Synthetic Studies directed towards Complex Diterpenoids. Part 15.[1] Synthesis and Stereochemistry of the Catalytic Reduction of $\Delta^{4b(5)}$-Gibbenes and Related Compounds

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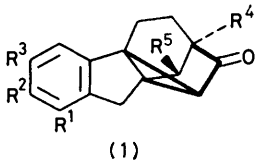
The synthesis of, and substituent effects in the stereoselectivity of catalytic hydrogenation of, a series of methyl- or methoxy-substituted (±)-4b,9-cyclogibba-1(10a),2,4-trien-8-ones (1a—g) and (±)-gibba-1(10a), 2,4,4b(5)-tetraen-8-ones (2a—g) are described, which lead to stereocontrolled syntheses of the respective C-4b epimeric gibbanes (3a—g) and (4a—g). The key intermediate tetrahydrofluorene-2-carboxylic acids (10a—g), prepared by cycloaddition reactions, are converted into the corresponding α-diazomethyl ketones (12a—g) which are subjected to intramolecular oxo-carbenoid addition or perchloric acid–trifluoroacetic acid-catalysed cyclisation leading to the cyclopropyl ketones (1a—g) and the $\Delta^{4b(5)}$-gibbenes (2a—g), respectively.

In earlier papers in this series we described two simple, general preparative routes to tetracyclic gibbanes [2-4] and similar systems,[1,5,6] incorporating intermediate bridged bicyclo[3.2.1]octanone moieties, *via* intramolecular alkylations of appropriate γδ-unsaturated α′-diazomethyl ketones, and involving metal-catalysed oxocarbenoid additions and acid-catalysed cyclisations. We also showed [2-4] that the cyclopropyl ketones, such as (1h),[2] (1i),[3] and (1j) [4] are hydrogenolysed regio- and stereoselectively in the presence of palladium–charcoal in ethanol giving the corresponding 4bα-gibbanes (3h), (3i), and (3j) in isolated yields of 92, 91, and 80%, respectively. In contrast, the related $\Delta^{4b(5)}$-gibbenes (2h),[2] (2i),[3] and (2j) [4] produced *ca.* 7 : 3, 3 : 1, and 1 : 4 mixtures, respectively, of the corresponding 4bα- and 4bβ-gibbanes (3h) and (4h), and (3i) and (4i), and (3j) and (4j). The dramatic reversal of stereochemistry in the latter substrate, leading mainly to the 4bβ-epimer (4j), appeared interesting both from the stereochemical and synthetic view points. As a consequence we thought it necessary to undertake further investigations to evaluate the effect of various substituents in the cyclopropyl ketones and the respective $\Delta^{4b(5)}$-gibbenes in determining the stereochemistry of their hydrogenation products. This paper constitutes a detailed account [7] of our studies concerning the synthesis and stereoselectivity in the catalytic reduction of the cyclopropyl ketones (1a—g) and the $\Delta^{4b(5)}$-gibbenes (2a—g) leading to a simple stereocontrolled route to a number of new C-4b epimeric gibbane synthons.[4,8]



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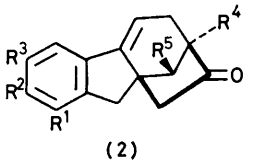

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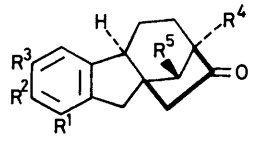

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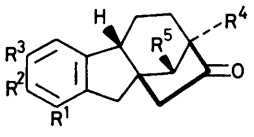

(4)

a; R^1 = OMe, R^2 = R^3 = R^4 = R^5 = H
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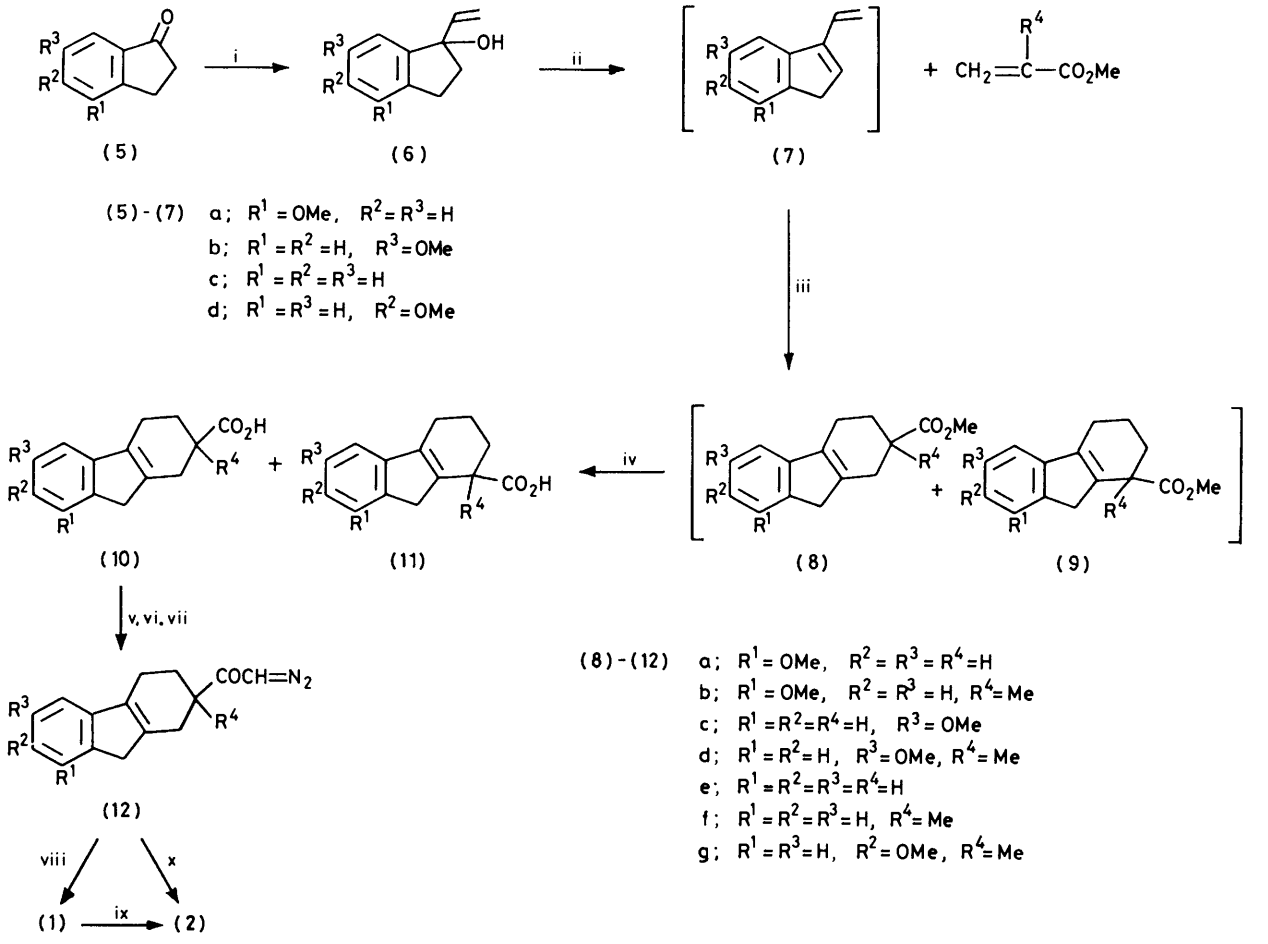
c; R^1 = R^2 = R^4 = R^5 = H, R^3 = OMe
d; R^1 = R^2 = R^5 = H, R^3 = OMe, R^4 = Me
e; R^1 = R^2 = R^3 = R^4 = R^5 = H
f; R^1 = R^2 = R^3 = R^5 = H, R^4 = Me
g; R^1 = R^3 = R^5 = H, R^2 = OMe, R^4 = Me
h; R^1 = R^3 = R^4 = R^5 = H, R^2 = OMe
i; R^1 = R^3 = R^4 = H, R^2 = OMe, R^5 = Me
j; R^1 = Me, R^2 = R^3 = R^4 = R^5 = H
k; R^1 = R^4 = Me, R^2 = R^3 = R^5 = H

RESULTS AND DISCUSSION

The tetrahydrofluorenecarboxylic acids (10a—g) were prepared by the application of the Diels–Alder reaction [4] (Scheme). The crude vinyl carbinols (6a—d), prepared from the respective indan-1-ones (5a—d) by condensation with vinylmagnesium bromide *via* a modified method,[5] were subjected to cycloaddition with methyl acrylate (MA) or methyl α-methylacrylate (MMA) in the presence of a catalytic amount of toluene-*p*-sulphonic acid and hydroquinone in refluxing benzene to afford the regioisomeric ester adducts (8a—g) and (9a—g) after *in situ* isomerisation of the intermediate trisubstituted double-bond-isomers with hydrogen chloride. Alkaline hydrolysis of the ester adducts gave crystalline regioisomeric acid mixtures, which on fractional crystallisation readily afforded the less soluble tetrahydrofluorene-2-carboxylic acids (10a—g). In some cases the pure regioisomeric 1-carboxylic acids (11) could be separated from the more soluble fractions. The structures of these acids have been established by their i.r. and u.v. spectra as well as the n.m.r. spectra of the corresponding methyl esters (8a—g). The structural assignment of the regioisomeric C-2 acids (10a—g) is based upon their further transformation to the respective gibbanes (*vide infra*). In general the cycloaddition reaction with MA is relatively more regioselective, and the yields of the acids are higher, in comparison with the reaction with MMA [4] (see Experimental section). Although the overall yields of the tetrahydrofluorenecarboxylic acids from the starting indanones are not altogether satisfactory, the simplicity



