cyclopentanone C=O), 1700 (cyclohexanone C=O), 1590 cm^{-1} (anisole). Material from a similar run showed the following spectral properties: uv max (95% EtOH) 215 nm (ϵ 6960), 272 (2030), 279 (1840); nmr ($CDCl_3$) δ 6.85 (m, 4, aromatic), 5.90 (t, 1, J = 8 Hz, HCO), 3.87 (s, 3, OCH_3), 2.02 (s, CH_3C=O), 1.26 (s, C_{7a} CH_3, minor isomer), 1.02 ppm (s, C_{7a} CH_3, major isomer); mass spectrum m/e 358 (M^+).

An ice-cold solution of this diketo ester (0.171 g, 0.475 mmol) in 3 ml of methanol was stirred while 0.625 ml of 10 N aqueous HCl was added. The resulting solution was stirred at 0–5° for 10 min and then at room temperature for 3.5 hr. Work-up with ether gave 0.162 g of oily product. This material was stirred and heated at reflux in 5 ml of benzene containing 25 mg of *p*-toluenesulfonic acid monohydrate. After cooling the solution was diluted with ether, washed once with aqueous sodium bicarbonate solution, dried, and concentrated at reduced pressure, giving 138 mg of semicrystalline residue. Chromatography on 7.5 g of silica gel gave 63 mg (42.5% based on **31a**) of pure, racemic equilenin 3-methyl ether (**33a**) (eluted with 49:1 benzene–ether; tlc, one spot, R_f 0.57). Recrystallization from ethanol gave colorless plates, mp 183–186° (lit.[30] mp 186°; lit.[31,33] mp 185–186°; lit.[32] mp 188–190°). The ir, uv, and nmr spectra and tlc mobility of this racemic material were identical with those of *d*-equilenin methyl ether, mp 195–196°, prepared by methylation of (+)-equilenin (Searle) as described by Wilds, *et al.*[33]

Crystallography.—Crystals of **22a** were obtained from an ethanol–methylene chloride mixture as well-formed prisms. The crystal data are a = 14.67 (1), b = 7.09 (1), c = 24.81 (3) Å, β = 116.90 (5)°, d_{obsd} (aqueous KI) = 1.42, d_{calcd} = 1.435 g cm^{-3} for Z = 4, space group $P2_1/c$.

The intensities of 4571 independent X-ray diffraction maxima with $2\theta < 140°$ were measured on a Hilger-Watts Model Y290 four-circle diffractometer using Ni-filtered Cu Kα radiation. A rapid, stationary crystal–stationary detector technique was used to collect the data and an empirical correction was applied to convert the peak top data to integrated scan data. A total of 3531 reflections were significantly greater than background and these data were used for the structure analysis. The dimensions of the data crystal were 0.35 × 0.35 × 0.45 mm. The data were corrected for absorption (μ = 29.8 cm^{-1}).

The structure was solved by the heavy atom method. Refinement of the structure was carried out by full matrix least squares. All atoms had isotropic temperature factors except the bromine, which was assigned anisotropic thermal parameters; hydrogen atoms were not included. At the conclusion of the refinement, R = 0.132. A difference Fourier calculated at this point had no features greater than 1.0 electron/Å^3 in magnitude.[39]

Acknowledgments.—We wish to express our gratitude to the personnel of the Physical Chemistry Department of Hoffmann-La Roche Inc., Nutley, N. J., for carrying out many of the spectral and microanalytical determinations required in this work and to the members of the Kilo Laboratory who assisted in the preparation of certain of the starting materials.

Registry No.—**5a,** 40901-47-1; **5b,** 38102-79-3; **5c,** 38102-77-1; **10,** 38102-72-6; **11,** 38102-67-9; **12a,** 38171-50-5; **13a,** 38171-49-2; **13b,** 40901-54-0; **13b** (*R*)-(+)-α-methylbenzylamine salt, 38102-75-9; **13c,** 40903-49-9; **13c** (*S*)-(−)-α-methylbenzylamine salt, 38171-48-1; **14a,** 38102-69-1; **14b,** 40901-59-5; **15,** 38102-70-4; **16,** 38102-71-5; **18a,** 40901-62-0; **18b,** 38680-53-4; **19b,** 38680-54-5; **20a,** 40903-58-0; **20b,** 40901-66-4; **21b,** 40903-60-4; **22a,** 40901-68-6; **22b,** 38680-56-7; **24a,** 38680-42-1; **24b,** 38680-57-8; **25a,** 18300-15-7; **25b,** 15375-09-4; **26b,** 17780-12-0; **27b,** 1670-49-1; **28a,** 40901-76-6; **29a,** 40903-70-6; **30a,** 40901-78-8; **31a,** 38680-49-8; **32a,** 38680-50-1; **33a,** 4820-56-8; (*R*)-(+)-α-methylbenzylamine, 3886-69-9; 2-methyl-1,3-cyclopentanedione, 765-69-5; (*R*)-(+)-α-methoxy-α-trifluoromethylphenylacetic acid, 20445-31-2; *p*-toluenesulfonic acid, 104-15-4.

