position. The conformational energy corresponding to the axial form is 2.9—9.2 kJ mol^{-1} higher than the equatorial one and increases along with the substituent size [*cf.* (**2a**), (**14a**), and (**3a**)]. However, bulky substituents decrease the energy of the twist-boat which becomes more significant in equilibrium and in the case of *trans*-α,α′-dimethylglutaric anhydride (**10a**) is even energetically preferred. α-Phenylglutaric anhydride (**4a**) shows exceptional behaviour; the energy of the axial substituted sofa conformer is considerably lower than that of the twist-boat conformer. The striking feature of the results is the flexibility of the anhydride moiety which may be easily distorted from

Table 2. C.d. data of bicyclic anhydrides and imides (λ in nm, [θ] in ° cm^2 $dmol^{-1}$)

Compound	Solvent[a]	λ (10^{-3} [θ])[b]	Compound	Solvent[b]	λ (10^{-3} [θ])[b]
(**16a**)[c]	CD	247 (−0.57), 223 (1.36)	(**16b**)[c]	CD	261.5 (−1.19), 234.5 (1.62)
				M	257 (−1.50), 232 (1.99)
(**17a**)	CD	245 (0.44), 225 (0.54)	(**17b**)[c]	CD	263 (1.15)
				M	
(**18a**)[c]	CD	255 (−0.014), 220 (0.79)	(**18b**)[c]	CD	257 (−0.15), 236 (−0.53)
				M	267 (0.037), 233 (—0.54)
(**20a**)	C	242sh (−0.43), 225 (−1.06)	(**20b**)	C	268 (−0.10), 230 (−0.99)
	M	240sh (−0.49), 222.5 (−1.09)		M	252.5 (1.03), 227 (−2.06)
	HFP	233sh (−0.37), 218 (−1.57)		HFP	251 (1.13), 225 (−2.29)
			(**20c**)	C	275 (−0.016), 259 (0.26), 235 (−1.23)
				M	255 (1.02), 225 (−1.65)
(**21a**)	C	248.5 (−0.55), 223.5 (0.66)	(**21b**)	C	269.5 (−0.46), 234.5 (2.20)
	M	241 (−0.91), 218 (0.27)		M	260 (−1.39), 233 (2.59)

[a] C, cyclohexane; CD, cyclohexane–dioxane (4:1); M, methanol; HFP, hexafluoropropan-2-ol. [b] The highest intensity vibronic band. [c] Partially racemic sample; the data are not corrected for optical purity.

planarity with small energy expenditure and, consequently, the twist-boat conformer should contribute significantly to the conformational equilibria of several compounds. This contrasts with the conventional picture of anhydride and imide chromophores which are assumed to be planar.[9] Also n.m.r. spectra of substituted glutaric anhydrides have been discussed in terms of rapid equilibrium between two unperturbed (C_s) sofa forms with axial and equatorial α-substituents.[10] However, in open chain compounds the anhydride group is strongly twisted; *e.g.* the dihedral angle between two acetyl planes in acetic[11] (gas phase) and monochloroacetic[12] (crystal) anhydrides are 79 and 43° respectively, while the corresponding angle in mixed acetic–formic anhydride[6] is 126° in the gas phase. Analogously the n.m.r. spectra of macrocyclic anhydrides show considerable twisting of the chromophore.[13] The large differences among torsional angles of the glutaric anhydride fragment in several *X*-ray structures[14] confirm the flexibility of the ring and the influence of substituents on its conformation. The only examples of α-substituted glutarimides with known crystal structures are thalidomide (α-phthalimidoglutarimide)[15] and its *p*-bromo analogue;[16] both exist in distorted sofa conformations. Similar geometries are reported for a few α,α-disubstituted glutarimides.[17] However, in all cases the distortion of the chromophores rarely exceeds 10° in terms of the C–O–C=O or C–N–C=O torsion angles. Different types of geometries are presented by bridgehead bicyclic compounds (**16**)—(**21**) for which the sizeable twisting of the chromophores is almost impossible; *e.g.* anhydride moieties in 3-oxabicyclo[3.2.1]-octane-2,4-dione (**19**) and its 6,6-dimethyl derivative (**18a**) were calculated to be almost planar. The MM2 calculations for methyl substituted bicyclic compounds (**16a**), (**17a**), and (**21a**) show only slight deviation of the chromophore from planarity. However, due to van der Vaals interactions between 8-methyl and 3-oxygen in camphoric anhydride (**20a**) the oxygen atom is pushed down 0.176 Å below the plane formed by the carbonyl groups as shown by the *X*-ray crystal structure.[18] This kind of distortion lowers local symmetry of the chromophore from C_{2v} to C_s. It is noteworthy that the MM2 result nearly exactly reproduces the *X*-ray geometry of compound (**23a**). The reported crystal structure of *N*-substituted camphorimide shows even stronger deviation of the imide group from planarity; the nitrogen atom lies 0.4163 Å below the plane composed of carbonyl groups.[19]

C.D. Spectra of Substituted 3-*Oxa- and* 3-*Aza-bicyclo*[3.2.1]-*octane*-2,4-*diones*.—The perfect models for testing the sector rules should possess planar C_{2v} symmetry anhydride and imide chromophores and rigid skeletons. From considerations in the preceding section it appears that all optically active anhydrides and imides are more or less distorted from planarity. Bicyclic bridgehead models (**16**)—(**18**) are closest to the ideal and for this reason we start a discussion of the chiroptical properties with these compounds. The c.d. data are collected in Table 2 and some spectra are depicted in Figures 2 and 3.

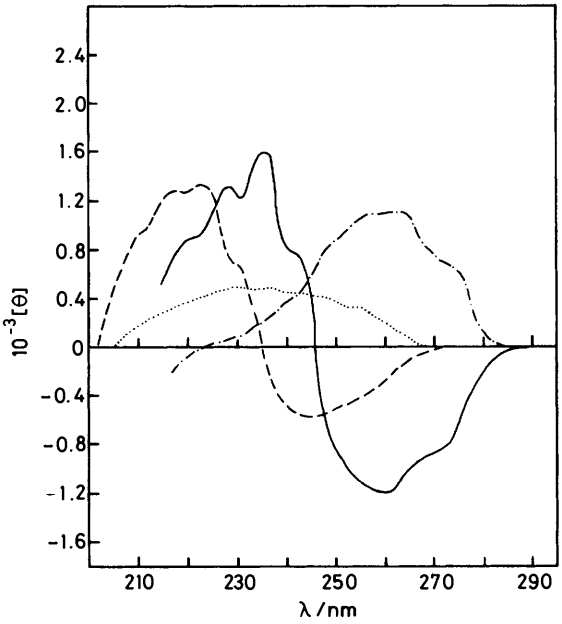


Figure 2. C.d. spectra of anhydrides (**16a**) (– – –), (**17a**) (· · ·), imides (**16b**) (——), and (**17b**) (— · — · —) in cyclohexane–dioxane (4:1)

Imides show two C.e.s near 260 and 230 nm both corresponding to n—π* electronic transitions:[1] these appear in the u.v. spectrum as two absorption bands of moderate intensity. U.v. spectra of anhydrides reveal a broad band centred at 235 nm which belongs to the two overlapping n—π* transitions as is evidenced by different vibronic structures of the two branches of the absorption band (Figure 3). In the c.d. spectra these bands are better separated and correspond to the C.e.s near 245 and 220 nm. Generally the same signs are observed for structurally related anhydrides and imides. Some differences appear in