SCHEME *Reagents*: i, CH_2=CHMgBr, THF; ii, *p*-TsOH, benzene, hydroquinone; iii, HCl(g), benzene; iv, KOH, H_2O, MeOH; v, NaOMe, MeOH; vi, $(COCl)_2$, pyridine, benzene; vii, CH_2N_2, Et_2O, Et_3N; viii, 'activated CuO', THF–cyclohexane, *hν*; ix, HCl(g), $CHCl_3$; x, 70% $HClO_4$–TFA (1 : 1), $CHCl_3$

of the reaction provides an easy, general route to the key intermediate tetrahydrofluorene-2-carboxylic acids (10a—g), normally difficult to obtain,[2] and to some tetrahydrofluorene-1-carboxylic acids, valuable intermediates for compounds related to gibberellins.[9]

Using a standard method (Scheme) the acids (10a—g) were converted *via* their sodium salts [4] into the corresponding acyl chlorides which, in turn, were treated with an excess of diazomethane in ether in the presence of triethylamine. The diazoketones (12a—g) thus obtained in excellent yield were characterised by their i.r. and n.m.r. spectra. Intramolecular oxocarbenoid addition of the diazoketones (12a—g) in the presence of activated CuO '[7] in boiling cyclohexane–tetrahydrofuran under irradiation with tungsten lamps afforded the respective cyclopropyl ketones (1a—g) in 70—95% yield. Fragmentation [4] of the cyclopropyl ketones on exposure to hydrogen chloride in chloroform produced the corresponding $\Delta^{4b(5)}$-gibbenes (2a—g) in 90—93% yield. The gibbenes were also obtained in 65—94% yield by direct cyclisation of the diazoketones (12a—g) using 70% perchloric acid and trifluoroacetic acid [10] in dry chloroform. Cyclisation of the diazoketones with 48% tetrafluoroboric acid [5] in nitromethane or with BF_3–ether [4-6] or trifluoroacetic acid [11] in dry methylene dichloride, however, gave relatively lower yields of the respective $\Delta^{4b(5)}$-gibbenes.

In accord with our previous findings [2-4] with (1h, i, k), the aromatic conjugated cyclopropane σ-bond in the cyclogibbanes (1a, c, e—g) underwent facile regio- and stereo-specific hydrogenolysis in the presence of 10% Pd–C in ethanol with inversion at the C-4b asymmetric centre, leading to the respective 4bα-gibbanes (3a, c, e—g) in almost quantitative yield. However, hydrogenolysis of the cyclogibbanes (1b) and (1d) under identical conditions produced mixtures of the respective 4bα- and 4bβ-epimers (3b) and (4b) and (3d) and (4d) in a ratio of *ca.* 4 : 1 (g.l.c. and ^{1}H n.m.r.). The results are summarised in the Table. The stereochemistry of the gibbane (3g) was confirmed by direct comparison with an authentic sample.[12,*] The stereochemical assignments of the other 4bα-gibbanes were made from comparisons with analogous compounds [2-4] as well as, in

* We thank Professor G. Stork for comparing our sample of the gibbane (3g) with his sample prepared through a stereospecific route.

some cases, from the significant chemical shifts of the C-10 methylene protons in their ^{1}H n.m.r. spectra [4,13] (Experimental section).

The results of the present work (Table), along with our earlier observations,[2-4] clearly established that the catalytic hydrogenolysis of the cyclogibbanes is stereospecific (entries 1, 5, 9, 11, and 13) or highly stereoselective (entries 3 and 7) irrespective of the substitution pattern.

The results of the catalytic hydrogenation of the $\Delta^{4b(5)}$-gibben-8-ones (2a—g) in the presence of 10% Pd–C in ethanol are also summarised in the Table. In some cases separation of the pure 4bα- and 4bβ-epimers has been achieved by rigorous fractional crystallisation. Our earlier results [2-4] on the catalytic hydrogenation of the gibbenes (2h—k) have also been included in the Table for comparison.

Distribution of the 4bα- and 4bβ-gibbanes (3) and (4) in the 10% Pd–C-catalysed hydrogenation of the cyclogibbanes (1) and $\Delta^{4b(5)}$-gibbenes (2) in ethanol

Entry	Starting compound	Ketone product [a] 4bα	4bβ	Product ratio (4bα : 4bβ)
1	(1a)	(3a)	—	100 : 0 [b]
2	(2a)	(3a)	(4a)	10 : 90 [b]
3	(1b)	(3b)	(4b)	80 : 20 [c]
4	(2b)	(3b)	(4b)	50 : 50 [c]
5	(1c)	(3c)	—	100 : 0 [b]
6	(2c)	(3c)	(4c)	40 : 60 [b]
7	(1d)	(3d)	(4d)	80 : 20 [b,c]
8	(2d)	(3d)	(4d)	50 : 50 [b,c]
9	(1e)	(3e)	—	100 : 0 [b]
10	(2e)	(3e)	(4e)	64 : 36 [b]
11	(1f)	(3f)	—	100 : 0 [b]
12	(2f)	(3f)	(4f)	60 : 40 [c]
13	(1g)	(3g)	—	100 : 0 [b]
14	(2g)	(3g)	(4g)	75 : 25 [c]
15	(2h) [d]	(3h)	(4h)	69 : 31 [c]
16	(2i) [e]	(2i)	(4i)	75 : 25 [c]
17	(2j) [e]	(3j)	(4j)	20 : 80 [c]
18	(2k) [f]	(3k)	(4k)	63 : 27 [c]

[a] Average yield of the crude product 97—99%. [b] Determined by g.l.c. Ratio for entry 1 also determined by t.l.c. [c] Determined by ^{1}H n.m.r. [d] Ref. 2. [e] Ref. 3. [f] Ref. 4.

The data recorded in the Table provide the following generalisations relating to the effects of the methyl- and methoxy-substituents in the $\Delta^{4b(5)}$-gibbenes (2a—k) on the stereochemical course of the catalytic hydrogenation under the given conditions: (i) in general the bridge-head C-7 methyl substituent in the gibbenes marginally contributes to the stereoselectivity of the addition of hydrogen from the opposite face of the two-carbon bridge (ring-D), *i.e.* the α-face (entries 4, 8, 12, 14, and 18). A similar effect has been observed in the case of the 11β-methyl [3] (entry 16) and 10β-methyl [14] substituents. (ii) The 2-methoxy-substituent in the aromatic ring has practically no influence in directing the stereochemical outcome in the reduction of the 4b,5-double bond (entries 14, 15, and 16) and shows similar stereochemical results with respect to that of the aromatic ring-unsubstituted gibbenes (2e and f) (entries 10 and 12). However, the 3-methoxy substituent in the gibbene has a marginal directive influence in the addition of hydrogen from the same side of the two-carbon bridge, *i.e.* the β-face (entries 6 and 8). (iii) A 1-methoxy- or methyl-substituent has a profound influence in directing the addition of hydrogen from the β-face of the gibbenes (entries 2 and 17). This effect, which is possibly steric in nature, provides an important controlling factor in the stereoselective synthesis of the 4bβ-gibbanes from the respective $\Delta^{4b(5)}$-gibbenes. The effects of the polar C-10 substituents in the $\Delta^{4b(5)}$-gibbenes on the stereoselectivity of the hydrogenation of the 4b,5-double bond have been recorded in several cases.[15] Similar influences by polar angular substituents in controlling the stereochemistry of catalytic reduction in some tetrahydrofluorenes have also been observed.[16]

In addition to providing simple and general stereocontrolled synthetic routes to C-4b epimeric gibbane synthons, the present investigation clearly demonstrated that, although in the reductive cleavage of the cyclogibbanes (1) a high degree of stereoselectivity is generally maintained, a subtle change in the substituents, even in the aromatic ring of the $\Delta^{4b(5)}$-gibbenes (2), can cause a drastic change in the stereochemistry [4,17] of the hydrogenation products with a Pd–C catalyst. The origin of the high stereoselectivity in the cleavage of the aromatic conjugated cyclopropyl bond has been explained by Kieboom *et al.* and others.[18]

EXPERIMENTAL

M.p.s were measured in open capillary tubes in a sulphuric-acid bath and are uncorrected. I.r. spectra were recorded on Perkin-Elmer 21 and Beckmann Acculab 4 or 20a spectrometers for chloroform solutions. U.v. spectra were recorded on a Beckman DU spectrophotometer for solutions in 95% ethanol. ^{1}H N.m.r. spectra were recorded at 60 MHz or 100 MHz (if specified) on Varian Associates T-60 A or HA 100 spectrometers, respectively, for solutions in CCl_4 or $CDCl_3$, respectively, with $SiMe_4$ as internal standard. Analytical g.l.c. was performed on a Hewlett Packard 5730A chromatograph equipped with a flame-ionisation detector employing a 6 ft × $\frac{1}{8}$ in 3% SE 52 column with N_2 as the carrier gas. Column chromatography was performed on neutral alumina (Brockmann Grade 1). Light petroleum refers to the fraction with b.p. 60—80 °C.