Supplementary Material Available.—Listings of structure factors and atomic parameters will appear following these pages in the microfilm edition of this volume of the journal. Photocopies of the supplementary material from this paper only or microfiche (105 × 148 mm, 20× reduction, negatives) containing all of the supplementary material for the papers in this issue may be obtained from the Journals Department, American Chemical Society, 1155 16th St., N.W., Washington, D. C. 20036. Remit check or money order for $3.00 for photocopy or $2.00 for microfiche, referring to code number JOC-73-3229.

(39) See paragraph at end of paper regarding supplementary material.

The Stereocontrolled Synthesis of *trans*-Hydrindan Steroidal Intermediates

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Catalytic hydrogenation of simple $\Delta^{3a(4)}$-indan derivatives (*e.g.*, **1a**) gave mainly (88.5%) the thermodynamically favored cis-fused bicyclic products. In the presence of a β-oriented bulky C-1 substituent ~30% of trans-fused derivatives and with an additional bulky substituent at C-4 ~50% of trans-fused hydrogenation products could be obtained. With a carboxylic acid or a carboxylic ester substituent at C-4 practically full stereocontrol has been achieved to yield the desired trans-fused bicyclic compounds (**8** and **13**). A theoretical explanation of the stereochemical results has been included.

During the course of an investigation of a new total synthesis of steroidal compounds the problem of the stereocontrolled preparation of *trans*-hydrindan derivatives became of prime importance. These bicyclic compounds correspond to the CD portion of the steroidal skeleton, and if properly functionalized they may become suitable building blocks of a new totally synthetic scheme to obtain steroidal compounds.

It has been previously reported[2a] that indan derivatives, *e.g.*, the bicyclic unsaturated keto alcohol **1a**, gave, under a variety of hydrogenation conditions, only the thermodynamically more stable C/D cis keto alcohol **2**. We found 88.5% of cis compound **2** in the reaction mixture by vpc, which is in fair agreement with a more recent publication reporting ~80% of **2** as estimated by nmr spectroscopy.[2b]

It was of interest to discover whether the desired C/D trans stereoisomer could be obtained by the catalytic hydrogenation of a properly modified and substituted bicyclic system. The *tert*-butyl ether **1b** has therefore been subjected to catalytic hydrogenation under a variety of reaction conditions. It was hoped that preferential α-side attack would occur owing to the β-oriented bulky substituent at the C-1 position of the molecule. The *tert*-butyl ether group was removed by hydrolysis of the reduction products, and the resulting mixture of **2** and **3** was subjected to fractionation by

(1) To whom correspondence should be addressed at the Faculty of Pharmacy, University of Toronto, Toronto 181, Ontario, Canada.

(2) (a) C. B. C. Boyce and J. S. Whitehurst, *J. Chem. Soc.*, 4547 (1960); (b) K. H. Baggaley, S. G. Brooks, J. Green, and B. T. Redman, *J. Chem. Soc. C*, 2671 (1971).

preparative vpc. The desired C/D trans bicyclic hydroxy ketone **3** was thus obtained in 96% purity.

The best result in the catalytic hydrogenation was obtained by using a 5% Pd-on-carbon catalyst and cyclohexane as solvent. This yielded approximately 30% of the desired C/D trans bicyclic hydroxy ketone **3** as shown by vpc and by nmr analysis (Table I).

TABLE I

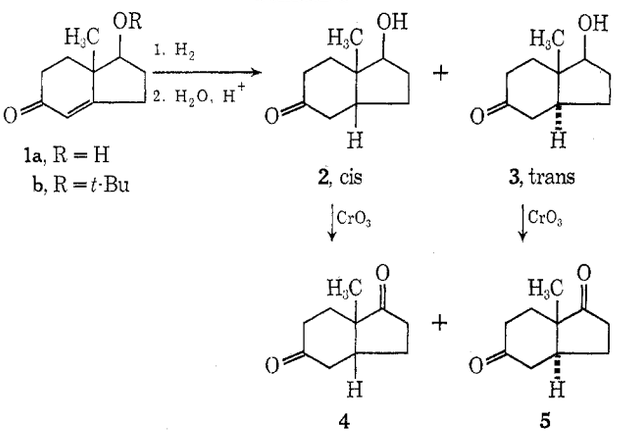
CATALYTIC HYDROGENATION OF **1b** FOLLOWED BY REMOVAL OF *tert*-BUTYL GROUP

		Vpc		Nmr	
Catalyst	Solvent	cis, %	trans, %	cis, %	trans, %
Pd/C	Cyclohexane	60.5	34.5	70	30
Pd/C	*n*-Hexane	62.5	27.5	80	20
$Pd/BaSO_4$	Cyclohexane	72.0	24.0		

Oxidation of the hitherto unknown trans-fused keto alcohol **3** gave the trans bicyclic diketone **5**, a crystalline solid after purification by preparative thin layer chromatography. This compound was identical with a sample prepared by an independent route.[2b]

Authentic samples of the C/D cis compounds **2** and **4** were also prepared for reference by literature procedures[2a] (Scheme I).