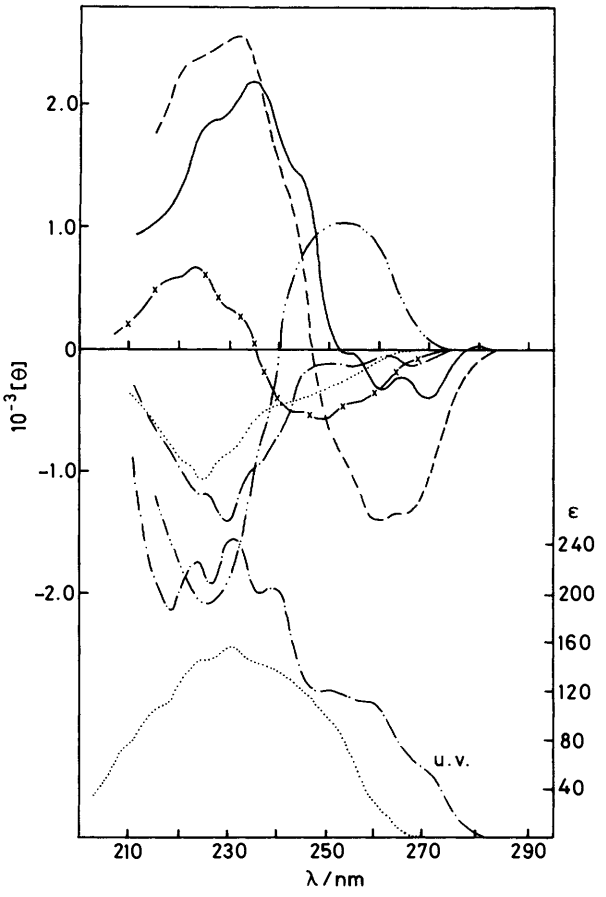


Figure 3. C.d. spectra of the anhydrides (**20a**) (· · · ·), (**21a**) (— × — × —) in cyclohexane, the imide (**20b**) in cyclohexane (— · — · —) and methanol (— ·· — ·· —), the imide (**21b**) in cyclohexane (——) and methanol (– – – –), u.v. of (**20a**) (· · · ·) and (**20b**) (— · — · —) in cyclohexane

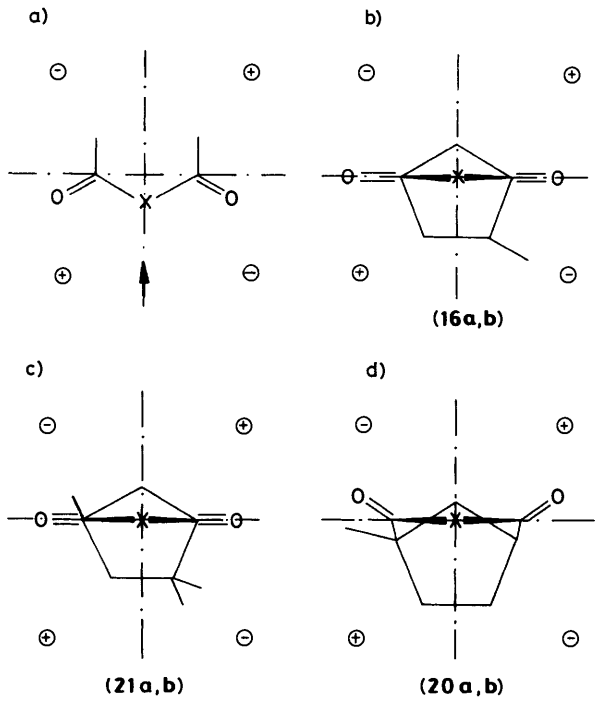


Figure 4. The octant projections of compounds (**16a,b**), (**21a,b**), and (**20a,b**)

solvent dependent spectra of compounds (**18a,b**) and (**20a,b**). The long-wavelength C.e. signs of (**16a,b**) and (**17a,b**) support the validity of the octant rule postulated in the preceding paper;[1] *i.e.*, the *exo*-methyl located in the back lower right octant (Figure 4b) is responsible for the negative C.e. of (**16a,b**), but the *endo*-methyl in the corresponding front octant (close to the nodal surface) contributes with the positive sign to the C.e. of (**17a,b**) (Figure 2). The same C.e. signs in both n—π* regions shown by *endo*-substituted compounds (**17a,b**) is an apparent anomaly though in the case of the imide (**17b**) the higher energy band shows low intensity and tends to change sign in polar solvents. The origin of this anomaly is not clear; it results probably from the proximity of the *endo*-methyl to the nodal surface. Solvation may alter the relative position of the substituent to the nodal surface and then influences not only the magnitude but the sign of the C.e. as well. The same effect is probably responsible for the sign reversal of the weak 260 nm c.d. band of the imide (**18b**) caused by polar solvents. The weak c.d. shown by 6,6-dimethyl derivatives (**18a,b**) results from the opposite contributions of *exo*- and *endo*-substituents. It is interesting that the above-mentioned anomaly is not observed in the case of the anhydride (**18a**) because the contribution from the *endo*-methyl substituent to the 220 nm C.e. is negative in accordance with the rule.

The deviation of chromophores from planarity can strongly affect the magnitude and the C.e. sign as illustrated by the spectra of camphoric acid derivatives (**20a,b**). Although camphorimide (**20b**) and isofenchoimide (**21b**) have the same configuration at C-1, their c.d. curves are of near mirror images in methanol (Figure 3). Similarly, considerable differences are noted in the spectra of the corresponding anhydrides (**20a**) and (**21a**). However, these findings are less surprising in the light of the MM2 and *X*-ray results. The octant projection of (**21a,b**) (Figure 4c) reveals that the 1-methyl group in the upper left octant contributes the negative sign to the long-wavelength C.e. whereas distortion of the chromophores in camphoric acid derivatives (**20a,b**) changes the position of the horizontal nodal plane; the relative position of the 1-methyl is then shifted to the lower left octant (Figure 4d) and contributes a positive sign to the C.e. The solvent dependence of the c.d. of the imide (**20b**), and to a lesser extent of the anhydride (**20a**), reflects the changes of chromophore distortion exerted by solvation of polar imide and anhydride groups which enhances their interaction with the close 8-methyl substituent. An analogous effect is caused by *N*-substitution and due to strong distortion of the chromophore in *N*-methylcamphorimide (**20c**) the C.e. at 260 nm is positive and only weakly solvent dependent. Apparently, for compounds with substituents located far from the chromophore, as in (**16a,b**), slight deviation of chromophores cannot effect the C.e. sign. The 12-sector rule proposed by Snatzke and co-workers[2] for anhydrides predicts the opposite C.e. signs to those observed for most of the above compounds.