Preparation of Tetrahydrofluorenecarboxylic Acids.—*1,2,-3,4-Tetrahydro-8-methoxyfluorene-2-carboxylic acid* (10a). To an ice-cold, well stirred solution of vinylmagnesium bromide, prepared from magnesium turnings (2 g, 0.08 g-atom) in dry tetrahydrofuran (THF) (13 ml) and a freshly prepared vinyl bromide solution, prepared from 1,2-dibromoethane (25 g, 0.13 mol) in dry THF (13 ml), was added dropwise under nitrogen a solution of 4-methoxyindan-1-one (5a) [19] (6 g, 0.037 mol) in dry THF (28 ml). The resulting mixture was stirred for 2 h at room temperature and finally refluxed for 2 h. The solvent was removed by distillation on a steam-bath. The residue was cooled in an ice–water bath and decomposed with ice-cold aqueous ammonium chloride. The product was extracted with benzene and the extract was washed with water and dried (Na_2SO_4). The benzene solution of the crude alcohol (6a) was azeotropically refluxed under nitrogen for 10 h with freshly distilled methyl acrylate (15 g, 0.174 mol), toluene-*p*-sulphonic acid (50 mg), and hydroquinone (20 mg) using

a Dean and Stark apparatus. The mixture was then cooled in an ice–water bath and a constant stream of dry HCl was passed through it for 30 min. After a further 20 min the mixture was washed with water, 5% aqueous sodium carbonate, and again with water, and then dried. Evaporation of the solvent followed by fractional distillation yielded a mixture of the regioisomeric esters (8a) and (9a) as a pale yellow oil (6.2 g), b.p. 160—170 °C at 0.2 mmHg; $\lambda_{max.}$ 260 nm (log ε 4.02); $\nu_{max.}$ 1 730 cm^{-1}. The ester adducts were hydrolysed by refluxing them for 2 h under nitrogen with a solution of potassium hydroxide (5.6 g, 0.1 mol) in a mixture of water (5 ml) and methanol (51 ml). After removal of methanol under reduced pressure the solution was diluted with water and the neutral fraction was removed by ether extraction. The aqueous alkaline layer was acidified with 6M hydrochloric acid and the precipitated acid was extracted with ethyl acetate (4 × 40 ml). The extract was washed with brine, dried, and evaporated to dryness to afford a mixture of the crude acids (10a) and (11a) (5.5 g, 61%), m.p. 144—162 °C. Repeated crystallisation from methanol afforded the pure *acid* (10a) as light yellow needles (3.4 g, 38% overall yield from starting indanone), m.p. 203—204 °C; $\lambda_{max.}$ 260 nm (log ε 4.1); $\nu_{max.}$ 1 700 cm^{-1} (Found: C, 73.6; H, 6.65. $C_{15}H_{16}O_3$ requires C, 73.75; H, 6.6%). The methyl ester (8a), prepared by treating the acid (10a) with diazomethane, had $\nu_{max.}$ 1 730 and 1 600 cm^{-1}; δ 1.60—2.80 (7 H, m), 3.10br (2 H, s, ArCH_2), 3.60 (3 H, s, CO_2Me), 3.73 (3 H, s, ArO*Me*), and 6.73—7.10 (3 H, m, ArH).

From the mother liquor the regioisomeric 1-*acid* (11a), m.p. 144 °C, was isolated (1.6 g, 21%) by crystallisation from methanol; $\lambda_{max.}$ 264 nm (log ε 4.1); $\nu_{max.}$ 1 700 and 1 600 cm^{-1} (Found: C, 73.5; H, 6.6. $C_{15}H_{16}O_3$ requires C, 73.75; H, 6.6%). The methyl ester (9a), prepared from the acid (11a) and diazomethane, had $\nu_{max.}$ 1 725 and 1 600 cm^{-1}; δ 1.50—2.65 (6 H, m), 3.00—3.50br [3 H, ArCH_2 and MeOC(:O)C*H*], 3.60 (3 H, s, CO_2Me), 3.73 (3 H, s, ArO*Me*), and 6.40—7.25 (3 H, m, ArH).

1,2,3,4-*Tetrahydro*-8-*methoxy*-2-*methylfluorene*-2-*carboxylic acid* (10b). The crude alcohol (6a), prepared from 4-methoxyindan-1-one (5a) (9 g, 0.05 mol), was treated with methyl methacrylate (30 g, 0.3 mol), toluene-*p*-sulphonic acid (50 mg), and hydroquinone (30 mg) under the conditions described above to yield a mixture of the ester adducts (8b) and (9b) as a pale yellow oil (9.03 g), b.p. 160—167 °C at 0.2 mmHg; $\lambda_{max.}$ 260 nm (log ε 4.0); $\nu_{max.}$ 1 730 cm^{-1}. Saponification of the mixture with a solution of potassium hydroxide (9 g) in water (9 ml) and methanol (81 ml) by refluxing for 2 h under nitrogen afforded a mixture of the crude acids (6.1 g, 43%) as a light brown solid. Fractional crystallisation from methanol furnished the pure 2-*carboxylic acid* (10b) (3.3 g, 23% from the starting indanone), m.p. 244—245 °C, as light yellow needles; $\lambda_{max.}$ 260 nm (log ε 4.2); $\nu_{max.}$ 1 700 cm^{-1} (Found: C, 74.6; H, 7.2. $C_{16}H_{18}O_3$ requires C, 74.4; H, 7.0%). The methyl ester (8b), prepared by treating the acid (10b) with diazomethane, had $\nu_{max.}$ 1 730 and 1 600 cm^{-1}; δ 1.25 (3 H, s, Me), 1.45—2.90 (6 H, m), 3.10 (2 H, s, ArCH_2), 3.53 (3 H, s, CO_2Me), 3.73 (3 H, s, ArO*Me*), and 6.33—7.26 (3 H, m, ArH).

From the mother liquor the regioisomeric 1-*acid* (11b), m.p. 162 °C, was also isolated by crystallisation from methanol (2.25 g, 16%), $\lambda_{max.}$ 260 nm (log ε 4.16); $\nu_{max.}$ 1 700 and 1 600 cm^{-1} (Found: C, 74.5; H, 7.2. $C_{16}H_{18}O_3$ requires C, 74.4; H, 7.0%). The methyl ester (9b), prepared by treating the acid (11b) with diazomethane had $\nu_{max.}$ 1 725 and 1 600 cm^{-1}; δ 1.42 (3 H, s, Me), 1.63—2.66 (6 H, m), 3.26 (2 H, s, ArCH_2), 3.56 (3 H, s, CO_2Me), 3.73 (3 H, s, ArO*Me*), and 6.43—7.26 (3 H, m, ArH).

1,2,3,4-*Tetrahydro*-6-*methoxyfluorene*-2-*carboxylic acid* (10c). The crude alcohol (6b), prepared from 6-methoxyindan-1-one (5b) [20] (30 g, 0.185 mol), was treated with methyl acrylate (34.4 g, 0.4 mol), toluene-*p*-sulphonic acid (50 mg), and hydroquinone (30 mg) under the conditions described above to yield a mixture of the ester adducts (8c) and (9c) (15.25 g, 32%) as a pale yellow oil, b.p. 165—170 °C at 0.2 mmHg; $\lambda_{max.}$ 255 nm (log ε 3.98); $\nu_{max.}$ 1 728 cm^{-1}. Saponification of the mixture with a solution of potassium hydroxide (15 g) in water (15 ml) and methanol (135 ml) by refluxing for 2 h under nitrogen afforded a mixture of the crude acids (10c) and (11c) (10.7 g, 24%) as a yellow solid. Crystallisation from ethyl acetate afforded the pure 2-*carboxylic acid* (10c) (5.34 g, 12% overall yield from the starting indanone), m.p. 188—189 °C, as light yellow needles; $\lambda_{max.}$ 262 nm (log ε 3.97); $\nu_{max.}$ 1 700 cm^{-1} (Found: C, 73.65; H, 6.6. $C_{15}H_{16}O_3$ requires C, 73.75; H, 6.6%). The methyl ester (8c), prepared by treating the acid (10c) with diazomethane, had $\nu_{max.}$ 1 730 and 1 600 cm^{-1}; δ 1.70—2.00 (7 H, m), 3.15br (2 H, s, ArCH_2), 3.60 (3 H, s, CO_2Me), 3.75 (3 H, s, ArO*Me*), 6.45—6.78 (2 H, m, Ar*H*), and 7.10—7.28 (1 H, m, ArH).

No pure regioisomeric acid (11c) could be isolated from the mother liquor.