SCHEME I[a]



[a] All compounds reported in this paper are racemic. For convenience, only one enantiomer is shown.

Data of nmr spectroscopy and of vpc are compiled in Table II. In this series of compounds the additivity

TABLE II

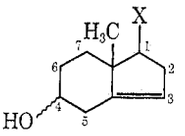
NMR AND VPC DATA OF BICYCLIC COMPOUNDS

Compd	δ (7a-methyl)	$\Delta W_{h/2}$	Retention time, min
2, cis keto alcohol	1.17	0.8	17.5
4, cis diketone	1.24	0.5	10.3
3, trans keto alcohol	1.02	1.2	18.3
5, trans diketone	1.12	1.55	11.7

of the chemical shifts of the methyl signals did not convincingly support the cis or trans configuration of the system. The nmr peak width at half-height ($W_{h/2}$) of the angular methyl group was therefore measured and compared with the $W_{h/2}$ of the tetramethylsilane signal ($\Delta W_{h/2}$).[3] In agreement with results of decalin derivatives,[4] it was found that the $\Delta W_{h/2}$ values were greater for the trans compound than for the corresponding cis isomers.

The vpc results were also in agreement with the stereochemical assignments. As expected, the C/D trans-fused compounds **3** and **5** showed longer retention times in comparison to the corresponding C/D cis-fused derivatives **2** and **4**, respectively. This is due to the increased adsorption of the relatively more planar trans-fused derivatives.[5]

Next we turned our attention to the catalytic hydrogenation of an isolated 3(3a) double bond in the bicyclic system. It has been reported[6] that the 1-carbomethoxy derivative **6a** gave 32% of the desired C/D trans-fused derivative upon catalytic reduction. Starting with the bicyclic compound **1a** we prepared the related 1-acetoxy and 1-hydroxy derivatives (**6b** and **6c**) using literature procedures,[6] and subjected them to



6a, X = CO_2CH_3
b, X = $OCOCH_3$
c, X = OH

catalytic hydrogenation. We obtained in each case only a C/D cis-fused derivative, as shown by conversion to the cis diketone **4**. A similar result has recently been reported[7] in the catalytic hydrogenation of the bicyclic Δ3(3a)-diol (**6c**).

All of these results pointed to the difficulties in trying to improve the yield of the desired C/D trans system in a catalytic hydrogenation reaction. It was also anticipated that subsequent alkylation would occur mainly at the undesired C-6 position, because of the preference of trans-fused bicyclic derivatives to enolize in that direction.[8]

On the other hand, the introduction of an appropriate group (*e.g.*, carboxylic ester function) at the C-4 position should activate that site toward alkylation reactions. It may also assist the stereocontrol of the catalytic hydrogenation, since we have previously shown that with a bulky substituent at the C-4 position a reasonable amount (at least 50%) of the desired C/D trans bicyclic derivative could be obtained.[9]

The unsaturated β-keto acid **7** was therefore prepared by carbonation of the conjugate anion derived from the bicyclic *tert*-butyl ether **1b** (Scheme II). The possibility of an isomeric C-6 substituted β-keto acid *via* carbonation of the homoannular conjugate anion was excluded by nmr spectroscopy; there was no vinylic proton in the spectrum of **7**.

Catalytic hydrogenation of **7** gave the saturated β-keto acid **8** in excellent yield. The α-equatorial configuration of the carboxyl group was established by nmr

(3) C. W. Shoppee, F. P. Johnson, R. E. Lack, J. S. Shannon, and S. Sternhell, *Tetrahedron Suppl. 8, Part II*, 421 (1966).

(4) K. L. Williamson, T. Howell, and T. A. Spencer, *J. Amer. Chem. Soc.*, **88**, 325 (1966).

(5) E. L. Eliel, N. L. Allinger, S. J. Angyal, and G. A. Morrison, "Conformational Analysis," Interscience, New York, N. Y., 1965, p 274.

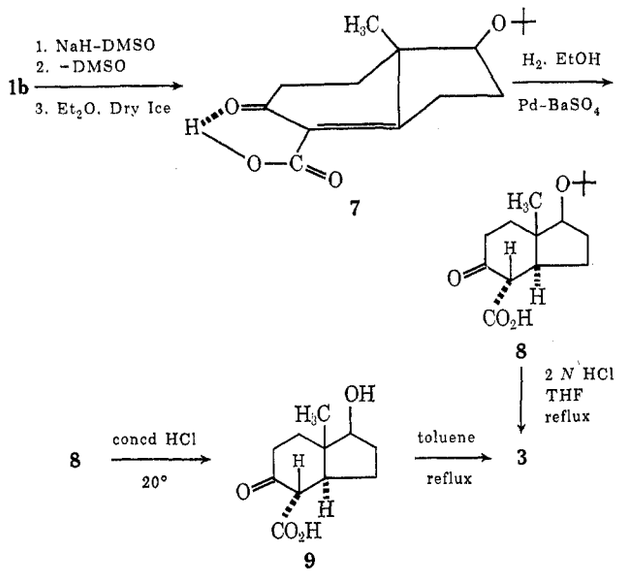
(6) M. Chaykovsky and R. E. Ireland, *J. Org. Chem.*, **28**, 748 (1963).

