404. *Lactones of Hydrogenated 8-Hydroxy-5-oxonaphthoic Acids.*

By Sunil K. Roy and D. M. S. Wheeler.

The *cis*-fused keto-lactones (II) and (IV) have been prepared, and have been epimerised to the *trans*-compounds (III), (VI), and (V). These results are discussed. A claim by other workers to have synthesised the lactone (II) is shown to be incorrect.

In our studies on the development of general routes for the syntheses of diterpenoid acids, we have hydrogenated the keto-lactone (I) [1] to the corresponding dihydro-compound (II). Protiva and his co-workers [2] recently claimed to have effected the same conversion by incubating compound (I) with yeast. As the properties of our reduction product (m. p. 117—118°) did not agree with those of Protiva's (m. p. 129—130°), we have prepared the saturated keto-lactone (IV) and have studied the epimerisation of the *cis*-compounds (II) and (IV) to the corresponding *trans*-fused materials. We have concluded that Protiva's assignment of structure (II) is not correct. Some of the compounds made in this work will be useful in our synthetic work in the diterpene series.

Results.—Hydrogenation of the diunsaturated lactone (I) [1] in the presence of rhodium yielded a dihydro-derivative, which on the basis of its method of preparation, and its ultraviolet and infrared spectra, has structure (II). When the hydrogenation was carried out in the presence of palladium an acid was obtained in addition to lactone (II); presumably the acid arises from hydrogenolysis of the allylic lactone grouping in (I). Protiva and his co-workers [3] have shown that hydrogenolysis of the lactone occurs when the alcohol (X) related to (I) is reduced in the presence of palladium or platinum. Our results indicate that, as might be expected, the presence of the ketone group in conjugation with the 6,7-double bond decreases the extent of the cleavage.

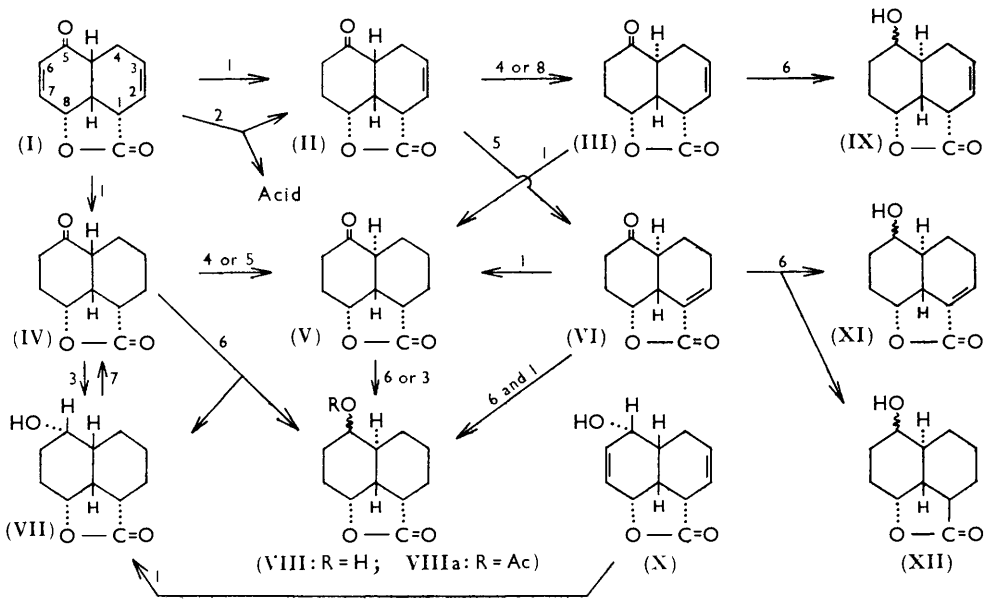
Further hydrogenation of the monounsaturated lactone (II) or addition of two mol. of hydrogen to the diunsaturated lactone (I) gave a tetrahydro-derivative of the latter. The presence of the ketone and γ-lactone groups in this compound is confirmed by its ultraviolet and infrared spectra. We assign structure (IV) to it.