C.D. Spectra of Substituted Glutaric Anhydrides and Imides.— The c.d. data of the title compounds are presented in Table 3. Their u.v. spectra resemble those of compounds described in the preceding section though several anhydrides show better separation of n—π* bands (Figure 5). Conformational equilibria cause some difficulties in the interpretation of the c.d. spectra. The c.d. curves of compounds (**2a,b**), (**10a,b**), and (**14a,b**) are of similar shape and show two humps with the same C.e. sign in both n—π* regions. This is in conflict with a typical pattern of anhydride and imide c.d. spectra which requires two C.e.s of opposite signs as mentioned earlier. According to the previous considerations[1] such curves point to several species with

Table 3. C.d. data of substituted glutaric anhydrides and imides (λ in nm, [θ] in ° cm^2 $dmol^{-1}$)

Compound	Solvent[a]	λ (10^{-3} [θ])[b]	Compound	Solvent[a]	λ (10^{-3} [θ])[b]
(**2a**)	CD	243 (0.94), 230 (0.93)	(**2b**)	CD	258 (0.77)
	HFP	232 (1.25), 225 (1.36)		M	255 (0.75)
				H_2O	250 (0.82)
				HFP	248 (0.74)
(**3a**)	CD	249 (−0.17), 224 (1.66)	(**3b**)	CD	273.5 (−0.98), 238 (4.33)
	HFP	239 (−3.50), 213 (3.83)		M	263 (−1.98), 230 (7.79)
				HFP	255.5 (−5.44), 225 (7.57)
(**4a**)	CD	238.5 (−3.02)	(**4b**)	CD	260 (−3.30), 222 (2.20)
				M	253.5 (−3.51), 200 (3.93)
				HFP	250 (−5.19)
(**5**)	CD	252 (5.13)	(**7**)	M	255 (5.40)
	M	254 (5.57)		H_2O	251 (6.67)
	HFP	248 (8.17)			
(**8**)	M	253 (2.24), 234 (3.09)	(**9**)	M	259.5 (−1.62), 228 (3.14)
(**10a**)	CD	243 (2.58), 224 (4.00)	(**10b**)	CD	262 (2.17), 2.37 (2.44)
	HFP	235sh (2.30), 218 (5.16)		M	257 (1.92), 235 (2.95)
				H_2O	251 (2.03), 233 (2.93)
				HFP	247 (1.28), 229.5 (2.72)
(**12**)[c]	A	255 (−3.88), 225 (1.55)	(**13**)[c]	A	258 (−6.90), 227 (8.1)
(**14a**)	C	247.5 (1.31), 224 (1.76)	(**14b**)	C	260 (2.54), 237 (1.12)
				M	257 (3.12), 224 (1.75)
				HFP	250 (3.10), 230 (2.61)
(**15a**)	C	245 (−4.32), 227 (−5.95)	(**15b**)	C	266 (−9.01), 228 (0.88)
				HFP	258 (−10.1), 236sh (−5.0)

[a] A, acetonitrile; C, cyclohexane; CD, cyclohexane–dioxane (4:1); M, methanol; HFP, hexafluoropropan-2-ol. [b] The highest intensity vibronic band. [c] From ref. 21.

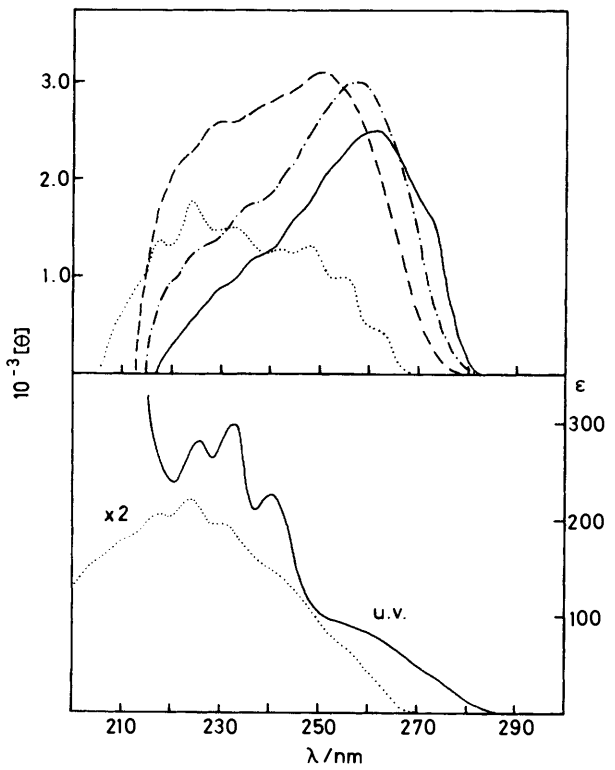


Figure 5. C.d. spectra of the anhydride (**14a**) in cyclohexane (····) imide (**14b**) in cyclohexane (——), methanol (— · — · —), and HFP (– – – –), u.v. of (**14a**) (····) and (**14b**) (——) in cyclohexane

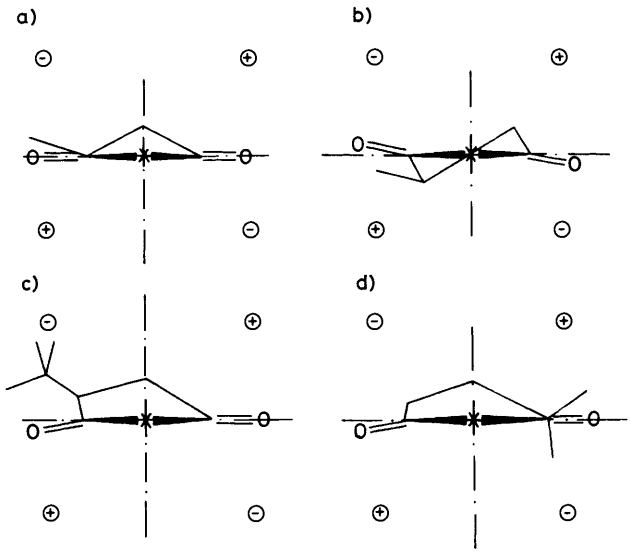


Figure 6. The octant projections of the sofa and twist-boat conformers of (**2a,b**), the distorted sofa forms of (**3a,b**) and (**11**)

different c.d. signs in equilibrium. It is evident from the octant projections of (**2a,b**) (Figure 6) that the sofa form with the equatorial substituent should exhibit weak negative c.d. at lower energies and positive c.d. at higher energies as the result of dis-symmetrically placed methyl substituent contribution (chiral third sphere).[20] In contrast, the skewed-boat form should exhibit strong C.e.s with the opposite signs in both regions in consequence of the chiral ring (second sphere) contribution. A small amount of the skewed-boat conformer in equilibrium with the sofa conformer requires the combination of both types of curve and may explain the shape of the spectra. Consequently, two more intense positive C.e.s in the c.d. of *trans*-α,α′-dimethyl derivatives (**10a,b**) can be attributed to the enhanced amount of the skewed-boat form (predicted by MM2) which is responsible for the long-wavelength C.e. and to strong octant contributions of the axial methyl and chiral skeleton in the distorted sofa conformer which are responsible for the C.e.

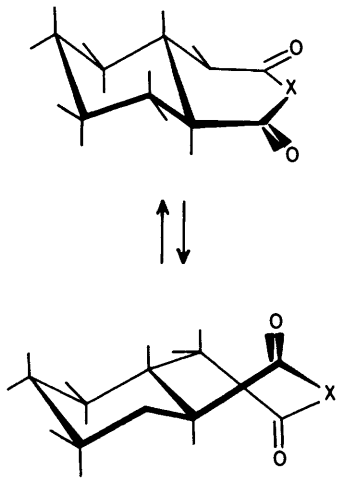


Figure 7.

at shorter wavelengths. The conformational equilibrium shown in Figure 7 may explain the c.d. of compounds (**14a,b**). Similar behaviour is expected for compounds with 2-oxa- and 2-aza-cholestane skeletons (**15a,b**). The strong magnitude of the C.e. at higher energy n—π^* transitions arises from the strong octant contribution of the 6-methyl group and probably from deformation of the skeleton caused by this substituent.

