Acid-catalysed Lactonisation and Iodolactonisation of Norbornene-carboxylic Acids

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The acid-catalysed lactonisation of 3-(norborn-5-en-2-yl)propionic acid and 4-(norborn-5-en-2-yl)butyric acid affords 3-(2-*exo*-hydroxynorborn-2-*endo*-yl)propionic acid spiro-γ-lactone and 4-(2-*exo*-hydroxynorborn-2-*endo*-yl)butyric acid spiro-δ-lactone, respectively. The corresponding spiro-iodo-δ-lactone is obtained on iodolactonisation of 4-(norborn-5-en-2-yl)butyric acid. These results, coupled with known results on lactonisation of other carboxylic acid derivatives of norbornene, point to common reaction pathways with a series of equilibrating norbornyl-type cations involved in product formation. Results with 3-*exo*-carboxy- and 3-*exo*-methylnorborn-5-en-2-*endo*-yl-carboxylic acids indicate that the relative importance of various intermediates in determining product formation is affected by the presence of substituents.

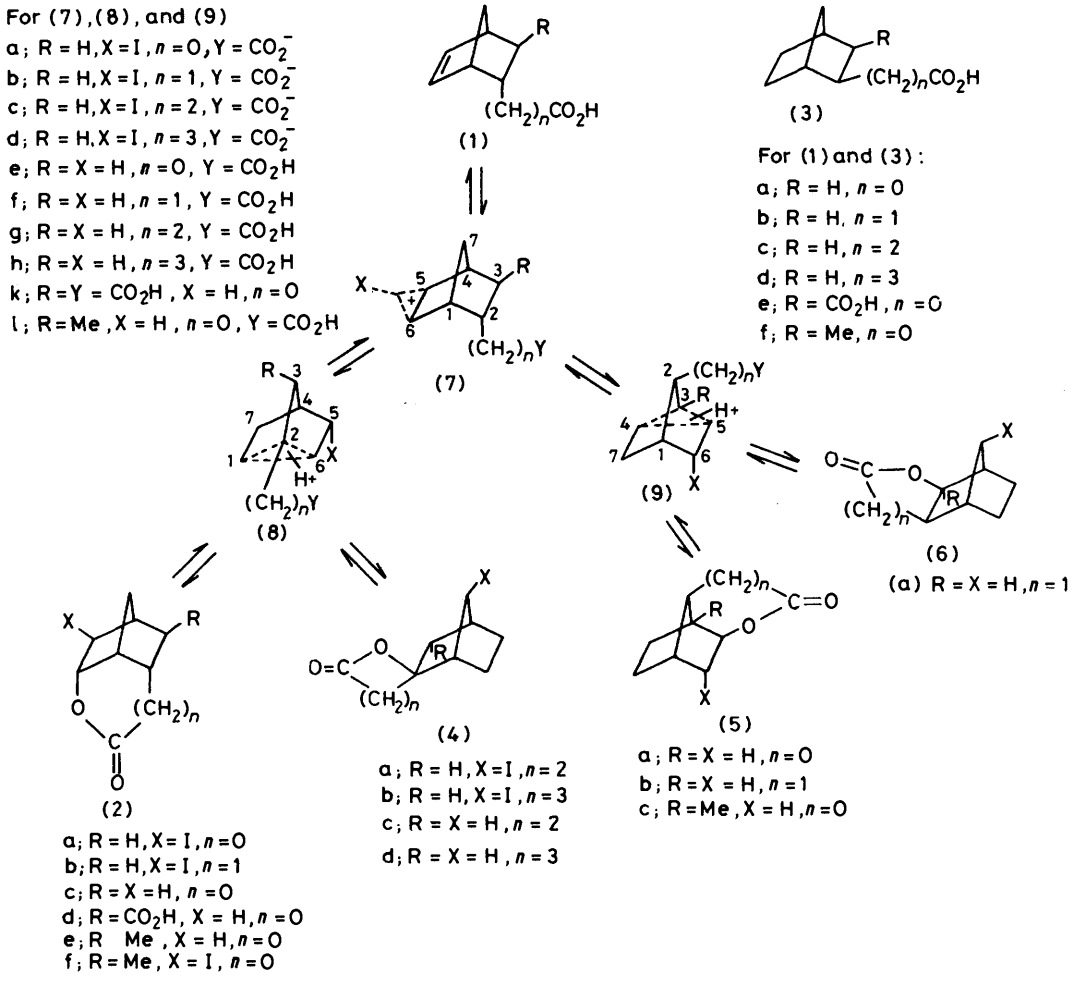
THE reaction of a solution of norborn-5-ene-2-*endo*-carboxylic acid (1a) in sodium hydrogen carbonate solution, with iodine and potassium iodide, affords the iodo-γ-lactone (2a);[1] an analogous reaction with norborn-5-en-2-*endo*-ylacetic acid (1b) gives the iodo-δ-lactone (2b).[2] However, when a mixture of 3-(norborn-5-en-2-*endo*-yl)propionic acid (1c) and its 2-*exo*-isomer (3c) is subjected to the same reaction procedure, structural rearrangement is involved in product formation and the spiro-iodo-γ-lactone (4a) results.[2] In contrast with iodolactonisation, structural rearrangement is far more widespread in the acid-catalysed lactonisation of carboxylic acid derivatives of norbornene. Beckmann and Geiger [3] showed that both of the norborn-5-ene-2-carboxylic acids (1a) and (3a) afforded a mixture of the γ-lactones (2c) and (5a); the norborn-5-en-2-ylacetic acids (1b) and (3b) were found by Davies and Dowle [4] to afford a mixture of the δ-lactone (5b) and γ-lactone (6a).