1,2,3,4-*Tetrahydro*-6-*methoxy*-2-*methylfluorene*-2-*carboxylic acid* (10d). The crude alcohol (6b), prepared from 6-methoxyindan-1-one (5b) (10 g, 0.062 mol), was treated with methyl methacrylate (30 g, 0.3 mol), toluene-*p*-sulphonic acid (50 mg), and hydroquinone (30 mg) under the conditions described above to yield a mixture of the ester adducts (8d) and (9d) as a pale yellow oil (5.20 g, 30%), b.p. 160—170 °C at 0.2 mmHg; $\lambda_{max.}$ 258 nm (log ε 3.98); $\nu_{max.}$ 1 730 cm^{-1}. Saponification of this mixture with a solution of potassium hydroxide (5 g) in water (5 ml) and methanol (45 ml) by refluxing for 2 h under nitrogen afforded a mixture of the crude acids (10d) and (11d) (3.3 g, 21.7%) as a light brown solid. Crystallisation from ethyl acetate afforded the pure 2-*carboxylic acid* (10d) (1.75 g, 11% overall yield from the starting indanone), m.p. 185—186 °C, as light yellow flakes; $\lambda_{max.}$ 260 nm (log ε 4.1); $\nu_{max.}$ 1 700 cm^{-1} (Found: C, 74.5; H, 7.2. $C_{16}H_{18}O_3$ requires C, 74.4; H, 7.0%). The methyl ester (8d), prepared by treating the acid (10d) with diazomethane, had $\nu_{max.}$ 1 730 and 1 600 cm^{-1}; δ 1.28 (3 H, s, Me), 1.60—2.75 (6 H, m), 3.10br (2 H, s, ArCH_2), 3.55 (3 H, s, CO_2Me), 3.70 (3 H, s, ArO*Me*), 6.50—6.75 (2 H, m, ArH), and 7.10—7.30 (1 H, m, ArH).

From the mother liquor the regioisomeric 1-*acid* (11d), m.p. 126 °C, was isolated by crystallisation from ethyl acetate (0.8 g, 5%); $\lambda_{max.}$ 260 nm (log ε 3.99); $\nu_{max.}$ 1 705 and 1 600 cm^{-1} (Found: C, 74.4; H, 7.3. $C_{16}H_{18}O_3$ requires C, 74.4; H, 7.0%). The methyl ester (9d), prepared by treating the acid (11d) with diazomethane, had $\nu_{max.}$ 1 725 and 1 600 cm^{-1}; δ 1.41 (3 H, s, Me), 1.43—2.57 (6 H, m), 3.13—3.37br (2 H, m, ArCH_2), 3.60 (3 H, s, CO_2Me), 3.73 (3 H, s, ArO*Me*), and 6.43—7.10 (3 H, m, ArH).

1,2,3,4-*Tetrahydrofluorene*-2-*carboxylic acid* (10e). The crude alcohol (6c), prepared from indan-1-one (5c) [21] (30 g, 0.23 mol), was treated with methyl acrylate (38.7 g, 0.45 mol), toluene-*p*-sulphonic acid (50 mg), and hydroquinone (30 mg) under the conditions described above to yield a mixture of the ester adducts (8e) and (9e) as a yellow oil

(40.0 g), b.p. 145—152 °C at 0.3 mmHg; $\lambda_{max.}$ 256 nm (log ε 4.23); $\nu_{max.}$ 1 725 cm^{-1}. Saponification of the mixture (8 g) with a 10% solution of methanolic aqueous potassium hydroxide (10%) afforded a mixture of the crude acids (10e) and (11e) (6.8 g, 70%) as a yellow solid. Three crystallisations from ethyl acetate afforded the pure 2-*carboxylic acid* (10e) (4.95 g, 51% from the starting indanone), m.p. 200—201 °C, as pale yellow needles; $\lambda_{max.}$ 258 nm (log ε 4.10); $\nu_{max.}$ 1 698 cm^{-1} (Found: C, 78.2; H, 6.7. $C_{14}H_{14}O_2$ requires C, 78.5; H, 6.6%). The methyl ester (8e), prepared by treating the acid (10e) with diazomethane, had $\nu_{max.}$ 1 725 and 1 600 cm^{-1}; δ 1.62—2.80 (7 H, m), 3.15br (2 H, s, ArCH_2), 3.62 (3 H, s, CO_2Me), and 7.12 (4 H, m, ArH).

No isomeric acid (11e) could be isolated from the mother liquor.

1,2,3,4-*Tetrahydro*-2-*methylfluorene*-2-*carboxylic acid* (10f). The crude alcohol (6c), prepared from indan-1-one (5c) (40 g, 0.3 mol), was treated with methyl methacrylate (51.6 g, 0.6 mol), toluene-*p*-sulphonic acid (50 mg), and hydroquinone (30 mg) under the conditions described above to yield a mixture of the ester adducts (8f) and (9f) as a pale yellow oil (35 g, 48%), b.p. 150—155 °C at 0.2 mmHg; $\lambda_{max.}$ 260 nm (log ε 3.98); $\nu_{max.}$ 1 725 cm^{-1}. Saponification of the mixture (8.75 g) with a solution of 90% ethanolic aqueous potassium hydroxide afforded a mixture of the crude acids (10f) and (11f) (7.1 g, 41%) as a light brown solid. Fractional crystallisation from ethyl acetate furnished the pure 2-*carboxylic acid* (10f) (5.2 g, 30% from indan-1-one), m.p. 200 °C, as pale yellow needles; $\lambda_{max.}$ 260 nm (log ε 4.08); $\nu_{max.}$ 1 700 cm^{-1} (Found: C, 79.1; H, 7.1. $C_{15}H_{16}O_2$ requires C, 78.9; H, 7.1%). The methyl ester (8f), prepared by treating the acid (10f) with diazomethane, had $\nu_{max.}$ 1 730 and 1 600 cm^{-1}; δ 1.26 (3 H, s, Me), 1.40—2.80 (6 H, m), 3.16br (2 H, s, ArCH_2), 3.63 (3 H, s, CO_2Me), and 7.10 (4 H, m, ArH).

From the mother liquor the regioisomeric 1-acid (11f) was isolated by crystallisation from ethyl acetate (1.3 g, 7% from indan-1-one), m.p. and mixed m.p. 146—147 °C.[22]

1,2,3,4-*Tetrahydro*-7-*methoxy*-2-*methylfluorene*-2-*carboxylic acid* (10g). The crude alcohol (6d), obtained from 5-methoxyindan-1-one (5d) [23] (30 g, 0.185 mol), was treated with methyl methacrylate (40 g, 0.4 mol), toluene-*p*-sulphonic acid (50 mg), and hydroquinone (30 mg) under the conditions described above to yield a mixture of the ester adducts (8g) and (9g) as a yellow oil (14.1 g, 28%), b.p. 160—165 °C at 0.2 mmHg; $\lambda_{max.}$ 264 nm (log ε 4.08); $\nu_{max.}$ 1 725 cm^{-1}. Saponification of this mixture with a solution of potassium hydroxide (14 g) in water (14 ml) and methanol (126 ml) by refluxing for 4 h under nitrogen afforded a mixture of the crude acids (10g) and (11g) (10.1 g, 21%) as a light brown solid. Fractional crystallisation from ethyl acetate furnished the pure 2-*carboxylic acid* (10g) (5.4 g, 12% from the starting indanone), m.p. 210—212 °C, as pale yellow flakes; $\lambda_{max.}$ 264 nm (log ε 4.27); $\nu_{max.}$ 1 696 cm^{-1} (Found: C, 74.3; H, 7.0. $C_{16}H_{18}O_3$ requires C, 74.4; H, 7.0%). The methyl ester (8g), prepared by treating the acid (10g) with diazomethane, had $\nu_{max.}$ 1 725 and 1 600 cm^{-1}; δ 1.24 (3 H, s, Me), 1.43—2.92 (6 H, m), 3.12 (2 H, s, ArCH_2), 3.62 (3 H, s, CO_2Me), 3.73 (3 H, s, ArO*Me*), and 6.30—7.31 (3 H, m, ArH).

From the mother liquor the regioisomeric 1-acid (11g) (3.3 g, 7% from indanone), m.p. and mixed m.p. 155—156 °C,[9b] was isolated by crystallisation from ether–light petroleum (1 : 1 v/v).

2-(*Diazoacetyl*)-1,2,3,4-*tetrahydro*-8-*methoxyfluorene* (12a).—The acid (10a) (1 g, 40 mmol) in dry methanol (30 ml) was neutralised with a dilute solution of sodium methoxide in methanol using phenolphthalein as indicator. After removal of solvent the residue was freed from the last traces of methanol by repeated distillation with dry benzene. The dried sodio-salt was suspended in dry benzene (20 ml) containing pyridine (0.1 ml), and the suspension was cooled in an ice bath and treated with oxalyl chloride (2 ml). The mixture was stirred at 0 °C for 30 min and at room temperature for 30 min and finally was warmed to 55—60 °C for 1 h. The precipitate was filtered off and the filtrate was concentrated under reduced pressure to afford the crude acid chloride which was dissolved in dry ether (50 ml) and the solution was added dropwise to a stirred solution of ice-cold ethereal diazomethane containing dry triethylamine (0.2 ml). The reaction mixture was left overnight at room temperature and then filtered. The filtrate was concentrated and the crude product was purified by filtration through a short column of neutral alumina (5 g) with ether–light petroleum (1 : 1 v/v) as eluant to yield the *diazoketone* as a light yellow solid (980 mg, 89%), $\nu_{max.}$ 2 115 and 1 630 cm^{-1}; δ 1.40—2.80 (7 H, m), 3.25br (2 H, s, ArCH_2), 3.90 (3 H, s, ArO*Me*), 5.35 [1 H, s, C(:O)CHN_2], and 6.60—7.40 (3 H, m, ArH).