The above interpretation of double humped c.d. curves may be questioned because one might expect that the combination of two bisignate curves could also lead to the bisignate curve characteristic for the dominating conformer in equilibrium or more probably to a complicated spectrum with several maxima and minima. An analysis of the spectra of glutamic acid derivatives (**7**)—(**9**) (Figure 8) and α-hydroxyglutarimide (**5**) will be helpful in clarifying this point. The c.d. of the imides (**5**) and (**7**) exhibit very strong positive C.e.s near 250 nm and very low C.e.s with the same sign at shorter wavelengths. Such spectra point to the predomination of the skewed-boat conformer which may be stabilized by intramolecular hydrogen bonding between the carbonyl and the neighbouring hydroxy or protonated amino group. Analogous behaviour has been noted for malic and aspartic acid imides.[1] A comparison of the curves of compounds (**7**)—(**9**) illustrates the significance of intramolecular hydrogen bonding on the c.d. of imides. The other side of the spectrum of compound (**9**) is an example of c.d. dominated by the sofa conformer. The c.d. curve of the imide (**9**) is in the middle, between the above extreme cases, and its shape resembles those of (**2a,b**), (**10a,b**), and (**14a,b**) as a result of conformational equilibrium between the sofa and the skewed-boat conformer. The observation that the skewed-boat conformer shows very intense C.e. at long-wavelengths and only weak c.d. at shorter wavelengths as in (**5**) and (**7**) is crucial. It can then dominate the low-energy part of the spectrum. Because of only a weak contribution of this conformer to the higher energy of the spectrum, the sofa form is responsible for the C.e. sign in this region and thus the equilibrium between these forms results in a double humped c.d. curve.

The derivatives of α-t-butylglutaric (**3a,b**) and α-phenylglutaric (**4a,b**) acids afford examples of the spectra characteristic for domination of the sofa conformer. Bulky substituents in both cases cause distortion of the six-membered ring from C_s symmetry and then, because of the octant effect of the α-substituent, a contribution arises from the chiral skeleton to the C.e. (Figure 6c). The corresponding c.d. spectra show intense C.e.s and are solvent dependent (Figure 9).

Several optically active α,α-disubstituted glutarimides have been synthesized and their c.d. spectra have been reported by

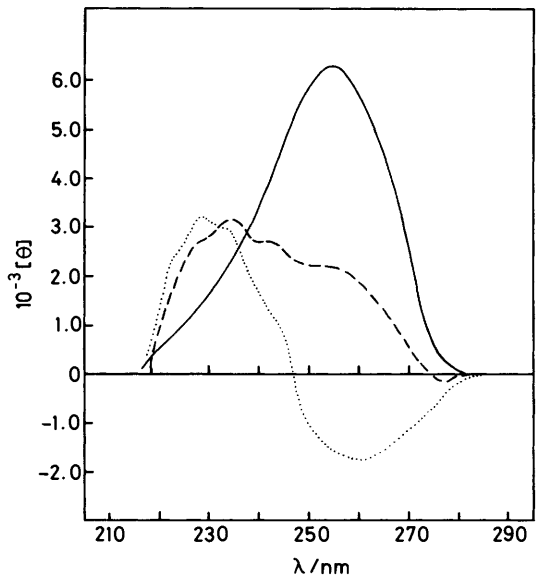


Figure 8. C.d. spectra of the imides (**7**), (**8**), and (**9**) (solid, broken, and dotted line respectively) in methanol

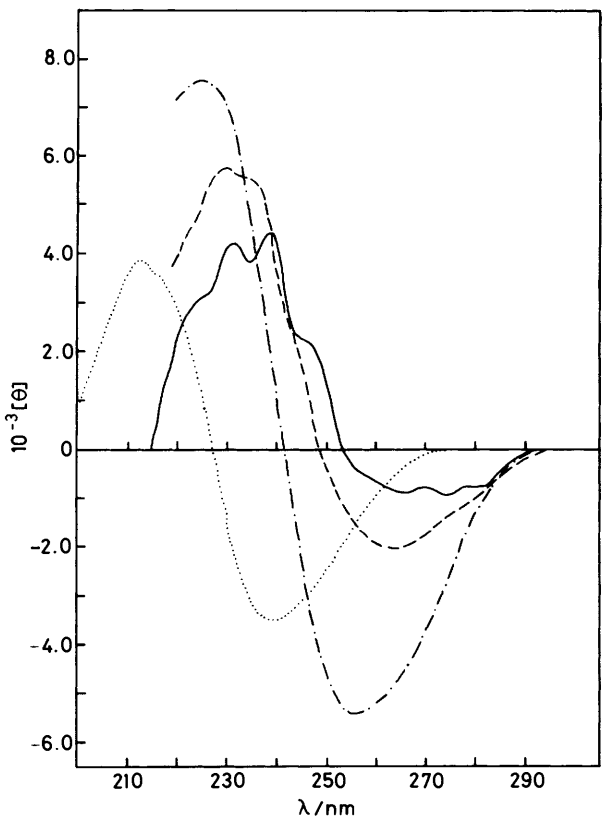


Figure 9. C.d. spectra of the anhydride (**3a**) in HFP (· · ·), the imide (**3b**) in cyclohexane–dioxane (4:1) (——), in methanol (– – –), and in HFP (— · — · —)

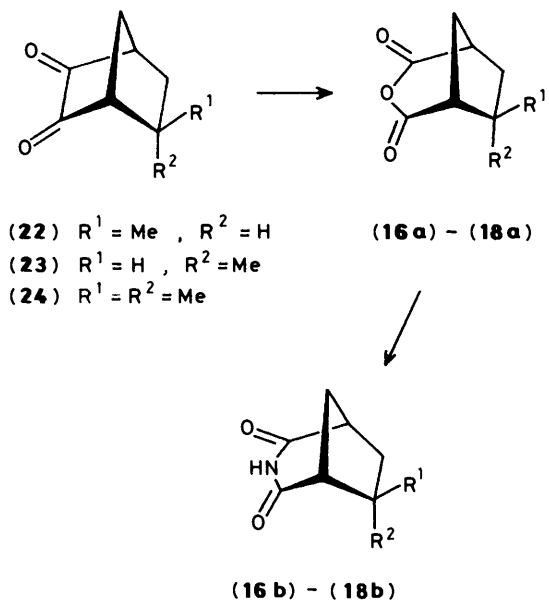
Knabe and Reischig.[21] These compounds show two strong oppositely signed C.e.s [*cf.* (**12**) and (**13**)] and this behaviour contrasts with chiroptical properties of the imides (**2b**) and (**10b**). The MM2 minimum energy conformation calculated for α,α-dimethylglutaric anhydride (**11**) which may serve as a prototype for (**12**) and (**13**), shows it is a strongly deformed sofa conformer. The octant effects from the skeleton and the axial

substitutent contribute the same signs (Figure 6d) and give rise to strong C.e.s of (**12**) and (**13**).