In an extension of this earlier work, we have now found that a mixture of the norborn-5-en-2-ylbutyric acids (1d) and (3d), when subjected to the iodolactonisation procedure, affords the spiro-iodo-δ-lactone (4b). The acid-catalysed lactonisation of the norborn-5-en-2-ylpropionic acids (1c) and (3c) gives the spiro-γ-lactone (4c), and the norborn-5-en-2-ylbutyric acids (1d) and (3d) give the spiro-δ-lactone (4d). These new results, when considered with those previously reported, clearly show that, although there are structural differences in the products formed from acids (1a) and (1b) on acid-catalysed lactonisation and iodolactonisation, the acids (1c) and (1d) behave similarly and afford spirolactones in both reactions. The apparent differences and similarities between iodolactonisation and acid-catalysed lactonisation along the series of acids (1a—d) is really explicable on the basis of a series of interconverting intermediates. Iodolactonisation of acids (1a—d) would involve the initial formation of the iodonium ions (7a—d). For ions (7a) and (7b), the iodonium ion centre is readily captured by the carboxylate anion to give the iodolactones (2a) and (2b), respectively. In the intermediates (7c) and (7d), derived from acids (1c) and (1d), it would appear that the iodonium ion centre and the carboxylate anion are not conveniently situated for reaction; the iodonium ion centre therefore collapses leading to a norbornyl-type cation in which the positive charge is shared between C-1, -2, and -6, as summarised in the composite non-classical ions (8c) and (8d). In the components of (8c) and (8d) in which the proton is attached at C-1, the positive charge appears at C-2 and cyclisation of the carboxylate anion centre on to C-2 then affords the iodospirolactones (4a) and (4b). In the case of the acid-catalysed lactonisation of acids (1a—d), the 'onium ions (7e—h) would be expected to be the first species formed on protonation. As these ions do not have comparable stabilities to those of the iodonium ions (7a—d), they do not lead directly to product formation unless the possible cyclisation of compound (7e) to give (2c) occurs. The 'onium ions (7e—h) can collapse to give the composite, non-classical ions (8e—h) in which the positive charge is distributed over C-1, -2, and -6, and (9e—h) where it is on C-3, -4, and -5. In the case of the ion (8e), cyclisation on to C-6 affords compound (2c), and for (9e) cyclisation on to C-5 gives (5b). There must be an equilibrium between products (2c) and (5b) *via* intermediates (7e), (8e), and (9e) since, on prolonged reaction, compound (2c) is the sole product. Both products (5b) and (6a) from the acid (1b) are derived from the intermediate (9f), whereas the products (4c) and (4d), formed respectively from the acids (1c) and (1d), must be derived from intermediates (8g) and (8h). The results are best accommodated by assuming the presence of all the intermediates (7), (8), and (9) on treatment of acids (1a—d) with acid. When products are formed exclusively from either of the intermediates (8) or (9) it does not mean that only one of them is present, but rather that the combination of kinetic and thermodynamic factors favours product formation from only one of them. In the iodolactonisation of acids (1c) and (1d), it is probable that both intermediates (8c,d) and (9c,d) are present, but for various reasons (8c,d) are favoured for product formation. This is likely to be for kinetic reasons because, once formed, there is no evidence that iodolactones can revert to the ions (8); there is therefore no possibility that the formation of alternative products related to compounds (5) and (6),

which would require an equilibrium between intermediates (7), (8), and (9), occurs.