The following diazoketones were prepared in a similar manner.

2-(*Diazoacetyl*)-1,2,3,4-*tetrahydro*-8-*methoxy*-2-*methylfluorene* (12b), from the acid (10b) (1 g, 35 mmol), was obtained as a pale yellow solid (1 g, 91%); $\nu_{max.}$ 2 120 and 1 630 cm^{-1}; δ 1.20 (3 H, s, Me), 1.60—2.80 (6 H, m), 3.20br (2 H, s, ArCH_2), 3.85 (3 H, s, ArO*Me*), 5.37 [1 H, s, C(:O)CHN_2], and 6.60—7.35 (3 H, m, ArH).

2-(*Diazoacetyl*)-1,2,3,4-*tetrahydro*-6-*methoxyfluorene* (12c) from the acid (10c) (1.8 g, 72 mmol), was a light yellow solid (1.81 g, 91%); $\nu_{max.}$ 2 125 and 1 630 cm^{-1}; δ 1.65—2.80 (7 H, m), 3.20br (2 H, s, ArCH_2), 3.75 (3 H, s, ArO*Me*), 5.13 [1 H, s, C(:O)CHN_2], and 6.35—7.20 (3 H, m, ArH).

2-(*Diazoacetyl*)-1,2,3,4-*tetrahydro*-6-*methoxy*-2-*methylfluorene* (12d), from the acid (10d) (1.5 g, 0.52 mmol), was a light yellow solid (1.48 g, 90%); $\nu_{max.}$ 2 120 and 1 630 cm^{-1}; δ 1.30 (3 H, s, Me), 1.60—2.85 (6 H, m), 3.15br (2 H, s, ArCH_2), 3.80 (3 H, s, ArO*Me*), 5.37 [1 H, s, C(:O)CHN_2], and 6.45—7.40 (3 H, m, ArH).

2-(*Diazoacetyl*)-1,2,3,4-*tetrahydrofluorene* (12e), from the acid (10e) (1.14 g, 50 mmol), was a pale yellow solid (1.15 g, 90%); $\nu_{max.}$ 2 115 and 1 630 cm^{-1}; δ 1.55—2.80 (7 H, m), 3.21br (2 H, s, ArCH_2), 5.25 [1 H, s, C(:O)CHN_2], and 6.85—7.35 (4 H, m, ArH).

2-(*Diazoacetyl*)-1,2,3,4-*tetrahydro*-2-*methylfluorene* (12f), from the acid (10f) (1.20 g, 50 mmol), was a pale yellow solid (1.18 g, 89%); $\nu_{max.}$ 2 110 and 1 620 cm^{-1}; δ 1.18 (3 H, s, Me), 1.51—2.80 (6 H, m), 3.18br (2 H, s, ArCH_2), 5.28 [1 H, s, C(:O)CHN_2], and 6.88—7.36 (4 H, m, ArH).

2-(*Diazoacetyl*)-1,2,3,4-*tetrahydro*-7-*methoxy*-2-*methylfluorene* (12g), from the acid (10g) (1 g, 35 mmol), was a light yellow solid (1 g, 91%); $\nu_{max.}$ 2 110 and 1 630 cm^{-1}; δ 1.22 (3 H, s, Me), 1.48—2.82 (6 H, m), 3.20br (2 H, s, ArCH_2), 3.75 (3 H, s, ArO*Me*), 5.35 [1 H, s, C(:O)CHN_2], and 6.45—7.30 (3 H, m, ArH).

Intramolecular Carbenoid Addition of the Diazoketones to the Cyclopropyl Ketones.—(±)-1-*Methoxy*-4b,9-*cyclogibba*-1(10*a*),2,4-*trien*-8-*one* (1a). A solution of the diazoketone (12a) (500 mg, 1.86 mmol) in cyclohexane (105 ml) and THF (10 ml) was refluxed with stirring in the presence of ' activ-

ated CuO '[7] (2.0 g) under irradiation by 250 W tungsten lamps. After 3 h the cooled mixture was filtered and the solvent was removed under reduced pressure. The crude residue was chromatographed over neutral alumina (5 g) with light petroleum as eluant to afford the pure *cyclopropyl ketone* (1a) (370 mg, 83%) as a crystalline solid, m.p. 127 °C (light petroleum); $\nu_{max.}$ 1 715 and 1 600 cm^{-1}; δ 1.22—2.75 (8 H, m), 3.03 (2 H, m, $ArCH_2$), 3.73 (3 H, s, $ArOMe$), and 6.43—7.20 (3 H, m, ArH) (Found: C, 79.85; H, 6.9. $C_{16}H_{16}O_2$ requires C, 80.0; H, 6.7%).

(±)-1-*Methoxy*-7-*methyl*-4*b*,9-*cyclogibba*-1(10*a*),2,4-*trien*-8-*one* (1b). A solution of the diazoketone (12b) (500 mg, 1.74 mmol) in cyclohexane (105 ml) and THF (60 ml) was stirred and refluxed with ' activated CuO ' (2.0 g) for 3 h under the conditions described above. Work-up and chromatography on neutral alumina (5 g) with light petroleum as eluant afforded the *cyclopropyl ketone* (1b) (410 mg, 89%) as crystals, m.p. 122 °C (light petroleum); $\nu_{max.}$ 1 715 and 1 595 cm^{-1}; δ 1.0 (3 H, s, Me), 1.26—2.66 (7 H, m), 3.10 (2 H, s, $ArCH_2$), 3.76 (3 H, s, $ArOMe$), and 6.56—7.20 (3 H, m, ArH) (Found: C, 80.05; H, 7.3. $C_{17}H_{18}O_2$ requires C, 80.3; H, 7.1%).

(±)-3-*Methoxy*-4*b*,9-*cyclogibba*-1(10*a*),2,4-*trien*-8-*one* (1c). A solution of the diazoketone (12c) (350 mg, 1.30 mmol) in cyclohexane (60 ml) and THF (25 ml) was stirred and refluxed for 4 h with ' activated CuO ' (1.5 g) under the conditions described above. Work-up and chromatography on neutral alumina (10 g) with light petroleum as eluant afforded the *cyclopropyl ketone* (1c) (240 mg, 79%) as crystals, m.p. 143—144 °C (light petroleum); $\nu_{max.}$ 1 715 and 1 600 cm^{-1}; δ 1.20—2.72 (8 H, m), 3.05 (2 H, s, $ArCH_2$), 3.72 (3 H, s, $ArOMe$), and 6.52—7.18 (3 H, m, ArH) (Found: C, 79.9; H, 6.5. $C_{16}H_{16}O_2$ requires C, 80.0; H, 6.7%).

(±)-3-*Methoxy*-7-*methyl*-4*b*,9-*cyclogibba*-1(10*a*),2,4-*trien*-8-*one* (1d). A solution of the diazoketone (12d) (290 mg, 1.01 mmol) in cyclohexane (60 ml) and THF (10 ml) was stirred and refluxed for 6 h with ' activated CuO ' (1.5 g) under the conditions described above. Work-up followed by chromatography on neutral alumina (5 g) with light petroleum as eluant afforded the *cyclopropyl ketone* (1d) (225 mg, 81%) as crystals, m.p. 158 °C (light petroleum); $\nu_{max.}$ 1 715 and 1 600 cm^{-1}; δ 1.01 (3 H, s, Me), 1.50—2.60 (7 H, m), 3.08 (2 H, s, $ArCH_2$), 3.73 (3 H, s, $ArOMe$), and 6.52—7.22 (3 H, m, ArH) (Found: C, 80.1; H, 7.2. $C_{17}H_{18}O_2$ requires C, 80.3; H, 7.1%).

(±)-4*b*,9-*Cyclogibba*-1(10*a*),2,4-*trien*-8-*one* (1e). A solution of the diazoketone (12e) (320 mg, 1.34 mmol) in cyclohexane–THF (7 : 3 v/v; 90 ml) was stirred and refluxed for 1.5 h with ' activated CuO ' (1.2 g) under the conditions described above. Work-up and chromatography on neutral alumina (10 g) with light petroleum as eluant afforded the *cyclopropyl ketone* (1e) (201 mg, 70%) as crystals, m.p. 103—104 °C (light petroleum); $\nu_{max.}$ 1 715 and 1 600 cm^{-1}; δ 1.43—2.66 (8 H, m), 3.20 (2 H, s, $ArCH_2$), and 7.20 (4 H, s, ArH) (Found: C, 85.6; H, 6.8. $C_{15}H_{14}O$ requires C, 85.65; H, 6.7%).

(±)-7-*Methyl*-4*b*,9-*cyclogibba*-1(10*a*),2,4-*trien*-8-*one* (1f). A solution of the diazoketone (12f) (200 mg, 0.8 mmol) in cyclohexane (150 ml) was stirred and refluxed for 6 h with ' activated CuO ' (1.0 g) under the conditions described above. Work-up and chromatography on neutral alumina (5.0 g) with light petroleum as eluant afforded the *cyclopropyl ketone* (1f) as crystals (170 mg, 95%), m.p. 113 °C (light petroleum); $\nu_{max.}$ 1 710 and 1 595 cm^{-1}; δ 0.98 (3 H, s, Me), 1.38—2.64 (7 H, m), 3.15 (2 H, s, $ArCH_2$), and 7.0—7.12 (4 H, m, ArH) (Found: C, 85.4; H, 7.5. $C_{16}H_{16}O$ requires C, 85.7; H, 7.2%).