In conclusion, the c.d. sign corresponding to the n—π* electronic transitions of cyclic anhydrides and imides can be predicted with the octant rule. However, the C.e. sign and magnitude are strongly affected by conformation and solvation equilibria which makes predictions difficult. Owing to conformational mobility of the systems even closely related species may differ in their c.d. sign. The above study points to the significance of MM calculations which afford information on molecular geometry and then facilitate interpretation of chiroptical phenomena.

Experimental

All spectroscopic measurements were carried out as described previously. Anhydrides (**2a**) (**4a**), and (**10a**) were obtained according to literature methods.[22–24] The configurations of the parent dicarboxylic acids were already known.[25,26] (+)-2-t-Butylglutaric and (+)-2-carboxycyclohexanylacetic acids were obtained from (*R*)-2-t-butylsuccinic and (*S*)-*trans*-cyclohexane-1,2-dicarboxylic acids[1] respectively by the Arndt-Eistert method so that their configuration was unquestionable. Anhydrides (**16a**)—(**18a**) were obtained from corresponding α-diketones (**22**)—(**24**)[27] by oxidation with hydrogen peroxide in acetic acid followed by dehydration with acetyl chloride.



Scheme 1.

Treatment of compounds (**16a**)—(**18a**) with methanolic ammonia and subsequent heating at 180 °C afforded the imides (**16b**)—(**18b**). The substrates (**22**)—(**24**) were of 71, 81, and 87% optical purity[27] respectively, and at least the same optical purity is expected for the products (**16a,b**)—(**18a,b**). Compounds (**21a,b**) were obtained from isofenchoquinone[28] in a similar manner. Substituted glutarimides were obtained by the procedure described in the preceding paper.[1] (−)-Camphoric anhydride (**20a**) is a commercial product (Alfa Ventron), camphorimides (**20b,c**) were prepared according to the literature procedures.[29]

(S)-2-*Methylglutaric Anhydride* (**2a**).—M.p. 47—48 °C; $[\alpha]_D^{20}$ −37.9° (*c* 3 in C_6H_6) {lit.[22] m.p. 50 °C; $[\alpha]_D^{20}$ −38.8°}.

(S)-2-*Methylglutarimide* (**2b**).—The anhydride (**2a**) (1.27 g, 10 mmol) was dissolved in benzene and gaseous ammonia was passed over the solution. After evaporation of the solvent, the residue was dissolved in DMF (20 ml), the solution cooled to −70 °C, and thionyl chloride (1.0 ml) added; the mixture was then left for 2 h at −5 °C. The DMF was evaporated at reduced pressure, saturated aqueous $NaHCO_3$ (10 ml) added, and the mixture extracted with chloroform. The extracts were dried ($MgSO_4$), decolourized with silica gel, and evaporated. The residue was crystallized from toluene to give the *title product* (0.69 g), m.p. 94—95 °C {lit.[30] (racemate) m.p. 91 °C]; $[\alpha]_D^{20}$ −11° (*c* 2 in $CHCl_3$)}; $\nu_{max.}$ (CCl_4) 3 395, 3 240br, 1 735, and 1 720 cm^{-1}; δ_H ($CDCl_3$) 8.18 (1 H, br, NH), 2.5 (3 H, m, $C_\alpha H + C_\alpha H_2$), 2.4—1.5 (2 H, complex m, $C_\beta H_2$ and 1.24 (3 H, d, Me) (Found: C, 56.5; H, 7.4 N, 10.8. $C_6H_9NO_2$ requires C, 56.7; H, 7.1; N, 11.0%).

(R)-2-*t-Butylglutaric Acid*.—Dimethyl (*R*)-t-butylsuccinate[1] (4.04 g, 20 mmol) was dissolved in methanol (30 ml), potassium hydroxide (1.68 g, 30 mmol) in water (5 ml) was added, and the mixture refluxed for 15 min. After evaporation of methanol and extraction with diethyl ether, the aqueous phase was acidified and extracted with diethyl ether. The extracts were dried ($MgSO_4$) and evaporated to give the monomethyl ester as an oil, δ_H($CDCl_3$) 10.94 (1 H, s, CO_2H), 3.58 (3 H, s, CO_2Me), 2.8—1.95 (3 H, m, $CHCH_2$), and 0.94 (9 H, s, CMe_3). The above half-ester (3.5 g) was dissolved in oxalyl chloride (20 ml) and after 0.5 h oxalyl chloride was evaporated off. The resultant acid chloride was added to an excess of diazomethane in diethyl ether and after 3 h at room temperature the solvent was evaporated off. The residue was dissolved in dioxane (50 ml) and a suspension of silver oxide (0.1 g) in water (10 ml) was added. The mixture was heated at 60 °C for 15 min, and after evolution of nitrogen ceased, refluxed for 5 min, filtered, and evaporated. The residue was dissolved in acetic acid (30 ml), concentrated hydrochloric acid (10 ml) was added, and the mixture refluxed for 10 h to hydrolyse the ester. The reaction mixture was then evaporated to dryness and the residue crystallized from toluene–hexane to give the *title product* (1.2 g), m.p. 94—95 °C; $[\alpha]_D^{20}$ +14° (*c* 2 in acetone); δ_H($CDCl_3$) 10.36 (2 H, s, 2 × CO_2H), 2.6—1.6 (5 H, complex m), and 0.97 9 H, s, CMe_3) (Found: C, 57.3; H, 8.65. $C_9H_{16}O_4$ requires C, 57.4; H, 8.6%).

(R)-2-*t-Butylglutaric Anhydride* (**3a**).—The above acid (0.5 g) was refluxed with acetyl chloride (5 ml) for 0.5 h, evaporated, and the residue crystallized from toluene–hexane to give the *title product* (0.41 g), m.p. 51—52 °C; $[\alpha]_D^{20}$ −22.1° (*c* 2.4 in C_6H_6); $\nu_{max.}$(CCl_4) 1 820 and 1 748 cm^{-1}; δ_H(CCl_4) 2.9—2.4 (2 H complex m, CH_2CO), 2.4—1.5 (3 H, complex m), and 1.05 (9 H, s, CMe_3) (Found: C, 63.5; H, 8.25. $C_9H_{14}O_3$ requires C, 63.5; H, 8.3%).

(R)-2-*t-Butylglutarimide* (**3b**).—Anhydride (**3a**) (0.23 g) was dissolved in benzene and gaseous ammonia was passed through. After evaporation of benzene, the residue was acidified with ethereal hydrogen chloride and the resultant monoamide esterified with diazomethane. The product was dissolved in methanol (5 ml) containing sodium methoxide (from 0.02 g sodium) and after 5 min the solvent was evaporated. The residue was dissolved in dilute hydrochloric acid and extracted with diethyl ether. The extracts were dried ($MgSO_4$), evaporated, and the residue was crystallized from toluene–hexane to give the *title product* (0.11 g), m.p. 158—159 °C; $[\alpha]_D^{20}$ −24° (*c* 1 in MeOH); $\lambda_{max.}$(MeOH) 255sh (ε 94) and 230 nm (280); $\lambda_{max.}$(H_2O) 204 nm (ε 18 500); $\nu_{max.}$(CCl_4) 3 390, 3 240br, and 1 730 cm^{-1}; δ_H($CDCl_3$) 8.68 (1 H, br, NH), 2.6 (2 H, m, CH_2CO), 2.1 (3 H, m) and 1.05 (9 H, s, CMe_3) (Found: C, 63.6; H, 9.25 N, 8.2. $C_9H_{15}NO_2$ requires C, 63.9; H, 8.9; N, 8.3%).