If we consider the intermediates (7), (8), and (9), it is clear that, if an electron-attracting substituent R is present at C-3, it will destabilise the positive charge in (9) relative to those in (7) and (8), so that the last two intermediates would then be favoured in product formation; in contrast, if R is an electron-donating substituent it should stabilise the positive charge in (9) relative to those in (7) and (8) so that (9) should be favoured for product formation. These expectations are borne out by experiment. The acid (1e), which has an electron-withdrawing 3-*exo*-carboxy-group, affords, on acid-catalysed lactonisation, exclusively lactone (2d), which has its origin in intermediates (7k) and (8k); the acid (1f), which has an electron-donating 3-*exo*-methyl group, affords, on acid-catalysed lactonisation, a mixture of the two lactones (2e) and (5c), derived from intermediates (8l) and (9l) respectively. However, on prolonged reaction the formation of compound (5c) is favoured which suggests that the presence of the methyl group may be causing increasing amounts of product to be formed from (9l). Analysis by g.l.c. of the mixture of lactones (2e) and (5c) was aided by the availability of an authentic specimen of (2e), obtained by reduction of the γ-iodolactone (2f) with tri-n-butyltin hydride.

It is clear that the iodolactonisation of acids (1c,d) and the acid-catalysed lactonisation of acids (1a—f) involve an equilibrium between intermediates (7), (8), and (9). This interconversion of intermediates results in loss of the stereochemistry at C-2 and consequently in these reactions a mixture of 2-*exo*- and 2-*endo*-acids (1) and (3) may be employed.



SCHEME 1

3-(Norborn-5-en-2-yl)propionic acid (1c) and (3c) can be prepared in low yield (6%) by the Diels–Alder reaction of cyclopentadiene with pent-4-enoic acid;[2] it is also available *via* an inconvenient, chain-extension procedure starting from norborn-5-ene-2-carboxylic acid (1a).[5] In the present work, the following chain-extension procedure starting from norborn-5-en-2-ylacetic acid (1b) and (3b) was employed (see Scheme 2); all the steps were accomplished in high yield.

4-(Norborn-5-en-2-yl)butyric acid (1d) and (3d) was

$$RCH_2CO_2H \longrightarrow RCH_2CH_2OH \longrightarrow RCH_2CH_2OTs \longrightarrow$$
(1b) and (3b) (10) (11)

$$RCH_2CH_2CN \longrightarrow R\overset{8}{C}H_2\overset{9}{C}H_2\overset{10}{C}O_2H$$
(12) (1c) and (3c)

SCHEME 2 The numbering used for the side chains in the n.m.r. assignments is shown in structures (1c) and (3c); R = norborn-5-en-2-yl.

prepared by a similar chain-extension procedure from 3-(norborn-5-en-2-yl)propanol (13), obtained from the Diels–Alder reaction of cyclopentadiene with pent-4-en-1-ol. The method compliments the patent procedure [6] in which compounds (1d) and (3d) are reported to be formed from the free-radical addition of acetic anhydride to ethylidenenorbornene.

Product structures in this work are based on ^1H and ^{13}C n.m.r. data given in the Experimental section. The ^{13}C assignments were tentatively made by comparison with published data on norbornane derivatives [7] and norbornane lactones.[2,4,8]

EXPERIMENTAL

Norborn-5-ene-2-*endo*,3-*exo*-dicarboxylic acid (1e), m.p. 188—190 °C (lit.,[9] m.p. 190 °C) and 3-methylnorborn-5-ene-2-carboxylic acid (1f) and (3f), m.p. 93—95 °C (lit.,[9,10] m.p. 95 °C) were prepared by literature procedures. Treatment of the γ-iodolactone (2f) (3.1 g, 11.15 mmol) with zinc powder (2.7 g) and acetic acid (7 ml) using the method of Berson and Ben-Efraim [11] afforded the *endo*-acid (1f) (1.42 g, 9.3 mmol) as a white crystalline solid, m.p. 95—97 °C, on recrystallisation from carbon tetrachloride (lit.,[12] m.p. 96 °C).