(±)-2-*Methoxy*-7-*methyl*-4*b*,9-*cyclogibba*-1(10*a*),2,4-*trien*-8-*one* (1g). A solution of the diazoketone (12g) (1.53 g, 5.43 mmol) in cyclohexane–THF (7 : 3 v/v; 240 ml) was stirred and refluxed for 3 h with ' activated CuO ' (4.8 g) under the conditions described above. Work-up and chromatography on neutral alumina (20 g) with light petroleum as eluant afforded the *cyclopropyl ketone* (1g) (1.05 g, 76%) as crystals, m.p. 126—128 °C (light petroleum); $\nu_{max.}$ 1 715 and 1 610 cm^{-1}; δ 1.03 (3 H, s, Me), 1.50—2.60 (7 H, m), 3.16 (2 H, s, $ArCH_2$), 3.76 (3 H, s, $ArOMe$), and 6.60—7.26 (3 H, m, ArH) (Found: C, 80.1; H, 7.4. $C_{17}H_{18}O_2$ requires C, 80.3; H, 7.1%).

(±)-1-*Methoxygibba*-1(10*a*),2,4,4*b*(5)-*tetraen*-8-*one* (2a).—*Method A. Acid-catalysed fragmentation of the cyclopropyl ketone* (1a). A stream of dry HCl gas was bubbled through a solution of the cyclopropyl ketone (1a) (122 mg, 0.5 mmol) in dry chloroform (10 ml) at room temperature for 2 h. Removal of solvent under reduced pressure left a solid which was purified by chromatography on neutral alumina (2 g) with light petroleum as eluant to yield the *unsaturated ketone* (2a) (112 mg, 92%) as hexagonal crystals, m.p. 136 °C (light petroleum); $\lambda_{max.}$ 226 and 260 nm (log ε 4.55 and 4.32); $\nu_{max.}$ 1 740 and 1 590 cm^{-1}; δ 1.76—2.90 (7 H, m), 3.0 (2 H, s, $ArCH_2$), 3.83 (3 H, s, $ArOMe$), 5.80 (1 H, t, *J* 3.5 Hz, olefinic H), and 6.60—7.33 (3 H, m, ArH) (Found: C, 79.8; H, 6.7. $C_{16}H_{16}O_2$ requires C, 80.0; H, 6.7%).

Method B. To a stirred solution of the diazoketone (12a) (250 mg, 0.93 mmol) in dry chloroform (25 ml) cooled to 0 to 5 °C was added a homogeneous mixture of trifluoroacetic acid (TFA) (0.25 ml, 3.3 mmol) and 70% perchloric acid (0.25 ml; 4.2 mmol) in chloroform (10 ml). After 1 h the solution was washed with water, 5% aqueous sodium carbonate, and water and then dried. Removal of solvent under reduced pressure and chromatography of the residue on neutral alumina (5 g) with light petroleum as eluant afforded the ketone (2a) (212 mg, 94%), m.p. and mixed m.p. 136 °C (light petroleum), identical with the sample described above (n.m.r. and i.r.). (Use of TFA catalyst in CH_2Cl_2 furnishes compound (2a) in only 60—65% yield.)

(±)-1-*Methoxy*-7-*methylgibba*-1(10*a*),2,4,4*b*(5)-*tetraen*-8-*one* (2b).—*Method A.* Cleavage of the cyclopropyl ketone (1b) (105 mg, 0.4 mmol) with dry HCl as above and recrystallisation of the crude product from light petroleum yielded the unsaturated *ketone* (2b) (90 mg, 90%) as pellets, m.p. 171 °C; $\lambda_{max.}$ 228 and 260 nm (log ε 4.48 and 4.28); $\nu_{max.}$ 1 740 and 1 590 cm^{-1}; δ 1.20 (3 H, s, Me), 1.68—2.46 (6 H, m), 3.0 (2 H, s, $ArCH_2$), 3.83 (3 H, s, $ArOMe$), 5.80 (1 H, t, *J* 4 Hz, olefinic H), and 6.50—7.30 (3 H, m, ArH) (Found: C, 80.15; H, 7.2. $C_{17}H_{18}O_2$ requires C, 80.3; H, 7.1%).

Method B. Treatment of a solution of the diazoketone (12b) (260 mg, 0.9 mmol) in chloroform (25 ml) with a homogeneous mixture of TFA (0.25 ml) and 70% perchloric acid (0.25 ml) in chloroform (10 ml) as above, followed by work-up and purification, afforded the ketone (2b) as crystals (191 mg, 74%), m.p. and mixed m.p. 171 °C (light petroleum), identical with the sample described above (n.m.r. and i.r.).

(±)-3-*Methoxygibba*-1(10*a*),2,4,4*b*(5)-*tetraen*-8-*one* (2c).—*Method A.* Cleavage of the cyclopropyl ketone (1c) (100 mg, 0.41 mmol) with dry HCl as above and recrystallisation of the crude product from light petroleum yielded the *unsaturated ketone* (2c) as rectangular plates (93 mg, 93%), m.p. 126—127 °C; $\lambda_{max.}$ 258 nm (log ε 4.13); $\nu_{max.}$ 1 735

and 1 605 cm^{-1}; δ 1.80—2.81 (7 H, m), 2.95 (2 H, s, ArCH_2), 3.76 (3 H, s, ArO*Me*), 5.76 (1 H, t, *J* 3.5 Hz, olefinic H), and 6.64—7.31 (3 H, m, ArH) (Found: C, 80.0; H, 6.8. $C_{16}H_{16}O_2$ requires C, 80.0; H, 6.7%).

Method B. Treatment of a solution of the diazoketone (12c) (500 mg, 1.86 mmol) in chloroform (50 ml) with a homogeneous mixture of TFA (0.5 ml) and 70% perchloric acid (0.5 ml) in chloroform (20 ml) as above, followed by work-up and purification, afforded the ketone (2c) as crystals (420 mg, 94%), m.p. and mixed m.p. 126—127 °C (light petroleum), identical with the sample described above (n.m.r. and i.r.).

(±)-3-*Methoxy*-7-*methylgibba*-1(10*a*),2,4,4*b*(5)-*tetraen*-8-*one* (2d).—*Method A.* Cleavage of the cyclopropyl ketone (1d) (210 mg, 0.8 mmol) with dry HCl as above and recrystallisation of the crude product from light petroleum yielded the *unsaturated ketone* (2d) as crystals (188 mg, 90%), m.p. 115 °C; $\lambda_{max.}$ 258 nm (log ε 4.2); $\nu_{max.}$ 1 735 and 1 610 cm^{-1}; δ 1.16 (3 H, s, Me), 2.0—2.28 (6 H, m), 2.96 (2 H, m, ArCH_2), 3.78 (3 H, s, ArO*Me*), 5.81 (1 H, t, *J* 4 Hz, olefinic H), and 6.62—7.20 (3 H, m, ArH) (Found: C, 80.2; H, 7.2. $C_{17}H_{18}O_2$ requires C, 80.3; H, 7.1%).

Method B. Treatment of a solution of the diazoketone (12d) (280 mg, 1 mmol) in chloroform (25 ml) with a homogeneous mixture of TFA (0.25 ml) and 70% perchloric acid (0.25 ml) in chloroform (10 ml) as above, followed by work-up and purification, afforded the ketone (2d) as needles (208 mg, 80%), m.p. and mixed m.p. 115 °C (light petroleum), identical with the sample described above (n.m.r. and i.r.).

(±)-*Gibba*-1(10*a*),2,4,4*b*(5)-*tetraen*-8-*one* (2e).—*Method A.* Cleavage of the cyclopropyl ketone (1e) (150 mg, 0.71 mmol) with dry HCl as above and recrystallisation of the crude product from light petroleum yielded the *unsaturated ketone* (2e) as needles (138 mg, 93%), m.p. 100—101 °C; $\lambda_{max.}$ 258 nm (log ε 4.26); $\nu_{max.}$ 1 738 and 1 600 cm^{-1}; δ 1.80—2.80 (7 H, m), 3.03 (2 H, m, ArCH_2), 5.78 (1 H, t, *J* 4 Hz, olefinic H), and 7.24 (4 H, m, ArH) (Found: C, 85.6; H, 6.8. $C_{15}H_{14}O$ requires C, 85.7; H, 6.7%).

Method B. Treatment of a solution of the diazoketone (12e) (320 mg, 1.34 mmol) in chloroform (25 ml) with a homogeneous mixture of TFA (0.25 ml) and 70% perchloric acid 0.25 ml) in chloroform (10 ml) as above, followed by work-up and purification, afforded the ketone (2e) as crystals (212 mg, 74%), m.p. and mixed m.p. 100—101 °C (light petroleum), identical with the sample described above (n.m.r. and i.r.). (BF_3–Et_2O- and 48% HBF_4-catalysed cyclisations in CH_2Cl_2 furnished compound (2e) in 68 and 70% yield, respectively.)