The epimerisations of the keto-lactones (II) and (IV) were carried out in acidic and basic media. The infrared and ultraviolet spectra of the product obtained by heating the former compound in the presence of acid indicate that its double bond has not migrated during the reaction. This suggests that the isomer has the structure (III). Chromatography of the lactone (II) on an alumina column also led to the isomer (III). When the lactone (II) was heated in the presence of base and the lactone ring subsequently re-formed, the product was different from the earlier one (III); it had an absorption maximum in the ultraviolet region at 220 mμ and so we assigned structure (VI) to it.[4] The infrared spectrum of this compound has a band at 1760 cm.$^{-1}$, which is within the absorption region of a conjugated γ-lactone; the γ-lactone bands of the other compounds in this series with the exception of (XI), a reduction product of (VI), are at shorter wavelengths. Treatment of the *trans*-compound (III) with base also led to the isomer (VI). The saturated keto-lactone (IV) was isomerised by treatment with either acid or base to a product, which had analysis and spectra consistent with the structure (V). Compound (V) was also obtained by hydrogenation of either of the monounsaturated products (III) or (VI). The yields of the *trans*-epimers were a little better when the epimerisations were done under acidic rather than basic conditions. The position of equilibrium in these reactions must strongly favour the *trans*-compounds; heating acidic solutions of the *trans*-lactones (III), (V), or

[1] Woodward, Bader, Bickel, Frey, and Kierstead, *Tetrahedron*, 1958, **2**, 1.
[2] Protiva, Čapek, Jílek, Kakáč, and Tadra, *Coll. Czech. Chem. Comm.*, 1961, **26**, 1537.
[3] Adlerová, Bláha, Borovička, Ernest, Jílek, Kakáč, Novák, Rajšner, and Protiva, *Coll. Czech. Chem. Comm.*, 1960, **25**, 221; Rajšner, Kakáč, and Protiva, *ibid.*, 1961, **26**, 91.
[4] Novák, Jílek, Kakáč, and Protiva, *Tetrahedron Letters*, 1959, No. 5, 10.

(VI) or basic solutions of (V) or (VI) yielded only the starting materials in every case, and no trace of any *cis*-compound.

The reductions of the compounds (II), (III), (IV), (V), and (VI) with sodium borohydride have also been studied. In general these gave only poor yields of crystalline products. The *trans*-compounds, (III), (V), and (VI), gave the corresponding alcohols (IX), (VIII), and (XI). In addition the saturated hydroxy-lactone (VIII) was obtained from (V) by catalytic hydrogenation under acid conditions and by hydrogenation of the crude material from a borohydride reduction of (VI). The structures (IX), (VIII), and (XI) are consistent with the infrared spectra of these compounds; the evidence is not sufficient to determine the stereochemistry of the 5-hydroxyl group in any of the alcohols. In the reduction of the keto-lactone (VI) a second alcohol was obtained with (XI). This second compound is assigned structure (XII), because its infrared spectrum shows the presence of a saturated γ-lactone, its ultraviolet spectrum shows no maximum in the 220—230 mμ region, and its analysis indicates it is a tetrahydro-derivative of (VI). If we assume that the stereochemistry of the reduction of the ketone groups in (V) and (VI) should be the same, the stereochemistry at position 1 in (XII) must be as indicated; the alternative possibility would be (VIII).



Reagents: 1, H_2–Rh. 2, H_2–Pd. 3, H_2–PtO_2. 4, MeOH–HCl. 5, MeOH–KOH. 6, $NaBH_4$. 7, CrO_3. 8, Al_2O_3.

The reduction of the *cis*-compound (IV) gave two products: the corresponding *cis*-alcohol (VII) and the *trans*-alcohol (VIII). The latter, presumably, arises from (V) which must be formed from (IV) under the conditions of the reaction. The hydroxy-lactone (VII) was also obtained by hydrogenation of the keto-lactone (IV) under acid conditions and by hydrogenation of the unsaturated hydroxy-lactone (X) [1] in the presence of rhodium. Oxidation of this hydroxy-lactone (VII) with the Jones reagent [5] gave back the keto-lactone (IV). These observations establish the structure and stereochemistry of product (VII). They also indicate that in all these reactions the reagents attack from the convex face of the *cis*-decalin.[1] Reduction of the monounsaturated keto-lactone (II)

[5] Djerassi, Engle, and Bowers, *J. Org. Chem.*, 1956, **21**, 1547.

with sodium borohydride led to only one isolable product, the *trans*-alcohol (IX). Thus lactone (II), like (IV), is partially epimerised under the conditions of the reduction. When the non-crystalline material from the reduction of lactone (II) was hydrogenated, the alcohol (VII) was obtained. This shows that the reduction mixture from (II) contained some of the *cis*-alcohol corresponding to (II) as well as the *trans*-alcohol (IX).