3-(*Norborn-5-en-2-yl*)*propionic Acid* (1c) *and* (3c).—To a stirred suspension of lithium aluminium hydride (1.9 g, 0.05 mol) in diethyl ether (160 ml) was added dropwise a solution of norborn-5-en-2-ylacetic acid (1b) and (3b) (3.0 g, 0.02 mol) [4] in diethyl ether (30 ml), and the mixture was then stirred for 1 h. A saturated solution of ammonium chloride was added until a granular precipitate formed. The precipitate was filtered off, the filtrate dried ($MgSO_4$), and the solvent evaporated to afford 2-(norborn-5-en-2-yl)-ethanol (10) (2.19 g, 0.02 mol, 84%) as a colourless liquid, b.p. 84—86 °C at 0.3 mmHg (lit.,[13] 93—94 °C at 6 mmHg); $\nu_{max.}$ ($CHCl_3$) 3 500 cm^{-1} (m, OH); δ (60 MHz; $CDCl_3$) 6.0 (m, 5-, 6-H), 4.10 (br s, OH), 3.50 (t, 9-H), 2.72 (m, 1-, 4-H), 2.0—0.8 (m, 2-, 3-*exo*-, 7a-, 7b-, 8-H), and 0.5 (2 × br d, 3-*endo*-H); *J* (3-*exo*, 3-*endo*) 12 Hz; *m/e* 138 (M^+), 120 ($M^+ - H_2O$), and 92 ($M^+ - H_2O - C_2H_4$).

A solution of the alcohol (10) (2.0 g, 0.014 mol) in pyridine (46 ml) was cooled in an ice-bath and toluene-4-sulphonyl chloride (7.2 g, 0.03 mol) added. The mixture was stirred and, after 0.5 h, a clear yellow solution resulted. This was kept in the refrigerator for 16 h during which time white crystals of pyridinium hydrochloride gradually formed. The mixture was poured into ice–water (150 g) and the resulting aqueous suspension was extracted with diethyl ether (4 × 50 ml). The combined ether extracts were washed with aqueous hydrochloric acid (50% v/v; 2 × 20 ml) and water (2 × 20 ml), dried ($MgSO_4$), filtered, and the solvent evaporated to afford 2-(norborn-5-en-2-yl)ethyl toluene-4-sulphonate (11) (3.8 g, 0.013 mol, 90%) as a yellow oil; $\nu_{max.}$ ($CHCl_3$) 1 600 cm^{-1} (m, aromatic); δ (60 MHz; $CDCl_3$) 7.75 (d, aromatic), 7.30 (d, aromatic), 5.95 (m, 5-, 6-H), 3.92 (t, 9-H), 2.70 (br s, 1-, 4-H), 2.43 (s, Me), 1.95—0.8 (m, 2-, 3-*exo*-, 7a-, 7b-, 8-H), and 0.45 (2 × br d, 3-*endo*-H); *J* (*o*-aromatic-H, *m*-aromatic-H) 8, *J* (3-*exo*, 3-*endo*) 12 Hz; *m/e* 292 (M^+), 277 (M^+ — Me), and 120 ($M^+ - C_7H_7SO_2OH$).

A mixture of the toluene-4-sulphonate (11) (3.7 g, 12.7 mmol) and powdered potassium cyanide (1.20 g, 1.80 mmol) in dimethyl sulphoxide (35 ml) was heated at 100 °C for 16 h, cooled to room temperature, and then poured into brine (200 ml). The resulting mixture was extracted with chloroform (4 × 50 ml). The combined extracts, after being washed with brine (2 × 30 ml) and water (30 ml, were dried ($MgSO_4$), filtered, and the solvent evaporated to give 2-(norborn-5-en-2-yl)ethyl cyanide (12) (1.50 g, 10.2 mmol, 81%) as a brown oil; $\nu_{max.}$ ($CHCl_3$) 2 250 cm^{-1} (m, CN); δ (60 MHz, $CDCl_3$) 6.10 (m, 5-, 6-H), 2.72 (m, 1-, 4-H), 2.30 (t, 9-H), 2.0—0.8 (m, 2-, 3-*exo*-, 7a-, 7b-, 8-H), and 0.5 (2 × br d, 3-*endo*-H); *J* (3-*exo*, 3-*endo*) 12 Hz; *m/e* 147 (M^+) and 120 (M^+ — HCN).