(±)-7-*Methylgibba*-1(10),2,4,4*b*(5)-*tetraen*-8-*one* (2f).—*Method A.* Cleavage of the cyclopropyl ketone (1f) (100 mg, 0.44 mmol) with dry HCl as above and recrystallisation of the crude product from light petroleum yielded the *unsaturated ketone* (2f), as needles (92 mg, 92%), m.p. 105 °C; $\lambda_{max.}$ 254 nm (log ε 4.32); $\nu_{max.}$ 1 735 and 1 595 cm^{-1}; δ 1.16 (3 H, s, Me), 2.0—2.30 (6 H, m), 3.01 (2 H, m, ArCH_2), 5.78 (1 H, t, *J* 4 Hz, olefinic H), and 7.11 (4 H, m, ArH) (Found: C, 85.5; H, 7.5. $C_{16}H_{16}O$ requires C, 85.7; H, 7.2%).

Method B. Treatment of a solution of the diazoketone (12f) (250 mg, 1.0 mmol) in chloroform (20 ml) with a homogeneous mixture of TFA (0.25 ml) and 70% perchloric acid (0.25 ml) in chloroform (15 ml) as above, followed by work-up and purification, afforded the ketone (2f) as needles (190 mg, 84%), m.p. and mixed m.p. 105 °C (light petroleum), identical with the sample described above (n.m.r. and i.r.).

(±)-2-*Methoxy*-7-*methylgibba*-1(10a),2,4,4*b*(5)-*tetraen*-8-*one* (2g).—*Method A.* Cleavage of the cyclopropyl ketone (1g) (105 mg, 0.4 mmol) with dry HCl as above and recrystallisation of the crude product from methanol yielded the *unsaturated ketone* (2g) as prisms (94 mg, 90%), m.p. 126 °C; $\lambda_{max.}$ 262 nm (log ε 4.3); $\nu_{max.}$ 1 740 and 1 610 cm^{-1}; δ 1.18 (3 H, s, Me), 2.03—2.35 (6 H, m), 3.00 (2 H, m, ArCH_2), 3.78 (3 H, s, ArO*Me*), 5.68 (1 H, t, *J* 3.5 Hz, olefinic H), and 6.62—7.36 (3 H, m, ArH) (Found: C, 80.4; H, 7.2. $C_{17}H_{18}O_2$ requires C, 80.3; H, 7.1%).

Method B. Treatment of a solution of the diazoketone (12g) (260 mg, 0.9 mmol) in chloroform (25 ml) with a homogeneous mixture of TFA (0.25 ml) and 70% perchloric acid (0.25 ml) in chloroform (10 ml) as above, followed by work-up and purification, afforded the ketone (2g) as needles (167 mg, 65%), m.p. and mixed m.p. 126 °C (light petroleum), identical with the sample described above (n.m.r. and i.r.). (BF_3–Et_2O-catalysed cyclisation of (12g) furnishes the ketone (2g) in 40—46% yield.)

Catalytic Hydrogenation of the Cyclopropyl Ketones (1a—g) *and the* $\Delta^{4b(5)}$-*Gibbenes* (2a—g).—(±)-1-*Methoxy*-4*bα*-*gibba*-1(10*a*),2,4-*trien*-8-*one* (3a). The cyclopropyl ketone (1a) (80 mg, 0.35 mmol) in absolute ethanol (8 ml) was hydrogenated over 10% Pd–C (30 mg) at room temperature and atmospheric pressure. After 10 min the catalyst was filtered off and the solvent was removed under reduced pressure to give the crude product (80 mg), m.p. 95—96 °C, which was shown to be homogeneous [t.l.c.; silica gel HF 254 (E. Merck), benzene–light petroleum–ethyl acetate (3 : 9 : 1 v/v) and g.l.c. (R_t 41.68 min; column temperature 170 °C)]. Crystallisation from light petroleum afforded the pure 4*bα*-*isomer* (3a) (72 mg, 90%), m.p. 100 °C; $\lambda_{max.}$ 270 and 278 nm (log ε 3.04 and 3.07); $\nu_{max.}$ 1 730 and 1 600 cm^{-1}; δ 1.38—2.66 (9 H, m), 2.78—3.36 (3 H, m, benzylic H), 3.81 (3 H, s, ArO*Me*), and 6.61—7.27 (3 H, m, ArH) (Found: C, 79.1; H, 7.45. $C_{16}H_{18}O_2$ requires C, 79.3; H, 7.5%).

(±)-1-*Methoxy*-4*bβ*-*gibba*-1(10*a*),2,4-*trien*-8-*one* (4a) *and compound* (3a). The unsaturated ketone (2a) (80 mg, 0.35 mmol) in absolute ethanol (10 ml) was hydrogenated over 10% Pd–C (35 mg). After 10 min the crude product (80 mg), m.p. 120—124 °C, obtained after filtration and removal of solvent, showed the presence of compounds (3a) and (4a) (g.l.c., R_t 41.7 and 46.1 min, respectively; column temperature 170 °C) in the ratio 1 : 9. On crystallisation from light petroleum, a pure sample of the 4*bβ*-*isomer* (4a) (70 mg) was obtained, m.p. 126 °C, mixed m.p. 82—88 °C with the corresponding 4*bα*-epimer (3a); $\lambda_{max.}$ 270 and 277 nm (log ε 3.02 and 3.08); $\nu_{max.}$ 1 735 and 1 595 cm^{-1}; δ 1.38—2.66 (9 H, m), 2.70—3.10 (3 H, m, benzylic H), 3.81 (3 H, s, ArO*Me*), and 6.60—7.60 (3 H, m, ArH) (Found: C, 79.4; H, 7.6. $C_{16}H_{18}O_2$ requires C, 79.3; H, 7.5%). (The ratio of the 4bα-to 4bβ-isomer varied from 5 : 95 to 15 : 85 with different batches of catalyst.)

(±)-1-*Methoxy*-7-*methyl*-4*bα*-*gibba*-1(10*a*),2,4-*trien*-8-*one* (3b) *and* (±)-1-*Methoxy*-7-*methyl*-4*bβ*-*gibba*-1(10*a*),2,4-*trien*-8-*one* (4b).—*Method A. Hydrogenolysis of the cyclopropyl ketone* (1b). The cyclopropyl ketone (1b) (100 mg, 0.42 mmol) in absolute ethanol (10 ml) was hydrogenated in the presence of 10% Pd–C (35 mg). The ^1H n.m.r. spectrum of the product (98 mg), m.p. 92—96 °C, showed it to be a mixture of the 4*bα*- and 4*bβ*-isomers in the ratio of *ca.* 4 : 1 from the integration of the tertiary methyl signals at δ 1.03 and 0.93, respectively. Two crystallisations from light

petroleum afforded the pure *4bα-isomer* (3b) (69 mg) as crystals, m.p. 117 °C; $\lambda_{max.}$ 272 nm (log ε 3.07); $\nu_{max.}$ 1 730 and 1 600 cm^{-1}; δ 1.03 (3 H, s, Me), 1.20—2.20 (8 H, m), 2.80—3.12 (3 H, m, benzylic H), 3.85 (3 H, s, ArO*Me*), and 6.65—7.34 (3 H, m, ArH) (Found: C, 79.4; H, 7.8. $C_{17}H_{20}O_2$ requires C, 79.65; H, 7.9%).

Method B. Hydrogenation of the unsaturated ketone (2b). The ketone (2b) (100 mg, 0.42 mmol) in absolute ethanol (10 ml) was hydrogenated in the presence of 10% Pd–C (35 mg). After 10 min, filtration followed by removal of solvent gave a crude product (100 mg), m.p. 83—87 °C; $\lambda_{max.}$ 270 nm (log ε 3.05); $\nu_{max.}$ 1 730 and 1 595 cm^{-1}. The ^1H n.m.r. spectrum showed the product to be a mixture of the 4bα-(3b) and 4bβ-(4b) isomers in a *ca.* 1 : 1 ratio as shown by the integration of the tertiary methyl signals at δ 1.03 and 0.93, respectively. This mixture could not be separated further by fractional crystallisation or by preparative t.l.c.

(±)-3-*Methoxy*-4bα-*gibba*-1(10*a*),2,4-*trien*-8-*one* (3c). The cyclopropyl ketone (1c) (120 mg, 0.52 mmol) in absolute ethanol (10 ml) was hydrogenated in the presence of 10% Pd–C (35 mg). The crude product (120 mg), m.p. 125—127 °C, was shown to be homogeneous (g.l.c., R_t 22.08 min; column temperature 190 °C). Crystallisation from light petroleum afforded long needles of the *4bα-isomer* (3c) (110 mg), m.p. 133—134 °C; $\lambda_{max.}$ 280 nm (log ε 3.57); $\nu_{max.}$ 1 730 and 1 600 cm^{-1}; δ(100 MHz) 1.20—2.44 (8 H, m), 2.55 (1 H, m, 7-H), 2.55—3.00 (2 H, q, δ_A 2.91, δ_B 2.63, J_{AB} 14 Hz, ArCH_2), 2.90—3.10 (1 H, m, 4b-H), 3.76 (3 H, s, ArO*Me*), and 6.45—7.24 (3 H, m, ArH) (Found: C, 79.3; H, 7.5. $C_{16}H_{18}O_2$ requires C, 79.3; H, 7.5%).