Discussion of Results.—We consider that in the *trans*-compounds (III), (V), and (VI) the 8-oxygen atom is attached axially and that the carbonyl group attached to the 1-carbon atom is also attached axially in (III) and (V). It does not seem likely that the stereochemistry at position 8 could have been altered during the epimerisations of lactones (II) and (IV) under basic conditions. The epimerisation of the saturated compound (IV) under acidic and basic conditions led to the same product (V), which shows that position 8 in (IV) is not affected by the acidic conditions.[6] The *trans*-dihydro-compounds (III) and (VI) gave the same product (V) on hydrogenation, which indicates that the stereochemistry at C-8 has not been changed during the epimerisation of (II) into (III). Our experiments showed that under acid conditions the αβ-unsaturated lactone (VI) did not rearrange to the βγ-unsaturated isomer (III). Since the latter also did not rearrange to the former under acid conditions we conclude that during the epimerisation (II) ⟶ (III) the 1-proton was not removed and so the stereochemistry at position 1 was not affected during epimerisation of the ring junction. As lactone (III) can be hydrogenated to lactone (V) the stereochemistry at position 1 in the latter must also remain unchanged in its formation from the *cis*-isomer (IV). These arguments are supported by the hydrogenation of the *trans*-lactone (VI) to (V). In (VI) it would be expected that the attack of hydrogen would be less hindered from the side of the molecule away from the 8-oxygen atom, thus leading to structure (V).

Therefore the attachment of the lactone ring in the *trans*-series is axial-axial which destabilises the *trans*-system. The destabilising effect should be more marked in the base-catalysed epimerisations during which the lactone ring is opened, and both rings of the *cis*-decalin are chairs, than in acid-catalysed epimerisations during which the lactone ring is closed and one or both of the *cis*-decalin rings must be in the boat form. Thus epimerisations should be more favoured under acid than under basic conditions, which is what we observed.

The results of this work together with our earlier studies,[7] establish that compounds derived from the Diels–Alder adduct [1] from vinylacrylic acid and *p*-benzoquinone can be selectively epimerised at both the 4a- and the 8a-centre. In addition the structure (XII), which we have suggested for one of our products is interesting because it involves a skew-type lactone between C-1 and C-8 of a *trans*-decalin system. Further work is in progress on the synthesis of this type of lactone.

As indicated above, the properties of our reduction product (II) differ from those of a compound (A) to which Protiva *et al.*[2] assigned the same structure. We consider that our synthesis is unambiguous and that their structure is incorrect. We have difficulty in suggesting a structure for compound A. Its infrared spectrum shows that it contains an unconjugated γ-lactone and an unconjugated ketone group. This eliminates (VI) as a possible structure. We think it probable that in Protiva's reaction the reduction of the 6,7-double bond was followed by an isomerisation. The compound (A) was reduced by sodium borohydride to a dihydro-compound (B); this dihydro-material and also A were reduced catalytically to C, a tetrahydro-derivative of A. Neither compound B nor C corresponds to any of the reduction products (VII), (VIII), (IX), (XI), or (XII) that we have obtained in our work. Further if compound A were a double-bond isomer of (II) or (III) we should expect that C would be one of the hydroxy-lactones (VII) and (VIII).

Protiva *et al.* reported that all their compounds were racemates. This implies that the reduction of the double bond in (I) and (as we suggest) a subsequent isomerisation

[6] Cf. Barton, *J. Org. Chem.*, 1950, **15**, 466.
[7] Wheeler and Wheeler, *J. Org. Chem.*, 1962, **27**, 3796.

effected by the yeast took place to an equal extent with both enantiomers. Usually microbiological reactions are more stereospecific.[8] Our work suggests that the reduction of lactone (I) by yeast deserves further investigation.