The nitrile (12) (1.50 g, 10.2 mmol) in aqueous potassium hydroxide (5 g in 50 ml) was stirred and heated at 100 °C for 40 h, and the resulting solution cooled and diluted with water (50 ml); this solution was extracted with diethyl ether (2 × 50 ml), acidified to pH 3, and extracted again with chloroform (5 × 50 ml). The combined chloroform extracts were washed with water (2 × 50 ml), dried ($MgSO_4$), filtered, and the solvent evaporated to afford an oil which was distilled to give 3-(norborn-5-en-2-yl)propionic acid (1c) and (3c) (1.40 g, 8.43 mmol, 83%) as a colourless liquid, b.p. 115—117 °C at 0.3 mmHg (lit.,[2] b.p. 102—103 °C at 0.05 mmHg); $\nu_{max.}$ ($CHCl_3$) 3 200 (m, CO_2H) and 1 710 cm^{-1} (s, CO); δ (60 MHz, $CDCl_3$) 11.0 (s, 10-H), 6.08 (m, 5-, 6-H), 2.78 (m, 1-, 4-H), 2.35 (t, 9-H), 1.95—0.9 (m, 2-, 3-*exo*-, 7a-, 7b-, 8-H), and 0.5 (2 × br d, 3-*endo*-H); *J* (3-*exo*, 3-*endo*) 12 Hz; *m/e* 166 (M^+), 121 ($M^+ - CO_2H$), and 92 ($M^+ - CO_2H$ — Et).

4-(*Norborn-5-en-2-yl*)*butanoic Acid* (1d) *and* (3d).—A mixture of cyclopentadiene (15.4 g, 0.2 mol) and pent-4-en-1-ol [14] (10 g, 0.12 mol) was heated in a sealed tube at 180 °C for 60 h. The tube was cooled and opened, and the product distilled to give 3-(norborn-5-en-2-yl)propanol (6.2 g, 0.04 mol, 35%) as a colourless liquid, b.p. 79—80 °C at 0.08 mmHg (lit.,[5] b.p. 75—78 °C at 0.1 mmHg); $\nu_{max.}$ ($CHCl_3$) 3 500 cm^{-1} (m, OH); δ (60 MHz; $CDCl_3$) 6.0 (m, 5-, 6-H), 3.85 (br s, OH), 3.50 (t, 10-H), 2.75 (m, 1-, 4-H), 2.5—0.8 (m, 2-, 3-*exo*-, 7a-, 7b-, 8-, 9-H), and 0.5 (m, 3-*endo*-H); *m/e* 152 (M^+), 134 ($M^+ - H_2O$), and 102 ($M^+ - C_3H_7OH$).

A solution of this alcohol (6.0 g, 0.04 mol) in pyridine (90 ml) was cooled in an ice-bath and toluene-4-sulphonyl chloride (15.0 g, 0.07 mol) added. The solution was kept in the refrigerator and then worked up as for compound (11) to give 3-(norborn-5-en-2-yl)propyl toluene-4-sulphonate (8.2 g, 0.03 mol, 67%) as a colourless liquid, b.p. 102—103 °C at 0.3 mmHg; $\nu_{max.}$ ($CHCl_3$) 1 600 cm^{-1} (m, aromatic); δ (60 MHz; $CDCl_3$) 7.80 (d, aromatic), 7.30 (d, aromatic), 6.0 (m, 5-, 6-H), 4.0 (t, 10-H), 2.75 (m, 1-, 4-H), 2.45 (s, Me), 2.2—0.9 (m, 2-, 3-*exo*-, 7a-, 7b-, 8-, 9-H), and 0.5 (m, 3-*endo*-H); *J* (*o*-aromatic-H, *m*-aromatic-H) 8 Hz; *m/e* 306 (M^+), 295 (M^+ — Me), and 134 ($M^+ - C_7H_7SO_2OH$).