(R)-2-*Phenylglutaric Anhydride* (**4a**).—M.p. 108 °C; $[\alpha]_D^{20}$ −42° (*c* 5 in AcOEt) {lit.,[24] m.p. 118—120 °C; $[\alpha]_D$ −41° (AcOEt); lit.,[25] m.p. 114.5—116 °C}.

(R)-2-*Phenylglutarimide* (**4b**).—The imide (**4b**) was obtained analogously to compound (**2b**). After cyclization, the reaction mixture was poured into 10% aqueous sodium acetate and extracted with diethyl ether. The extracts were dried ($MgSO_4$), evaporated to dryness, and the residue crystallized from toluene–hexane to give the *title product*, m.p. 137—139 °C [lit.,[31] (racemate) m.p. 142—143 °C]; $[\alpha]_D^{20}$ +9° (*c* 3 in $CHCl_3$); $\nu_{max.}(CCl_4)$ 3 390, 3 240br, and 1 735 cm^{-1}; $\delta_H(CDCl_3)$ 8.55 (1 H, br, NH), 7.24 (5 H, m, Ph), 3.73 (1 H, t, CHCO), 2.59 (2 H, m, CH_2CO), and 2.20 (2 H, m, $C_\beta H_2$) (Found: C, 69.7; H, 5.7; N, 7.1. $C_{11}H_{11}NO_2$ requires C, 69.8; H, 5.9; N, 7.4%).

(S)-2-*Hydroxyglutarimide* (**5**).—(*S*)-4-Carboxy-γ-butyrolactone[32] (3.9 g, 30 mmol) was dissolved in saturated methanolic ammonia (20 ml), left overnight, and then evaporated to dryness. The residue was dissolved in a small volume of methanol, acidified with ethereal hydrogen chloride, filtered, and the filtrate evaporated to dryness. The resultant monoamide was cyclized by refluxing with trifluoracetic anhydride (15 ml) for 1 h and then the solvent was evaporated off. The residue was dissolved in chloroform (50 ml) and washed with water (5 ml). The *title product* crystallized from the chloroform phase with very low yield (0.18 g), m.p. 142 °C (from propan-2-ol); $[\alpha]_D^{20}$ −91° (*c* 0.8 in acetone); $\lambda_{max.}$ (MeOH) 252sh nm (ε 88); $\lambda_{max.}(H_2O)$ 202 nm (ε 17 000); $\nu_{max.}(CHCl_3)$ 3 535br (OH), 3 370 (NH), 1 740, and 1 720 cm^{-1}; $\delta_H([^2H_6]$acetone) 9.36 (1 H, br, NH), 4.25 (1 H, m, $C_\alpha H$), 3.30 (1 H, br, OH), and 2.4—1.8 (4 H, complex m) (Found: C, 46.3; H, 5.4; N, 10.95. $C_5H_7NO_3$ requires C, 46.5; H, 5.5; N, 10.85%).

(S)-2-(*Benzyloxycarbonylamino*)*glutarimide* (**6**).—(*S*)-*N*-Benzyloxycarbonylglutamine (Fluka) was converted into the imide (**7**) analogously to compound (**4b**) and had m.p. 122 °C (from toluene) [lit.,[33] (racemate) m.p. 122—124 °C]; $[\alpha]_D^{20}$ −61° (*c* 2 in MeOH); $\nu_{max.}$(KBr) 3 425, 3 270, 1 735, 1 720, and 1 690 cm^{-1}; $\delta_H(CDCl_3)$ 8.75 (1 H, br, NH), 7.24 (5 H, s, Ph), 5.75 (1 H, d, CONH), 5.05 (2 H, s, $PhCH_2$), 4.29 (1 H, m, $C_\alpha H$), 2.61 (2 H, m, CH_2CO), and 2.31—1.5 (2 H, complex m, C_β-H_2) (Found: C, 59.2; H, 5.5; N, 10.4. $C_{13}H_{14}N_2O_4$ requires C, 59.5; H, 5.4; N, 10.7%).

(S)-2-*Aminoglutarimide Hydrobromide* (**7**).—The cleavage of the benzyloxycarbonyl group in the imide (**6**) with hydrogen bromide in acetic acid afforded the *title product*, m.p. 279 °C (with decomp.); $\lambda_{max.}$(MeOH) 253 (ε 86) and 228sh nm (250); $[\alpha]_D^{20}$ −61° (*c* 2 in MeOH); $\delta_H([^2H_6]$DMSO) 11.5 (1 H, s, NH), 8.83 (3 H, br, $^+NH_3$), 4.57 (1 H, m, $C_\alpha H$), 3.2—2.7 (2 H, complex m, CH_2CO), and 2.7—2.2 (2 H, complex m) (Found: C, 28.9; H, 4.5; N, 13.3. $C_5H_9BrN_2O_2$ requires C, 28.6; H, 4.3; N, 13.4%).

(S)-2-(*Methylsulphonylamino*)*glutarimide* (**8**).—The imide (**7**) (0.21 g, 1 mmol) was suspended in chloroform (5 ml), triethylamine (0.28 ml, 2 mmol) was added with shaking, the mixture was cooled to −5 °C, and methanesulphonyl chloride (0.15 ml, 1.9 mmol) was added. After 0.5 h at 0 °C the solvent was evaporated off and the residue was dissolved in ethyl acetate (50 ml) and washed with water (10 ml). The organic layer was dried ($MgSO_4$), evaporated to dryness and the residue was crystallized from ethanol–diethyl ether to give the *title product* (0.21 g), m.p. 169—170 °C; $[\alpha]_D^{20}$ −96° (*c* 1 in MeOH); $\nu_{max.}$(KBr) 3 440br, 3 290, 1 735, 1 720, and 1 700 cm^{-1}; $\delta_H(D_2O)$ 4.48 (1 H, m, $C_\alpha H$), 3.19 (3 H, s, $MeSO_2$), 3.0—2.8 (2 H, m, CH_2CO), and 2.4—2.0 (2 H, m) (Found: C, 34.95; H, 4.95; N, 13.9. $C_6H_{10}N_2O_4S$ requires C, 34.95; H, 4.9; N, 13.6%).