(7) D. J. Crispin, A. E. Vanstone, and J. S. Whitehurst, *J. Chem. Soc. C*, 10 (1970).

(8) L. Velluz, J. Valls, and G. Nominé, *Angew. Chem.*, **77**, 185 (1965).

(9) Z. G. Hajos, D. R. Parrish, and E. P. Oliveto, *Tetrahedron*, **24**, 2039 (1968).

SCHEME II



spectroscopy; the C-4 proton appeared as a doublet centered at δ 3.38. The large coupling constant ($J_{3aH,4H}$ = 13 Hz) confirmed the trans diaxial relationship of the C-3a and C-4 protons. The C/D trans stereochemistry of the β-keto acid **8** was proven by conversion to the C/D trans bicyclic hydroxy ketone **3** *via* hydrolysis and decarboxylation.

The same compound (**3**) could also be obtained upon hydrolysis of the *tert*-butyl ether group of **8** followed by thermal decarboxylation of the hydroxy β-keto acid **9** in refluxing toluene. The remarkable stability of the β-keto acid **8** toward concentrated hydrochloric acid is most likely due to the C/D trans ring fusion, which would not favor the introduction of a 4(5) double bond[8] and thus the formation of the cyclic transition state assumed for the decarboxylation of β-keto acids.[10]

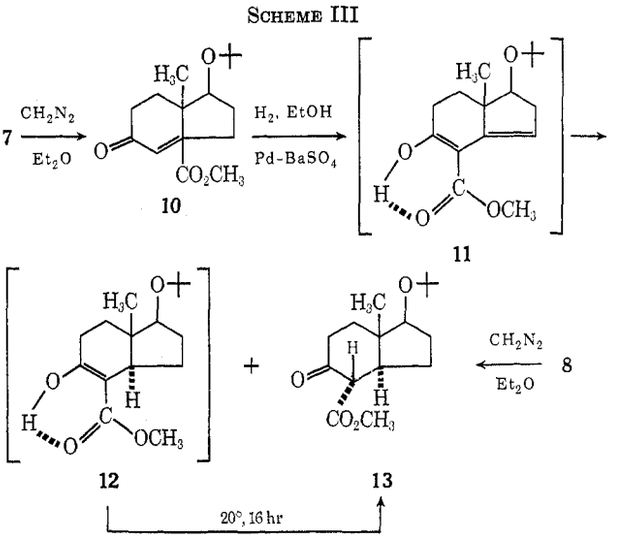
It was thus shown that the unsaturated β-keto acid **7** could be hydrogenated without substantial decarboxylation to the desired C/D trans-fused β-keto acid **8** of high purity. This major improvement over our previous results is undoubtedly due to a favorable combination of several factors. The infrared spectrum of the unsaturated β-keto acid **7** [ν_{max} 1733 (carboxyl carbonyl), 1620 (α,β-unsaturated carbonyl), 1600 cm^{-1} (olefinic double bond) in chloroform] showed hydrogen bonding between the conjugated carbonyl and the sp^2-oriented carboxylic acid group, thereby forming a pseudo B ring *via* chelation. The addition of piperidine relieved hydrogen bonding, and the α,β-unsaturated carbonyl group appeared at its normal position, *i.e.*, ν_{max} 1660 cm^{-1}.

If it were possible for the molecule to exist either in the half-chair or in the 1,2-diplanar conformation,[11] the hydrogen-bonded structure would most certainly prefer the half-chair conformation to relieve steric interactions between the pseudo B ring and the five-membered ring. Hydrogenation of the unsaturated β-keto acid in this rather planar conformation **7** should then favor addition of hydrogen from the less hindered bottom side of the molecule, opposite the β substituents at the C-1 and C-7a positions, to give a C/D trans-fused system.

According to a theory developed for the catalytic hydrogenation of α,β-unsaturated bicyclic ketones, 1,4 addition of hydrogen should lead to preferential cis hydrogenation, while 1,2 addition should give increased quantities of the trans-fused product.[12] In hydroxylic solvents hydrogen bonding to the keto group should inhibit 1,4 addition according to this theory. Intramolecular hydrogen bonding in the unsaturated β-keto acid **7** should thus correspond to the latter condition and give increased quantities of the trans-fused product owing to the strong inhibition of 1,4 addition, as was indeed the case.