Experimental

Infrared spectra were determined for chloroform solutions with Perkin-Elmer (models 21 and 137) spectrophotometers. Ultraviolet spectra were measured for methanol solutions on a Cary (model 12) spectrophotometer. The light petroleum had b. p. 60—80°. Florisil was 60—100 mesh.

cis-1,4,4a,5,6,7,8,8a-*Octahydro*-8α-*hydroxy*-5-*oxonaphthalene*-1α-*carboxylic Acid Lactone* (II).*—A solution of *cis*-1,4,4a,5,8,8a-hexahydro-8α-hydroxy-5-oxonaphthalene-1α-carboxylic acid lactone (I) (0·1 g.), prepared by the method of Woodward *et al.*,[1] in ethyl acetate (25 ml.) was hydrogenated in the presence of 5% rhodium–charcoal (15 mg.) (1 mol. uptake in 2—3 min.). The crude product was chromatographed on Florisil (5 g.), and the lactone (II) (95 mg.) was eluted in benzene as a solid, m. p. 105—113°, which crystallised from ether or ether–light petroleum in needles, m. p. 117—118°, $\lambda_{max.}$ 285 mμ (ε 29), $\nu_{max.}$ 1773 (γ-lactone), 1723 (saturated cyclohexanone), 1362, 1300, 1152, and 995 cm.$^{-1}$ (Found: C, 68·8; H, 6·3; O, 24·9. $C_{11}H_{12}O_3$ requires C, 68·7; H, 6·3; O, 25·0%).

The same reduction (in ethyl acetate solution) was also carried out in the presence of palladium–charcoal. The filtrate from the reaction was washed with dilute aqueous sodium carbonate, and evaporation of the ethyl acetate yielded the dihydro-lactone (II) (40% crude yield) which after crystallisation from ether had m. p. 117—118° (not depressed on mixing with material from the rhodium hydrogenation). Acidification of the sodium carbonate solution yielded an acid which was not purified.

Preparation of cis-*Decahydro*-8α-*hydroxy*-5-*oxonaphthalene*-1α-*carboxylic Acid Lactone* (IV).—The keto-lactone (I) (0·2 g.) in ethyl acetate (45 ml.) was hydrogenated in the presence of rhodium–charcoal (80 mg.). The uptake of hydrogen stopped after two mol. had been consumed. The crude product was chromatographed on Florisil (5 g.); the cis-*decahydro-lactone* (IV) (184 mg.) was obtained after elution in benzene–ether (2·5% of ether), as a solid (m. p. 91—95°), which crystallised from ether–light petroleum or ether in needles, m. p. 99—100°, $\lambda_{max.}$ 280 mμ (ε 34), $\nu_{max.}$ 1777 (γ-lactone), 1713 (saturated cyclohexanone), 1368, 1350, 1142, 1006, 977, and 963 cm.$^{-1}$ (Found: C, 67·8; H, 7·3; O, 24·6. $C_{11}H_{14}O_3$ requires C, 68·0; H, 7·3; O, 24·7%).

Epimerisation of cis-1,4,4a,5,6,7,8,8a-*Octahydro*-8α-*hydroxy*-5-*oxonaphthalene*-1α-*carboxylic Acid Lactone* (II).—(*a*) The *cis*-keto-lactone (II) (0·2 g.) was refluxed with methanolic hydrochloric acid (3 ml. of concentrated acid in 30 ml.) for 3 hr. The mixture was evaporated to dryness and the residue was extracted with ethyl acetate (100 ml.). The ethyl acetate solution was washed with saturated aqueous sodium chloride and dried (Na_2SO_4). The brown residue (183 mg.), obtained on evaporation of the ethyl acetate, was chromatographed on Florisil twice. Elution with benzene–ether (1% of ether for the first and 2·5% for the second column) yielded the trans-*lactone* (III) (112 mg.; m. p. 117—120°), which crystallised from ether in needles with m. p. 124° (81 mg.), $\lambda_{max.}$ 285 mμ (ε 30), $\nu_{max.}$ 1782 (γ-lactone), 1725 (saturated cyclohexanone), 1472, 1362, 1317, 1157, 1013, 1000, 979, and 957 cm.$^{-1}$ (Found: C, 68·75; H, 6·5; O, 24·9. $C_{11}H_{12}O_3$ requires C, 68·7; H, 6·3; O, 25·0%).