Potassium cyanide (2.3 g, 0.04 mol) was added to a solution of the above toluene-4-sulphonate (8.0 g, 0.03 mol) in dimethyl sulphoxide (40 ml). The mixture was stirred and heated at 100 °C for 16 h and the reaction worked up as

for compound (12) to afford 3-(norborn-5-en-2-yl)propyl cyanide (3.15 g, 0.02 mol, 75%) as a yellow oil; $\nu_{max.}$ ($CHCl_3$) 2 250 cm^{-1} (m, CN); δ (60 MHz; $CDCl_3$) 6.1 (m, 5-, 6-H), 2.72 (m, 1-, 4-H), 2.25 (t, 10-H), 2.0—0.8 (m, 2-, 3-*exo*-, 7a-, 7b-, 8-, 9-H), and 0.5 (m, 3-*endo*-H); *m/e* 161 (M^+), 134 (M^+ — HCN), and 91 (M^+ — HCN — Pr^n).

The above cyanide (3.1 g, 0.02 mol) in aqueous potassium hydroxide [KOH (10 g) in water (100 ml)] was stirred and heated at 110 °C for 60 h. The reaction was worked up as for compound (1c and 3c) to afford 4-(norborn-5-en-2-yl)butanoic acid (1d and 3d) (2.51 g, 0.02 mol, 73%) as a colourless liquid, b.p. 122—123 °C at 0.3 mmHg (lit.,[6] b.p. 120—124 °C at 0.2 mmHg) (Found: C, 73.15; H, 8.9. Calc. for $C_{11}H_{18}O_2$: C, 73.33; H, 8.89%); $\nu_{max.}$ ($CHCl_3$) 3 200 (m, OH) and 1 710 cm^{-1} (s, CO); δ (60 MHz; $CDCl_3$) 11.55 (s, CO_2H), 6.0 (m, 5-, 6-H), 2.75 (m, 1-, 4-H), 2.30 (t, 10-H), 2.10—1.0 (m, 2-, 3-*exo*-, 7-, 8-, 9-H), and 0.5 (br d, 3-*endo*-H); *m/e* 180 (M^+).

Acid-catalysed Lactonisation of 3-(*Norborn-5-en-2-yl*)*propionic Acids* (1c) *and* (3c).—A mixture (0.2 g, 1.2 mmol) of the *endo*-acid (1c) and the *exo*-acid (3c) was dissolved in sulphuric acid (6 ml; 50%) and the solution stirred at room temperature for 20 h. The resulting brown homogeneous solution was poured onto a mixture of ice (10 g) and water (40 ml), and the mixture extracted with diethyl ether (6 × 20 ml). The combined ether extracts were washed with sodium hydrogen carbonate solution (2 × 25 ml of 0.5N) water (2 × 25 ml) dried ($MgSO_4$), and the solvent evaporated to afford a yellow oil. The oil was distilled to give 3-(2-exo-*hydroxynorborn*-2-endo-*yl*)*propionic acid spiro-γ-lactone* (4c) (0.16 g 0.96 mmol) as a colourless oil, b.p. 95 °C at 0.3 mmHg (Found: C, 72.2; H, 8.75. $C_{10}H_{14}O_2$ requires C, 72.29; H, 8.43%); $\nu_{max.}$ (CCl_4) 1 780 cm^{-1} (s, CO); δ (60 MHz; $CDCl_3$) 2.80—1.20 (overlapping m); δ (^{13}C) ($CDCl_3$) 46.38 (d, C-1) 93.58 (s C-2) 29.73 (t, C-3), 45.67 (d C-4) 22.22 (t, C-5), 28.02 (t, C-6), 30.60 (t, C-7), 176.67 (s, C-10), 36.40 (t, C-9), and 37.93 (t, C-8); *m/e* 166 (M^+), 138 (M^+ — C_2H_4), and 124 (M^+ — CO_2).