The unsaturated β-keto ester **10** was then prepared by treating **7** with the theoretical amount of diazomethane in ether (Scheme III). The compound **10** was fully

SCHEME III



ketonic as indicated by ir, uv, and nmr spectroscopy. Catalytic hydrogenation of **10** with the theoretical amount of hydrogen yielded a reduction product which gave a strong ferric chloride test. The ultraviolet absorption [λ_{max}^{EtOH} 258 nm (ϵ 8050)] and the infrared spectrum with two relatively small bands at ν_{max} 1640 and 1601 cm^{-1} indicated the presence of an enolic component (**12**) in the mixture. However, after 16 hr at 20°, this mixture no longer showed an ultraviolet absorption, nor did it give a ferric chloride test. Its infrared and nmr spectra were superimposable with those of an authentic sample of **13** prepared from the C/D trans β-keto acid **8** with diazomethane in ether. The ease of the tautomerization of **12** → **13** is in agreement with the trans fusion of the ring system. That the β-keto ester **13** was fully ketonic, showed no uv absorption, and gave no ferric chloride test was to be expected in analogy with literature examples.[13a-c]

The rate of the catalytic hydrogenation of the unsaturated β-keto ester **10** was approximately four times

(10) E. S. Gould, "Mechanism and Structure in Organic Chemistry," Holt, Rinehart and Winston, New York, N. Y., 1965, p 347.

(11) Such conformers have been suggested for the A/B ring system of 3-keto-Δ^4 steroids; *cf.* E. Toromanoff in "Topics in Stereochemistry," Vol. 2, N. L. Allinger and E. L. Eliel, Ed., Interscience, New York, N. Y., 1967, p 168.

(12) R. L. Augustine, D. C. Migliorini, R. E. Foscante, C. S. Sodano, and M. J. Sisbarro, *J. Org. Chem.*, **34**, 1075 (1969).

(13) (a) E. Wenkert and B. G. Jackson, *J. Amer. Chem. Soc.*, **81**, 5601 (1959); (b) T. A. Spencer, T. D. Weaver, and W. J. Greco, Jr., *J. Org. Chem.*, **30**, 3333 (1965); (c) T. A. Spencer, R. M. Villarica, D. L. Storm, T. D. Weaver, R. J. Friary, J. Posler, and P. R. Shafer, *J. Amer. Chem. Soc.*, **89**, 5497 (1967).

slower than that of the unsaturated β-keto acid **7** under otherwise identical reaction conditions. With three times as much catalyst the reaction rates of the catalytic hydrogenation of **10** and of **7** became identical. The difference in the rates and also the appearance of an enolic reaction product in the hydrogenation of the β-keto ester **10** suggests the reduction of the 3(3a) double bond of intermediate **11** in the case of the β-keto ester **10**. With the β-keto acid **7**, however, hydrogenation proceeds *via* saturation of the 3a(4) double bond (*cf.* Schemes II and III, respectively). Pseudo B ring formation has to involve a proton at C-3 in the case of the β-keto ester **10**, while no such mobilization is necessary with the β-keto acid **7**, where the molecule already exists with a chelated pseudo B ring structure owing to the proton available at the carboxylic acid function.

It should be mentioned that it was shown earlier[14] that a C/D trans bicyclic intermediate can be obtained *via* hydrogenation of the copper chelate of a bicyclic β-keto ester, (±)-5,6,7,7a-tetrahydro-7aβ-methyl-1,5-dioxo-4-indanecarboxylic acid ethyl ester.[15] This compound, however, was different from our β-keto ester **10**, since it appeared to be fully enolized, and it had a carbonyl oxygen rather than a *tert*-butyl ether function at the C-1 position.

It has also been reported, after the conclusion of our experimental work, that hydrogenation of the above-mentioned fully enolized β-keto ester gives, even without copper chelate formation, the desired C/D trans β-keto ester, although in a considerably lower (64%) yield.[15]

It has also been known that hydrogenation of a $\Delta^{14(15)}$ double bond (steroidal numbering) in a BCD tricyclic derivative with an aromatic B ring and a 17-hydroxyl group yields the desired C/D trans-fused system.[16] The analogy with the hydrogenation of the pseudo B ring containing β-keto esters is apparent.