(*b*) The compound (III) was also obtained by chromatography of compound (II) on neutral alumina (Woelm, grade II).

(*c*) The keto-lactone (II) (0·2 g.) was refluxed in 5% methanolic potassium hydroxide (25 ml.) for 3 hr. The residue obtained on removal of solvent was dissolved in water (15 ml.). The aqueous solution was cooled to 0°, acidified to pH 2—3 with 5% hydrochloric acid, saturated with sodium chloride, and extracted with ethyl acetate (125 ml.). The ethyl acetate solution was washed with saturated aqueous sodium chloride and dried (Na_2SO_4). Removal of the

* For nomenclature see ref. 7. All the compounds reported are racemates.

[8] Tamm, *Angew. Chem.* (*Internat. Edn.*), 1962, **1**, 178.

solvent yielded an acid which was refluxed with benzene (25 ml.), acetic anhydride (1 ml.), and sodium acetate (0·1 g.) for 1½ hr. The benzene solution was washed with water and dilute aqueous sodium hydrogen carbonate and dried (Na_2SO_4). The residue, obtained on evaporation of the solvent, was chromatographed twice on Florisil (15 g. each time). Elution with benzene–ether (2·5% of ether each time) yielded trans-3,4,4a,5,6,7,8,8a-*octahydro*-8α-*hydroxy*-5-*oxonaphthalene*-1-*carboxylic acid lactone* (VI) (93 mg. m. p. 123—126°), which crystallised from ether in needles, m. p. 128—129° (67 mg.), $\lambda_{max.}$ 220 mμ (ε 9500), $\nu_{max.}$ 1760 (conjugated γ-lactone), 1717 (saturated cyclohexanone), 1677, 1370, 1332, 1142, 1000, 970, and 952 cm.$^{-1}$ (Found: C, 68·8; H, 6·2; O, 25·3%).

The m. p. of the epimer obtained by procedure (*c*) was depressed by addition of the product obtained in (*a*).

trans-*Decahydro*-8α-*hydroxy*-5-*oxonaphthalene*-1α-*carboxylic Acid Lactone* (V).—(*a*) A solution of the *cis*-keto-lactone (IV) (0·2 g.) in 5% methanolic potassium hydroxide (25 ml.) was refluxed for 3 hr. The reaction mixture was worked up in the same way as in the conversion of the keto-lactone (II) into its *trans*-epimer (VI) and the crude product was chromatographed on Florisil (28 g.). Elution with benzene–ether (1% of ether) afforded the trans-*lactone* (V), m. p. 109—112° (112 mg.), which crystallised from ether in needles, m. p. 112—114·5° (97 mg.). The compound analysed had m. p. 114—115°, $\lambda_{max.}$ 285 mμ (ε 38), $\nu_{max.}$ 1780 (γ-lactone), 1725 (saturated cyclohexanone), 1460, 1367, 1345, 1325, 1295, 1150, 1017, 983, and 890 cm.$^{-1}$ (Found: C, 68·3; H, 7·1; O, 24·7. $C_{11}H_{14}O_3$ requires C, 68·0; H, 7·3; O, 24·7%).

(*b*) The keto-lactone (IV) (0·2 g.) was refluxed for 3 hr. with methanolic hydrochloric acid (2·5 ml. of concentrated acid in 25 ml.). Most of the solvent was removed under reduced pressure and the crude product (187 mg.), which was isolated by extraction with ethyl acetate, was chromatographed on Florisil (30 g.), to yield the keto-lactone (V) (126 mg.; m. p. 109—112°) which crystallised from ether in needles, m. p. 113—115° (102 mg.) [not depressed by addition of (V) obtained by method (*a*); infrared spectrum identical].

(*c*) A solution of the keto-lactone (III) (30 mg.) in ethyl acetate (25 ml.) was hydrogenated in the presence of rhodium–charcoal. The product (21 mg.; m. p. 111—113°) (obtained after chromatography on Florisil) crystallised from ether–light petroleum in needles, m. p. 114—115°, and was identified as the lactone (V) by m. p., mixed m. p., and infrared spectrum.