Acid-catalysed Lactonisation of 4-(*Norborn-5-en-2-yl*)*butyric Acid* (1d) *and* (3d).—The mixture (0.2 g, 1.11 mmol) of *endo*-acid (1d) and *exo*-acid (3d) was dissolved in sulphuric acid (6 ml; 50%) and the solution stirred at room temperature for 20 h. Work-up of the resultant brown solution, as for compound (4c), afforded 4-(2-exo-*hydroxynorborn*-2-endo-*yl*)*butyric acid spiro-δ-lactone* (4d) (0.15 g, 0.83 mmol) as a colourless oil, b.p. 100 °C at 0.3 mmHg (Found: C 73.85; H, 9.05. $C_{11}H_{16}O_2$ requires C, 73.33; H, 8.89%); $\nu_{max.}$ (CCl_4) 1 730 cm^{-1} (s, CO); δ (60 MHz; $CDCl_3$) 2.6—1.0 (overlapping m); δ (^{13}C) ($CDCl_3$) 46.85 (d, C-1), 91.30 (s, C-2), 27.85 (t, C-3), 46.73 (d, C-4), 17.30 (t, C-5), 22.98 (t, C-6), 29.31 (t, C-7), 171.40 (s, C-11), 33.01 (t, C-10), 36.24 (t, C-9), and 36.80 (t, C-8); *m/e* 180 (M^+), 138 (M^+ — C_3H_6), and 136 (M^+ — CO_2).

Acid-catalysed Lactonisation of Norborn-5-ene-2-endo,3-exo-*dicarboxylic Acid* (1e).—The acid (1e) (2.0 g, 10.9 mmol) was dissolved in concentrated sulphuric acid (10 ml) and the solution heated at 60 °C for 1 h. It was then cooled to 0 °C in an ice–salt bath and small pieces of ice added until the volume reached 40 ml. The ice–salt bath was removed and the solution heated at 110 °C for 5 min and then cooled to afford 6-*endo*-hydroxy-3-*exo*-carboxynorborn-2-*endo*-ylcarboxylic acid γ-lactone (2d) (1.2 g, 6.6 mmol) as a white crystalline solid, m.p. 133—135 °C (lit.,[15] 133—134 °C) on recrystallisation from ethyl acetate; $\nu_{max.}$ (Nujol) 3 300 (m, OH) and 1 760 cm^{-1} (s, CO); δ (60 MHz; $CDCl_3$) 4.90 (t, 6-*exo*-H), 3.18 (m, 1-, 4-H), 2.80 (m, 2-*exo*-, 3-*endo*-H), and 1.80 (m, 5-*exo*-, 5-*endo*-, 7-*anti*-, 7-*syn*-H); *J* (1,6-*exo*) 6, *J* (5-*exo*,6-*exo*) 6 Hz; *m/e* 182 (M^+).

Acid-catalysed Lactonisation of 3-exo-*Methylnorborn*-5-*ene*-2-endo-*carboxylic Acid* (1f).—A solution of the acid (1f) (0.7 g, 4.6 mmol) in sulphuric acid (10 ml; 50%) [16] was stirred at room temperature for 22 h. The resultant brown homogeneous solution was poured onto a mixture of ice (20 g) and water (80 ml), and the mixture extracted with diethyl ether (6 × 40 ml). The combined ether extracts were washed with 0.5N-aqueous sodium hydrogen carbonate (2 × 50 ml), dried ($MgSO_4$) and the solvent evaporated to give a mixture (0.5 g) of 6-*endo*-hydroxy-3-*exo*-methylnorborn-2-*endo*-ylcarboxylic acid γ-lactone (2e) and 3-*exo*-methylnorborn-7-*anti*-ylcarboxylic acid γ-lactone (5c); $\nu_{max.}$ ($CHCl_3$) 1 765 cm^{-1} (s, CO); δ (60 MHz; $CDCl_3$) 4.75 (t, 6-*exo*-H), 3.15 (t, 1-H), 1.10 [d, Me of (2e)] and 4.27 (br s, 3-*endo*-H), and 1.26 [s, Me of (5c)]; *m/e* 152 (M^+), 128 (M^+ — CO), 109 (M^+ — CO — Me).

Product proportions for the reaction mixture were estimated by g.l.c. using a Perkin-Elmer F11 instrument fitted with a flame ionisation detector and a 2-m × 3-mm stainless steel column packed with Carbowax 20 M on Chromosorb W (80—100 mesh) at 170 °C: (2e) 47.9%, R_t 7.4 min; (5c) 52.1%, R_t 5.2 min.