(S)-N-*Methyl*-N-*methylsulphonylglutamic Acid*.—(*S*)-Dimethyl glutamate hydrochloride (Fluka) (4.23 g, 20 mmol) suspended in chloroform (30 ml) was cooled to −5 °C and triethylamine (5.6 ml, 40 mmol) was added with stirring and cooling; this was followed by methanesulphonyl chloride (1.6 ml, 21 mmol) added at 0 °C. After 3 h at room temperature the mixture was washed with water, dried ($MgSO_4$), and evaporated to give (S)-*dimethyl N-methylsulphonylaminoglutamate* (5.0 g as an oil, $\delta_H(CDCl_3)$ 5.39 (1 H, br, SO_2NH), 4.23 (1 H, m, $C_\alpha H$), 3.73 (3 H, s, CO_2Me), 3.63 (3 H, s, CO_2Me), 2.94 (3 H, s, $MeSO_2$), 2.6—2.3 (2 H, m, CH_2CO), and 2.3—1.7 (2 H, m). The above ester was treated with an excess of ethereal diazomethane (overnight) to give the *N*-methyl derivative as an oil (5.0 g), $\delta_H(CCl_4)$ 4.3 (1 H, m, $C_\alpha H$), 3.72 (3 H, s, CO_2Me), 3.59 (3 H, s, CO_2Me), 2.90 (3 H, s, $MeSO_2$), 2.73 (3 H, s, NMe), and 2.5–1.7 (4 H, complex m) which was hydrolysed with potassium hydroxide (2.0 g) in methanol–water (2:1) (30 ml) for 0.5 h at room temperature. After evaporation of the methanol, the reaction mixture was extracted with diethyl ether, and the aqueous phase acidified and then extracted with ethyl acetate. The organic layer was dried ($MgSO_4$) and evaporated to give the *title product* as an oil (2.9 g), $\delta_H([^2H_6]$acetone) 8.0 (2 H, s, 2 CO_2H), 4.53 (1 H, m, $C_\alpha H$), 2.93 (3 H, s, $MeSO_2$), 2.80 (3 H, s, NMe), and 2.5—2.1 (2 H, m, CH_2CO); cyclohexylammonium salt, m.p. 158—160 °C (Found: C, 50.5; H, 9.4; N, 9.4. $C_{19}H_{39}N_3O_6S{\cdot}H_2O$ requires C, 50.1; H, 9.1; N, 9.2%).

(S)-2-(N-*Methyl*-N-*methylsulphonylamino*)*glutarimide* (**9**).—The above acid was heated under reflux with acetyl chloride to give the corresponding anhydride; this was then immediately transformed into the imide (**9**) as described for compound (**2b**); it had m.p. 167 °C (from ethyl acetate); $[\alpha]_D^{20}$ −45° (*c* 0.4 in EtOH); $\lambda_{max.}$(MeOH) 255sh (ε 73) and 230sh nm (265); $\nu_{max.}$(KBr) 3 450br, 3 250br, 1 740, 1 720, and 1 703 cm^{-1}; $\delta_H([^2H_6]$acetone) 8.85 (1 H, br, NH), 4.77 (1 H, m, $C_\alpha H$), 2.97 (3 H, s, $MeSO_2$), 2.76 (3 H, s, NMe), and 2.5—2.1 (2 H, m) (Found: C, 37.9; H, 5.6; N, 12.6. $C_7H_{12}N_2O_4S$ requires C, 38.2; H, 5.5; N, 12.7%).

(2S,4S)-2,4-*Dimethylglutaric Anhydride* (**10a**).—M.p. 40.5—41.5 °C; $[\alpha]_D^{20}$ −75° (*c* in C_6H_6) {lit.[23] (enantiomer) m.p. 42—43.5 °C; $[\alpha]_D$ +69.6° (*c* 10 in C_6H_6)}; $\lambda_{max.}$(cyclohexane) 240sh (ε 75) and 224 nm (107); $\nu_{max.}(CCl_4)$ 1 805 and 1 760 cm^{-1}.

(2S,4S)-2,4-*Dimethylglutarimide* (**10b**).—The imide (**10b**) was obtained analogously to compound (**2b**). The crude product, contaminated with *meso*-diastereoisomer, was purified by chromatography on silica gel. The *title product* was crystallized from toluene and had m.p. 117—119 °C; $[\alpha]_D^{20}$ −29.5° (*c* 0.5 in C_6H_6); $\lambda_{max.}$(cyclohexane) 253sh (ε 85) and 233.5 nm (238); $\lambda_{max.}$(MeOH) 252sh (ε 85) and 229sh nm (260); $\lambda_{max.}(H_2O)$ 203.5 nm (ε 16 700); $\nu_{max.}(CCl_4)$ 3 390, 3 240br, 1 735, 1 720, and 1 705 cm^{-1}; $\delta_H(CDCl_3)$ 8.20 (1 H, br, NH), 2.66 (2 H, m, 2 × $C_\alpha H$), 1.76 (2 H, t, CH_2), and 1.23 (6 H, d, 2 × Me) (Found: C, 59.5; H, 8.0; N, 9.7. $C_7H_{11}NO_2$ requires C, 59.6; H, 7.85; N, 9.9%).

(1R,2S)-2-*Carboxycyclohexanylacetic Acid*.—Methanol (20 ml) was added to a solution of (*S*)-*trans*-cyclohexane-1,2-dicarboxylic anhydride (1.7 g, 11 mmol) in pyridine (10 ml) and the mixture was left overnight. It was then evaporated and the residue dissolved in diethyl ether and the solution washed with dilute hydrochloric acid, dried ($MgSO_4$), and evaporated. The resultant monoester was converted into the *title product* (1.2 g) in a similar manner to that described for (*R*)-2-t-butylglutaric acid, m.p. 114—115 °C (from toluene–hexane); $[\alpha]_D^{20}$ +13° (*c* 5 in $CHCl_3$) {lit.[34] m.p. 116 °C; $[\alpha]_D^{20}$ + 40.1° (in dioxane)}.

(1S,6R)-3-*Oxabicyclo*[4.4.0]*decane*-2,4-*dione* (**14a**).—The anhydride (**14a**) was obtained in a similar manner to compound (**3a**) and had m.p. 111—112 °C (from toluene–hexane); $[\alpha]_D^{20}$ −81° (in $CHCl_3$) {lit.,[34] m.p. 111 °C; $[\alpha]_D^{20}$ −72.1° (*c* 11 in dioxane)}; $\lambda_{max.}$(cyclohexane) 237sh (ε 91) and 224 nm (110).

(1S,6R)-3-*Azabicyclo*[4.4.0]*decane*-2,4-*dione* (**14b**).—The imide (**14b**) was obtained in a similar manner to compound (**4b**) and had m.p. 186—187 °C (from toluene–hexane); $[\alpha]_D^{20}$ −73° (*c* 1.2 in $CHCl_3$); $\lambda_{max.}$(cyclohexane) 253sh (ε 100) and 233 nm (290); $\lambda_{max.}$(MeOH) 252sh (ε 95) and 229sh (260); $\lambda_{max.}$(H_2O) 203 nm (ε 15 100); $\nu_{max.}$($CHCl_3$) 3 380, 3 240br, 1 738, 1 720, and 1 705 cm^{-1}; δ_H($CDCl_3$) 8.47 (1 H, br, NH), 2.37 (3 H, m, CHCO + CH_2CO), and 2.1—0.8 (9 H, complex m) (Found: C, 64.4; H, 7.9; N, 8.2. $C_9H_{13}NO_2$ requires C, 64.65; H, 7.8; N, 8.4%).

2-*Oxa*-5α-*cholestane*-1,3-*dione* (**15a**).—The anhydride (**15a**) was obtained from 1,3-seco-2-norcholestane-1,3-dioic acid[35,36] in a similar manner to compound (**3a**) and had m.p. 152 °C (lit.,[36] m.p. 154—155 °C).