It should finally be pointed out that, although the trans β-keto ester **13** did not give a ferric chloride test to indicate enolization, its sodium enolate could be formed with 0.01 *N* sodium methoxide in methanol at room temperature, as indicated by uv spectroscopy [λ_{max} 275 nm (ε 13,050)]. This was important in view of the desire to use this compound as a building block in a steroid total synthesis. The results of this investigation will be the topic of the accompanying publication.[17]

Experimental Section[18]

(±)-3aα,4,7,7a-Tetrahydro-1β-hydroxy-7aβ-methyl-5(6*H*)-indanone (2).—Catalytic hydrogenation of **1a** (1.66 g) was carried out in the presence of 0.2 g of 5% Pd/$CaCO_3$ in 50 ml of absolute ethanol at 1 atm pressure and 23°. Hydrogen uptake ceased after 45 min. The solution was filtered and evaporated *in vacuo* to give 1.63 g (97%) of the crude cis hydrogenation product, mp 81–90°, 88.5% pure by vpc. An analytical sample was prepared by preparative tlc and recrystallization from petroleum ether (bp 60–70°), followed by sublimation at 90° (0.015 mm): mp 93.5–95°; ir 3620, 3350–3550 (OH), and 1712 cm^{-1} (C=O); nmr δ 1.17 (s, 3, 7aβ-CH_3), 2.20 (s, OH), and 3.86 ppm (t, $J_{1H,2H}$ = 4.5 Hz, CHOH).

Anal. Calcd for $C_{10}H_{16}O_2$: C, 71.39; H, 9.59. Found: C, 71.46; H, 9.44.

General Procedure for the Catalytic Hydrogenation of 1b.—Hydrogenations were carried out at 1 atm pressure and 20° with a 0.5% solution of **1b** using a 1:10 catalyst to substrate ratio. Hydrogenation was stopped after the uptake of 1 mol of hydrogen and the solution was filtered and evaporated *in vacuo*. The crude hydrogenation product was subjected to hydrolysis (*cf.* Table I).

General Procedure for the Hydrolysis to the Cis (2) and Trans (3) Reduction Products.—The crude hydrogenation product was stirred and refluxed for 6 hr with a 1:1 mixture of tetrahydrofuran and 2 *N* aqueous HCl under nitrogen. It was cooled in an ice bath and neutralized with 5 *N* aqueous NaOH, and the solvent was evaporated *in vacuo*. The residue was extracted with ethyl acetate and with ether. The combined extract was washed with a saturated aqueous NaCl solution and dried (Na_2SO_4). Evaporation of the solvent *in vacuo* gave a mixture of **2** and **3**, which was analyzed by vpc and nmr (*cf.* Table I).

(±)-3aα,4,7,7a-Tetrahydro-1β-hydroxy-7aβ-methyl-5(6*H*)-indanone (3). A. From the Bicyclic *tert*-Butyl Ether 1b.—Hydrogenation of **1b** (5.0 g) in *n*-hexane with 5% Pd/C catalyst followed by hydrolysis gave 3.48 g of a mixture of **2** and **3**. This was repeatedly subjected to vapor phase chromatography in 40-mg portions on a Barber-Coleman Model 5072 instrument with flame detection and a split ratio of 5:95. The column was a 4 ft × 12 mm (i.d.) glass column with 20% Carbowax 20M on 60–80 mesh Chromosorb P. Nitrogen flow was 200 cc/min and the temperature was held at 200°. By this technique 0.22 g (6.3%) of **3** (96% pure by analytical vpc) was obtained as an oil: ir 3620 (OH), 3300–3550 (associated OH), and 1715 cm^{-1} (C=O); nmr δ 1.02 (s, 3, 7aβ-CH_3), 2.28 (s, 1, OH), and 3.78 ppm (t, $J_{1H,2H}$ = 4.5 Hz, CHOH).

Anal. Calcd for $C_{10}H_{16}O_2$: C, 71.39; H, 9.59. Found: C, 71.11, H, 9.32.

B. From the Trans Bicyclic β-Keto Acid 8.—Compound **8** (1.34 g of 93.7% purity) was hydrolyzed and decarboxylated by heating it at reflux under nitrogen for 6 hr in a mixture of 2.5 ml of tetrahydrofuran and 2.5 ml of 2 *N* aqueous HCl. The solution was neutralized with 2 *N* aqueous NaOH and evaporated *in vacuo*. The residue was extracted with ether, and the extract was washed with a small amount of saturated aqueous NaCl solution, dried (Na_2SO_4), and evaporated *in vacuo* to give 838 mg of the trans keto alcohol **3** as a waxy solid, mp 41–42°. The compound was shown by ir and nmr to be identical with the sample described under A.

C. From the Hydroxy β-Keto Acid 9.—The trans compound **9** (17.3 mg) was decarboxylated by heating it at reflux in 1.5 ml of toluene for 30 min under nitrogen. The solvent was evaporated *in vacuo* to give 13.7 mg of **3** (95.5% pure by vpc), which was identified by ir and nmr spectroscopy.

(±)-3aα,4β,5,6,7,7a-Hexahydro-1β-hydroxy-7aβ-methyl-5-oxo-4a-indancarboxylic Acid (9).—The trans β-keto acid **8** (246 mg) was suspended in 6 ml of concentrated HCl and stirred for 24 hr under nitrogen at 20°. The resulting solution was evaporated *in vacuo* at 30° to give a crude solid. This was triturated with ether to give 182 mg (93%) of the hydroxy β-keto acid **9**, mp 102–104° dec. Recrystallization from ether gave 112.5 mg of analytically pure **9**: mp 123° dec; ir (KBr) 3350 and 2500–2750 (OH), 1730 (C=O of acid), and 1700 cm^{-1} (C=O); nmr (acetone) δ 1.09 (s, 3, 7aβ-CH_3) and 3.38 ppm (d, $J_{3aH,4H}$ = 13 Hz, -CHCOOH).