(*d*) Similarly reduction of the *trans*-keto-lactone (VI) (28 mg.) yielded the keto-lactone (V) (20 mg. m. p. 110—113°), again identified by mixed m. p. and infrared spectrum.

Treatment of the Keto-lactones (III), (V), *and* (VI) *with Acid and Base.*—(*a*) The keto-lactone (III) (90 mg.), when refluxed with methanolic hydrochloric acid (2 ml. of concentrated acid in 20 ml.) for 1 hr., yielded only the starting material (73 mg.; m. p. 119—123°) which after crystallisation had m. p. 120—123° (62 mg.) and was identified by mixed m. p. and infrared spectrum.

(*b*) The *trans*-keto-lactone (III) (0·1 g.) was refluxed in 5% methanolic potassium hydroxide (30 ml.) for 1 hr. The mixture was worked up in the same way as in the epimerisation with base of the *cis*-keto-lactone (II), and the crude product was chromatographed on Florisil (5 g.). A solid (30 mg.), which was eluted in benzene–ether (2·5% of ether), crystallised in needles from ether with m. p. 123—125°. Mixed m. p. and infrared comparison identified the product as the *trans*-keto-lactone (VI).

(*c*) The product obtained by refluxing the keto-lactone (V) (0·12 g.) in methanolic hydrochloric acid (2 ml. of concentrated acid in 20 ml.) for 1 hr. was chromatographed on Florisil and only starting material (V), established by mixed m. p. and infrared spectrum, was recovered (97 mg., m. p. 110—113°; after one crystallisation 79 mg., m. p. 113—115°).

(*d*) The lactone (V) (0·1 g.) was refluxed with 5% methanolic potassium hydroxide (20 ml.) for 1 hr. Working up of the reaction mixture as in the preparation of (V) and chromatography of the product (83 mg.) on Florisil gave the starting material (V) (72 mg.; m. p. 112—115°; after one crystallisation m. p. 115—116°, 61 mg.), identified by m. p., mixed m. p., and infrared spectrum.

(*e*) The *trans*-ketone-lactone (VI) (50 mg.) was heated with methanolic hydrochloric acid (3 ml. of concentrated acid in 30 ml.) for 2 hr. and was then worked up as in (*c*). The oily product on chromatography on Florisil (5 g.) gave a solid, m. p. 121—127° (31 mg.). After crystallisation from ether this had m. p. 126—128° (20 mg.) and was identified as the starting material (VI) (mixed m. p. and infrared spectrum).

(*f*) The keto-lactone (VI) (50 mg.) was refluxed with 5% methanolic potassium hydroxide

(10 ml.) for 2 hr. Purification of the reaction product as in the preparation of (VI) afforded only unchanged starting compound (VI) (37 mg.) (m. p., mixed m. p., and infrared spectrum).

Reductions with Sodium Borohydride.—(*a*) A solution of the keto-lactone (III) (0·14 g.) in propan-2-ol (35 ml.) was stirred with sodium borohydride (0·17 g.) for 3 hr. The mixture was cooled to 0° and decomposed with glacial acetic acid (pH 3—4), and the solvent was removed under reduced pressure. The residue was dissolved in water (20 ml.), and the aqueous solution, saturated with sodium chloride, was extracted with ethyl acetate (100 ml.). The ethyl acetate solution was washed with aqueous sodium hydrogen carbonate, dried (Na_2SO_4), and concentrated. The semisolid residue (0·14 g.) was chromatographed on Florisil (12 g.). Elution with benzene–ether (1% of ether) gave sticky solid (62 mg.) which on crystallisation from ether–light petroleum gave trans-1,4,4a,5,6,7,8,8a-*octahydro*-5,8α-*dihydroxynaphthalene*-1α-*carboxylic acid γ-lactone* (IX) in colourless needles, m. p. 157—160° (27 mg.). These on further crystallisation from ether had m. p. 161—162°, $\nu_{max.}$ 3600, 3495, 1775 (γ-lactone), 1760sh, 1353, 1152, 1020, 995, 962, 952, and 925 cm.$^{-1}$ (Found: C, 68·2; H, 7·4; O, 24·7. $C_{11}H_{14}O_3$ requires C, 68·0; H, 7·3; O, 24·7%).