6-endo-*Hydroxy*-3-exo-*methylnorborn*-2-endo-*ylcarboxylic Acid γ-Lactone* (2e).—The γ-iodolactone (2f) (1.39 g, 5 mmol) was treated with tri-n-butyltin (0.325 g, 1 mmol) and sodium borohydride (0.236 g, 6.3 mmol) in ethanol (180 ml) by the method of Corey and Suggs [17] to afford 6-*endo*-hydroxy-3-*exo*-methylnorborn-2-*endo*-ylcarboxylic acid γ-lactone (2e) (0.4 g, 2.6 mmol) as a white crystalline solid, m.p. 70—72 °C on recrystallisation from ethyl acetate–light petroleum (b.p. 60—80 °C) (lit.,[9] m.p. 70—71 °C); $\nu_{max.}$ ($CHCl_3$) 1 765 cm^{-1} (s, CO); δ (60 MHz; $CDCl_3$) 4.75 (t, 6-*exo*-H), 3.10 (t, 1-H), 2.10 (m, 2-*exo*-, 4-H), 1.9—1.25 (m, 5-, 7-*anti*-, 7-*syn*-, 3-*endo*-H), and 1.10 (d, Me); *J* (1,6-*exo*) 6, *J* (1,2-*exo*) 6, *J* (5-*exo*,6-*exo*) 6, *J* (3-*endo*,Me) 7 Hz; *m/e* 151 (M^+), 136 (M^+ — Me), and 108 (M^+ — Me — CO).

Iodolactonisation of 4-(*Norborn-5-en*-2-endo-*yl*)*butyric Acid* (1d) *and* (3d).—A mixture (1.41 g, 7.8 mmol) of acids (1d) and (3d) in 0.5N-aqueous sodium hydrogen carbonate (47 ml), and a solution of iodine (1.98 g, 7.8 mmol) and potassium iodide (78 g, 47 mmol) in water 25 ml were allowed to react according to the iodolactonisation procedure of van Tamelen and Shamma.[18] The reaction was carried out with protection from light. Initially the reaction mixture was kept in an ice-bath for 0.5 h; it was then stirred for 1 h and left at room temperature for 16 h. Extraction of the reaction mixture with chloroform (6 × 30 ml) did not afford any iodolactone in the extract. The reaction mixture was then acidified and extracted with chloroform (4 × 40 ml), the combined extracts were washed with water (50 ml), dried ($MgSO_4$) and the solvent evaporated to give a yellow oil (0.8 g). This oil was purified by preparative layer chromatography [60 × 20 × 0.1-cm silica gel plate ($CHCl_3$)] to afford 4-(2-exo-*hydroxy*-7-anti-*iodonorborn*-2-endo-*yl*)*butyric acid spiro-δ-lactone* (4b) (0.48 g, 1.57 mmol) as a white crystalline solid, m.p. 94.5—96 °C on recrystallisation from ethyl acetate–light petroleum (b.p. 60—80 °C) (Found: C, 42.9; H, 5.0; I, 41.7. $C_{11}H_{15}IO_2$ requires C, 43.14; H, 4.9; I, 41.5%); $\nu_{max.}$ ($CHCl_3$) 1 735 cm^{-1} (s, CO); δ (90 MHz; $CDCl_3$) 4.47 (br s, 7-*syn*-H), 2.44 (m, 1-, 4-, 3-*exo*-, 10-H), 1.97 (m, 9-, 8-, 3-*endo*-,

5-*exo*-H), 1.64 (m, 6-*exo*-H), 1.44 (m, 5-*endo*-H), and 1.22 (m, 6-*endo*-H); δ (^{13}C) ($CDCl_3$) 170.4 (s, C-11), 88.30 (s, C-2), 54.30 (d, C-1), 44.70 (d, C-4), 43.90 (t, C-3), 32.07 (t, C-10), 29.08 (t, C-8), 26.91 (t, C-5), 30.14 (d, C-7), 21.93 (t, C-6), and 17.0 (t, C-9); *m/e* 306 (M^+), 278 ($M^+ - CO$), 208 ($M^+ - C_3H_6O$), and 179 ($M^+ - I$).

A. S. thanks the Malaysian Government for the award of a research studentship.

[2/055 *Received*, 12*th January*, 1982]

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