Anal. Calcd for $C_{11}H_{16}O_4$: C, 62.25; H, 7.60. Found: C, 62.44; H, 7.40.

(±)-3aα,4,7,7a-Tetrahydro-7aβ-methyl-1,5(6*H*)-indandione (5).—The trans keto alcohol **3** (250 mg) was dissolved in 15 ml of acetone and oxidized with 0.48 ml of 8.0 *N* CrO_3–H_2SO_4 while stirring at 0° for 10 min. The reaction was quenched with 30 ml of ice–water, and the solvent was evaporated *in vacuo*. The residue was extracted with ethyl acetate, and the extract was washed with $NaHCO_3$ and NaCl solution, dried (Na_2SO_4), and evaporated *in vacuo* to give an oily crude product.

A. Isolation of 5 by Preparative Tlc.—Preparative tlc of this crude product on 8 in. × 8 in. × 1 mm thick silica gel plates with

(14) G. Stork, private communication.

(15) G. Nominé, G. Amiard, and V. Torelli, *Bull. Soc. Chim. Fr.*, 3664 (1968).

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(18) All melting points were determined in a Thomas-Hoover melting point apparatus and are corrected; unless otherwise noted all uv spectra were taken in ethyl alcohol; ir spectra were taken in absolute chloroform; nmr spectra were taken in $CDCl_3$ on a Varian A-60 or HA-100 spectrometer with tetramethylsilane as an internal standard; analytical vpc was performed on an F & M Model 810 instrument in the flame mode using a 6 ft × 0.25 in. aluminum column with 1% PEG 4000 MA on 60–70 mesh Anakrom ABS with nitrogen flow of 100 cc/min and programmed temperature.

1:1 benzene–ethyl acetate gave 210 mg of the desired crystalline material **5**. Crystallization from a small amount of ether gave 131 mg of pure **5**: mp 52.5–53° (lit.[2b] mp 52–53°); ir 1740 (five-ring C=O), and 1712 cm^{-1} (six-ring C=O); nmr, *cf.* Table II.

B. Isolation of 5 by Preparative Vpc.—The crude oxidation product (68 mg) was subjected to preparative vpc in 14-mg aliquots on a Barber-Coleman Model 5072 instrument with flame detection and a split ratio of 5:95. The column was a 6 ft × 6 mm (i.d.) glass column with 2% Carbowax 20M + 2% KOH on 20–30 mesh Chromosorb A. Nitrogen flow was 200 cc/min; temperature was held at 170°. Fractionation gave 43 mg (63%) of **5**. The compound was shown by ir and nmr to be identical with the sample described under A.

(±)-1β-*tert*-Butoxy-5,6,7,7a-tetrahydro-7aβ-methyl-5-oxo-4-indancarboxylic Acid (7).—To a 53% dispersion of NaH in mineral oil (1.03 g), which had been washed with anhydrous ether and dried under nitrogen, was added 45 ml of DMSO (distilled from calcium hydride). The mixture was stirred at 20°, and a solution of the enone **1b** (5.0 g) in 45 ml of dry DMSO was added at once. The mixture was stirred under nitrogen until hydrogen evolution ceased (*ca.* 4 hr). The DMSO was then distilled under high vacuum with a 75° bath. The residue (conjugate anion of **1b**) was dissolved in 90 ml of anhydrous ether, and added as rapidly as possible (*ca.* 2 min) to a 1-l. flask containing a thick slurry of anhydrous solid CO_2 stirred in 225 ml of anhydrous ether. The reaction mixture was rapidly stirred for 6 hr with a Dry Ice–methanol cooling bath and was then allowed to stand at 20° for 16 hr. The ethereal solution was extracted with 250 ml of 0.02 *N* aqueous NaOH while stirring under nitrogen for 1 hr. The aqueous layer was separated, and the ether layer was washed two more times with water. The ethereal solution was dried (Na_2SO_4) and evaporated *in vacuo* to give 3.14 g (62.8%) of unchanged starting material (**1b**). The aqueous solution was filtered from a small amount of impurity and was then carefully acidified at ice-bath temperature with 2 *N* aqueous HCl to pH 2.5. It was then extracted two times with benzene and once with ether. The combined extract was washed with saturated NaCl solution, dried (Na_2SO_4), filtered, and evaporated *in vacuo* to give 2.14 g (35.8%) of the unsaturated bicyclic β-keto acid **7** as a dry solid, mp 153–160° dec. An analytically pure sample of **7** was obtained by crystallization from acetone: mp 159.5° dec; uv 249 nm (ε 9800); ir, *cf.* discussion; nmr δ 1.20 ppm [s, 12, $-C(CH_3)_3$ and 7aβ-CH_3].