Compound (3c) *and* (±)-3-*methoxy*-4bβ-*gibba*-1(10*a*),2,4-*trien*-8-*one* (4c). The unsaturated ketone (2c) (160 mg, 0.7 mmol) in absolute ethanol (12 ml) was hydrogenated in the presence of 10% Pd–C (50 mg). The crude product (157 mg) had m.p. 96—100 °C; $\lambda_{max.}$ 278 nm (log ε 3.55); $\nu_{max.}$ 1 730 and 1 600 cm^{-1} and showed (g.l.c.) the presence of compounds (3c) and (4c) (R_t 22.10 and 23.12 min, respectively; column temperature 190 °C) in a ratio of *ca.* 2 : 3. This mixture could not be separated further by fractional crystallisation or by preparative t.l.c.

(±)-3-*Methoxy*-7-*methyl*-4bα-*gibba*-1(10*a*),2,4-*trien*-8-*one* (3d). The cyclopropyl ketone (1d) (100 mg, 0.42 mmol) in absolute ethanol (10 ml) was hydrogenated in the presence of 10% Pd–C (35 mg). The crude product (98 mg), m.p. 132—135 °C, showed the presence of compounds (3d) and (4d) (g.l.c., R_t 30.98 and 37.00 min, respectively; column temperature 190 °C) in the ratio of *ca.* 4 : 1. The ^1H n.m.r. spectrum also indicated that the product was a mixture of compounds (3d) and (4d) (ratio *ca.* 17 : 3) from the integration of the tertiary methyl signals at δ 1.06 and 0.96, respectively. Two crystallisations from light petroleum afforded the pure *4bα-isomer* (3d) (72 mg) as needles, m.p. 140—141 °C; $\lambda_{max.}$ 274 nm (log ε 3.10); $\nu_{max.}$ 1 730 and 1 600 cm^{-1}; δ 1.06 (3 H, s, Me), 1.40—3.24 (11 H, m), 3.71 (3 H, s, ArO*Me*), 6.45—7.18 (3 H, m, ArH) (Found: C, 79.5; H, 7.7. $C_{17}H_{20}O_2$ requires C, 79.65; H, 7.9%).

Compound (3d) *and* (±)-3-*Methoxy*-7-*methyl*-4bβ-*gibba*-1(10*a*),2,4-*trien*-8-*one* (4d). The unsaturated ketone (2d) (80 mg, 0.35 mmol) in absolute ethanol (10 ml) was hydrogenated over 10% Pd–C (30 mg). The crude product (80 mg) had m.p. 108—114 °C; $\lambda_{max.}$ 272 nm (log ε 3.08); $\nu_{max.}$ 1 730 and 1 605 cm^{-1} and showed (g.l.c.) the presence of compounds (3d) and (4d) (R_t 31.07 and 37.09 min, respectively; column temperature 190 °C) in a *ca.* 1 : 1 ratio. The ^1H n.m.r. spectrum also indicated the product to be a mixture of (3d) and (4d) in a *ca.* 1 : 1 ratio from the integration of the tertiary methyl signals at δ 1.06 and 0.96, respectively. This mixture could not be separated further by fractional crystallisation or preparative t.l.c.

(±)-4bα-*Gibba*-1(10*a*),2,4-*trien*-8-*one* (3e). The cyclopropyl ketone (1e) (210 mg, 1 mmol) in absolute ethanol (10 ml) was hydrogenated in the presence of 10% Pd–C (50 mg). The crude product (207 mg), m.p. 90—95 °C, was shown to be homogeneous by g.l.c. (R_t 14.21 min). Recrystallisation from light petroleum afforded the pure *4bα-isomer* (3e), m.p. 108—110 °C; $\lambda_{max.}$ 264 nm (log ε 3.04); $\nu_{max.}$ 1 730 cm^{-1}; δ (100 MHz) 1.15—2.66 (9 H, m), 2.50—3.16 (2 H, q, δ_A 2.96, δ_B 2.69 J_{AB} 14.5 Hz, ArCH_2), 3.05—3.20 (1 H, m, 4b-H), and 7.05—7.30 (4 H, m, ArH) (Found: C, 84.6; H, 7.4. $C_{15}H_{16}O$ requires C, 84.9; H, 7.6%).

Compound (3e) *and* (±)-4bβ-*gibba*-1(10*a*),2,4-*trien*-8-*one* (4e). The unsaturated ketone (2e) (210 mg, 1 mmol) in absolute ethanol (10 ml) was hydrogenated in the presence of 10% Pd–C (50 mg). The crude product (208 mg), m.p. 60—70 °C, was shown to be a mixture of (3e) and (4e) (g.l.c., R_t 14.21 and 15.01 min; column temperature 170 °C) in a *ca.* 16 : 9 ratio. Careful fractional crystallisation from methanol afforded the pure 4bα-isomer (3e) (150 mg) as needles, m.p. and mixed m.p. 108—110 °C, identical with the sample described above (n.m.r. and i.r.). From the mother liquor the *4bβ-isomer* (4e) (30 mg) was also isolated, m.p. 103 °C (methanol); $\nu_{max.}$ 1 730 cm^{-1}; δ (100 MHz) 1.26—2.43 (8 H, m), 2.56 (1 H, m, 7-H), 2.61—3.08 (2 H, q, δ_A 2.98, δ_B 2.70, J_{AB} 15 Hz, ArCH_2), 3.06 (1 H, t, J_{AB} 6 Hz, 4b-H), and 7.12 (4 H, m, ArH) (Found: C, 84.7; H, 7.4. $C_{15}H_{16}O$ requires C, 84.9; H, 7.6%).

(±)-7-*Methyl*-4bα-*gibba*-1(10*a*),2,4-*trien*-8-*one* (3f). The cyclopropyl ketone (1f) (110 mg, 0.5 mmol) in absolute ethanol (10 ml) was hydrogenated in the presence of 10% Pd–C (40 mg). The crude product (108 mg), m.p. 86—89 °C, was shown to be homogeneous by g.l.c. (R_t 24.15 min; column temperature 190 °C). Recrystallisation from light petroleum afforded the pure *4bα-isomer* (3f), m.p. 93—94 °C; $\lambda_{max.}$ 268 nm (log ε 3.02); $\nu_{max.}$ 1 735 cm^{-1}; δ 1.03 (3 H, s, Me), 1.41—3.15 (11 H, m), and 7.00 (4 H, m, ArH) (Found: C, 84.7; H, 8.1. $C_{16}H_{18}O$ requires C, 84.9; H, 8.0%).

Compound (3f) *and* (±)-7-*methyl*-4bβ-*gibba*-1(10*a*),2,4-*trien*-8-*one* (4f). The unsaturated ketone (2f) (110 mg, 0.5 mmol) in absolute ethanol (10 ml) was hydrogenated in the presence of 10% Pd–C (40 mg). The ^1H n.m.r. spectrum of the crude product (107 mg), m.p. 68—75 °C; $\lambda_{max.}$ 268 nm (log ε 3.04); $\nu_{max.}$ 1 735 and 1 600 cm^{-1}, revealed it to be a mixture of the 4bα-(3f) and 4bβ-(4f) isomers in the ratio of *ca.* 3 : 2 from the integration of the tertiary methyl signals at δ 1.03 and 0.93, respectively. The mixture could not be separated by fractional crystallisation or preparative t.l.c.

(±)-2-*Methoxy*-7-*methyl*-4bα-*gibba*-1(10*a*),2,4-*trien*-8-*one* (3g). The cyclopropyl ketone (1g) (150 mg, 0.63 mmol) in absolute ethanol (15 ml) was hydrogenated in the presence of 10% Pd–C (50 mg). The crude product (147 mg), m.p. 123—126 °C, was shown to be homogeneous by g.l.c. (R_t 22.66 min; column temperature 190 °C). Recrystallisation from light petroleum afforded the pure 4bα-isomer (3g), m.p. and mixed m.p. 131—132 °C (lit.,[12] m.p. 132—134 °C); $\lambda_{max.}$ 227 (log ε 4.06) and 278 nm (3.54); $\nu_{max.}$ 1 738 cm^{-1}; δ 1.08 (3 H, s, Me), 1.34—2.40 (8 H, m), 2.45—3.11 (2 H, q, δ_A 2.95, δ_B 2.61, J_{AB} 15 Hz, ArCH_2), 2.90—3.25 (1 H, m,

4b-H), 3.77 (3 H, s, ArO*Me*), and 6.71 (3 H, m, ArH) (Found: C, 79.4; H, 7.8. Calc. for $C_{17}H_{20}O_2$: C, 79.65; H, 7.7%).

Compound (3g) *and* (±)-2-*methoxy*-7-*methyl*-4bβ-*gibba*-1(10*a*),2,4-*trien*-8-*one* (4g). The unsaturated ketone (2g) (200 mg, 0.84 mmol) in absolute ethanol (12 ml) was hydrogenated in the presence of 10% Pd–C (50 mg). The ^{1}H n.m.r. spectrum of the crude product (198 mg), m.p. 80—90 °C, indicated it to be a mixture of the 4bα-(3g) and 4bβ-(4g) isomers in the ratio of *ca.* 3 : 1 from integration of the tertiary methyl signals at δ 1.08 and 0.98, respectively. Careful fractional crystallisation afforded only the 4bα-isomer (3g), m.p. and mixed m.p. 131—132 °C, identical with the authentic sample described above.

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