2-*Aza*-5α-*cholestane*-1,3-*dione* (**15b**).—The imide (**15b**) was obtained in a similar manner to compound (**4b**) and had m.p. 215—217 °C (from ethanol); $[\alpha]_D^{20}$ +125° (*c* 1 in $CHCl_3$); $\lambda_{max.}$(cyclohexane) 260s (ε 120) and 236.5 nm (300); $\nu_{max.}$(CCl_4) 3 390, 3 250br, 1 732, and 1 720 cm^{-1} (Found: C, 77.9; H, 10.9; N, 3.6. $C_{26}H_{43}NO_2$ requires C, 77.75; H, 10.8; N, 3.5%).

(1R)-exo-6-*Methyl*-3-*oxabicyclo*[3.2.1]*octane*-2,4-*dione* (**16a**).—30% Hydrogen peroxide (1 ml) was added to a solution of (1*R*)-*exo*-5-methylbicyclo[3.2.1]heptane-2,3-dione[27] (**22**) (0.7 g, 5 mmol) in acetic acid (5 ml) to induce a vigorous reaction. Subsequently, the colourless reaction mixture was evaporated under reduced pressure and the residue refluxed with acetyl chloride (5 ml) for 0.5 h. The mixture was then evaporated and the residue crystallized from toluene–hexane to give the *title product* (0.52 g), m.p. 73—74 °C; $[\alpha]_D^{20}$ −48.5° (*c* 2 in $CHCl_3$); $\nu_{max.}$(CCl_4) 1 795, 1 755, and 1 745 cm^{-1}; δ_H($CDCl_3$) 3.11 (1 H, m, CHCO), 2.83 (1 H, m, CHCO), 2.7—1.3 (5 H, complex m), and 1.14 (3 H, d, Me) (Found: C, 62.2; H, 6.65. $C_8H_{10}O_3$ requires C, 62.3; H, 6.5%).

(1R)-exo-6-*Methyl*-3-*azabicyclo*[3.2.1]*octane*-2,4-*dione* (**16b**).—The anhydride (**16a**) (0.20 g) was treated with methanolic ammonia for 0.5 h, after which the reaction mixture was evaporated and the residue heated at 180 °C for 15 min. The product was dissolved in chloroform, decolourized with silica gel, evaporated, and crystallized from toluene–hexane to give the *title product* (80 mg) m.p. 81—84 °C; $[\alpha]_D^{20}$ −43° (*c* 1 in $CHCl_3$); $\lambda_{max.}$(cyclohexane) 258 (ε 120) and 232 nm (200); $\nu_{max.}$(CCl_4) 3 395, 3 230br, 1 745, 1 730, and 1 715 cm^{-1}; δ_H($CDCl_3$) 8.50 (1 H, br, NH), 2.87 (1 H, m, CHCO), 2.51 (1 H, m, CHCO), 2.4—1.3 (5 H, complex m), and 1.06 (3 H, d, Me) (Found: C, 62.35; H, 7.4; N, 9.2. $C_8H_{11}NO_2$ requires C, 62.7; H, 7.2; N, 9.1%).

(1R)-endo-6-*Methyl*-3-*oxabicyclo*[3.2.1]*octane*-2,4-*dione* (**17a**).—The anhydride (**17a**) was obtained in a similar manner to compound (**16a**) and had m.p. 81—85 °C (from toluene–hexane); $[\alpha]_D^{20}$ +17.3° (*c* 2 in C_6H_6); $\nu_{max.}$(CCl_4) 1 790, 1 760, and 1 745 cm^{-1}; δ_H($CDCl_3$) 3.25 (2 H, m, 2 × CHCO), 2.9—1.3 (5 H, complex m), and 1.14 (3 H, d, Me) (Found: C, 62.1; H, 6.7. $C_8H_{10}O_3$ requires C, 62.3; H, 6.5%).

(1R)-endo-6-*Methyl*-3-*azabicyclo*[3.2.1]*octane*-2,4-*dione* (**17b**).—The imide (**17b**) was obtained in a similar manner to compound (**16b**) and had m.p. 121—122 °C (from toluene–hexane); $[\alpha]_D^{20}$ +20° (*c* 1 in $CHCl_3$); $\lambda_{max.}$(cyclohexane) 259 (ε 110) and 232.5 nm (170); $\nu_{max.}$(CCl_4) 3 400, 3 235br, 1 730, and 1 715 cm^{-1}; δ_H($CDCl_3$) 8.14 (1 H, br, NH), 2.93 (2 H, m, 2 × CHCO), 2.7—1.2 (5 H, complex m), and 1.06 (3 H, d, Me) (Found: C, 62.4; H, 7.3; N, 8.9. $C_8H_{11}NO_2$ requires C, 62.7; H, 7.2; N, 9.1%).

(1R)-6,6-*Dimethyl*-3-*oxabicyclo*[3.2.1]*octane*-2,4-*dione* (**18a**).—The anhydride (**18a**) was obtained in a similar manner to compound (**16a**) and had m.p. 83—84 °C (from toluene–hexane); $\nu_{max.}$(CCl_4) 1 795 and 1 750 cm^{-1}; δ_H($CDCl_3$) 3.17 (1 H, m, CHCO), 2.79 (1 H, m, CHCO), 2.14 (2 H, m, CH_2), 1.87 (2 H, m, CH_2), and 1.17 (6 H, s, 2 Me) (Found: C, 64.05; H, 7.3. $C_9H_{12}O_3$ requires C, 64.3; H, 7.2%).

(1R)-6,6-*Dimethyl*-3-*azabicyclo*[3.2.1]*octane*-2,4-*dione* (**18b**).—The imide (**18b**) was obtained in a similar manner to compound (**16b**), and had m.p. 137—140 °C (from toluene–hexane); $\nu_{max.}$(CCl_4) 3 390, 3 230br, 1 740, 1 720, and 1 710 cm^{-1}; δ_H($CDCl_3$) 8.39 (1 H, br, NH), 3.03 (1 H, m, CHCO), 2.64 (1 H, m, CHCO), 2.10 (2 H, m, CH_2), 1.84 (2 H, m, CH_2) and 1.15 (6 H, s, 2 × Me) (Found: C, 64.6; H, 7.95; N, 8.3. $C_9H_{13}NO_2$ requires C, 64.65; H, 7.8; N, 8.4%).

(1R)-1,6,6-*Trimethyl*-3-*oxabicyclo*[3.2.1]*octane*-2,4-*dione* (**21a**).—(1*S*)-1,6,6-Trimethylbicyclo[2.2.1]heptane-2,3-dione[28] was oxidized with 30% hydrogen peroxide as described for compound (**16a**). The *title product* crystallized from the reaction mixture and had m.p. 96 °C (from toluene–hexane); $[\alpha]_D^{20}$ −14.5° (*c* 1 in C_6H_6) {lit.,[37] m.p. 98 °C; $[\alpha]_D$ −13.5 (in C_6H_6)}.

(1R)-1,6,6-*Trimethyl*-3-*azabicyclo*[3.2.1]*octane*-2,4-*dione* (**21b**).—The amide (**21b**) was obtained in a similar manner to compound (**16b**) and had m.p. 118—119 °C; $[\alpha]_D^{20}$ +13° (*c* 1 in EtOH) {lit.,[37] m.p. 120—121 °C; $[\alpha]^{18}$ +12.7° (in EtOH)}; $\lambda_{max.}$(cyclohexane) 255 (ε 130) and 232 nm (190).

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