Anal. Calcd for $C_{15}H_{22}O_4$: C, 67.64; H, 8.33. Found: C, 67.63; H, 8.62.

(±)-1β-*tert*-Butoxy-3aα,4β,5,6,7,7a-hexahydro-7aβ-methyl-5-oxo-4-indancarboxylic Acid (8).—The unsaturated β-keto acid **7** (1.84 g) was dissolved in 92 ml of ethanol and hydrogenated in the presence of 184 mg of 10% Pd/$BaSO_4$ at 1 atm pressure and 20°. The theoretical amount of hydrogen was taken up in 20 min. The solution was filtered and evaporated *in vacuo* to give 1.81 g (97.9%) of **8**, mp 107.5–109° dec. Vpc indicated a 93.7% trans and 5.1% cis isomer ratio. This grade of compound was used in subsequent operations. An analytically pure sample of **7** was obtained by crystallization from ether: mp 114–114.5° dec; ir (10% piperidine in absolute $CHCl_3$) 1705 (C=O) and 1630, 1585, and 1390 cm^{-1} (COO^-); nmr δ 1.03 (s, 3, 7aβ-CH_3), 1.15 [s, 9, $-C(CH_3)_3$], and 3.38 ppm (d, $J_{3aH,4H}$ = 13 Hz, –CHCOOH).

Anal. Calcd for $C_{15}H_{24}O_4$: C, 67.13; H, 9.02. Found: C, 66.95; H, 9.09.

(±)-1β-*tert*-Butoxy-5,6,6,7a-tetrahydro-7aβ-methyl-5-oxo-4-indancarboxylic Acid Methyl Ester (10).—The unsaturated β-keto acid **7** (134 mg) was suspended in 5 ml of ether. The suspension was cooled to 0°, and 7.6 ml of a diazomethane solution in ether (0.076 mmol/ml) was added dropwise with stirring. After 10 min the solution was evaporated *in vacuo* to give 141 mg (99.4%) of the methyl ester **10**, mp 73–76°. Crystallization from petroleum ether (bp 30–60°) gave analytically pure **10**: mp 76.5–77°; uv 240 nm (ε 10,500); ir 1735 (ester C=O) and 1675 cm^{-1} (unsaturated C=O); nmr δ 1.17 (s, 3, 7aβ-CH_3), 1.18 [s, 9, $-C(CH_3)_3$], and 3.80 ppm (s, 3, CO_2CH_3).

Anal. Calcd for $C_{16}H_{24}O_4$: C, 68.54; H, 8.63. Found: C, 68.41; H, 8.92.

(±)-1β-*tert*-Butoxy-3aα,4β,5,6,7,7a-hexahydro-7aβ-methyl-5-oxo-4α-indancarboxylic Acid Methyl Ester (13). A. From the Trans β-Keto Acid 8.—Compound **8** (50 mg) was dissolved in 1.0 ml of ether. The solution was cooled to 0°, and 1.05 ml of a solution of diazomethane in ether (0.19 mmol/ml) was added dropwise with stirring. After 15 min the solution was evaporated *in vacuo* to give 52.2 mg (99.2%) of the β-keto ester **13**, mp 112.5–113.5°. Crystallization from ether–petroleum ether gave analytically pure **13**: ir 1743 (ester C=O) and 1710 cm^{-1} (C=O); nmr δ 0.99 (s, 3, 7aβ-CH_3), 1.12 [s, 9, $-C(CH_3)_3$], 3.34 (d, $J_{3aH,4H}$ = 13 Hz, $-CHCO_2CH_3$), and 3.69 ppm (s, 3, CO_2CH_3).

Anal. Calcd for $C_{16}H_{26}O_4$: C, 68.03; H, 9.28. Found: C, 68.09; H, 9.49.

B. By the Catalytic Hydrogenation of 10.—The bicyclic unsaturated β-keto ester **10** (54.4 mg) was dissolved in 2.7 ml of absolute ethyl alcohol, and hydrogenated in the presence of 18.2 mg of 10% Pd/$BaSO_4$ catalyst at 1 atm pressure and 21°. Hydrogen uptake ceased after 15 min. The solution was filtered and evaporated *in vacuo* to give 56 mg of a crude mixture (**12** and **13**, as indicated by uv and ir spectroscopy). A sample after standing at 20° for 16 hr had mp 104–109° and ir and nmr spectra which were superimposable with those of an authentic sample of **13** prepared from **8** (*cf.* also discussion).

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Registry No.—**1a**, 17553-80-9; **1b**, 39765-89-4; **2**, 40682-65-3; **3**, 27504-54-7; **4**, 25222-16-6; **5**, 33205-64-0; **7**, 27510-27-6; **8**, 27504-53-6; **9**, 27801-96-3; **10**, 27504-57-0; **13**, 27504-58-1.