(*b*) A solution of the *trans*-keto-lactone (VI) (160 mg.) in propan-2-ol (30 ml.) was stirred at room temperature for 3 hr. with sodium borohydride (185 mg.). The mixture was worked up as in (*a*). The oily product (142 mg.) was chromatographed (twice) on Woelm alumina (grade III) and gave two fractions (A) (22 mg.) and (B) (37 mg.) on elution with benzene–ether (1% and 5% of ether, respectively). The fractions (A) and (B) were mixed with similar fractions (A, 21 mg., and B, 27 mg.) obtained from another experiment [starting with 120 mg. of (VI)]. Fraction (A) crystallised from ether–light petroleum to give trans-*decahydro*-5,8α-*dihydroxynaphthalene*-1β-*carboxylic acid γ-lactone* (XII) as needles, m. p. 148—149°, (8 mg.), $\nu_{max.}$ 3580, 3480, 1768 (γ-lactone), 1376, 1335, 1315, 1150, 1117, 1076, 1010, 980, 970, and 910 cm.$^{-1}$ (Found: C, 67·55; H, 8·1. $C_{11}H_{16}O_3$ requires C, 67·3; H, 8·2%). Fraction B also crystallised from ether–light petroleum to give trans-3,4,4a,5,6,7,8,8a-*octahydro*-5,8α-*dihydroxynaphthalene*-1-*carboxylic acid γ-lactone* (XI) as needles, m. p. 130—131° (8 mg.), $\lambda_{max.}$ 285 mμ (ε 7400), $\nu_{max.}$ 3580, 3480, 1756 (conjugated γ-lactone), 1450, 1372, 1350, 1332, 1315, 1282, 1148, 1112, 1005, 985, and 975 cm.$^{-1}$ (Found: C, 68·2; H, 7·4. $C_{11}H_{14}O_3$ requires C, 68·0; H, 7·3%).

In another experiment the keto-lactone (VI) (93 mg.) was treated with sodium borohydride in methanol for 3 hr., and the crude product was hydrogenated in the presence of rhodium. Chromatography on Florisil of the hydrogenation product gave material (52 mg.) which crystallised from ether–light petroleum with m. p. 112—113°, and was identified as the lactone (VIII) [see (*c*) below] by mixed m. p.

(*c*) The keto-lactone (V) (0·1 g.) was stirred in dry propan-2-ol (20 ml.) with sodium borohydride (0·2 g.) for 17 hr. at room temperature. The mixture was worked up as in (*a*) except that hydrochloric acid was added to the aqueous solution before the extraction with ethyl acetate. The partially solid product (81 mg.) was chromatographed on Florisil (8 g.) and trans-*decahydro*-5,8α-*dihydroxynaphthalene*-1α-*carboxylic acid γ-lactone* (VIII) (42 mg.) was eluted in benzene–ether (5% of ether). The lactone, crystallised from ether–light petroleum, had m. p. 112—113°, $\nu_{max.}$ 3600, 3480, 1770 (γ-lactone), 1455, 1387, 1370, 1350, 1325, 1295, 1147, 1112, 1017, 985, and 950 cm.$^{-1}$ (Found: C, 67·3; H, 8·1; O, 24·3. $C_{11}H_{16}O_3$ requires C, 67·3; H, 8·2; O, 24·5%).

The reduction of the keto-lactone (V) (0·1 g.) was also carried out in methanol solution and the alcohol (VIII) (76 mg.; m. p. 112—113°; identity established by mixed m. p.) was obtained after chromatography on Florisil.

The *acetate* (VIIIa) was formed from the alcohol (VIII) (50 mg.) by the acetic anhydride–sodium acetate method, followed by chromatography twice on Florisil. Elution with benzene–ether (2·5% of ether) gave the acetate (28 mg.) which crystallised from ether–light petroleum and from light petroleum in colourless plates, m. p. 98—99°, $\nu_{max.}$ 1775 (γ-lactone), 1737 (ester), 1457, 1377, 1350, 1325, 1150, 1117, and 962 cm.$^{-1}$ (Found: C, 66·0; H, 7·6; O, 26·6. $C_{13}H_{18}O_4$ requires C, 65·5; H, 7·6; O, 26·9%).

(*d*) The *cis*-keto-lactone (II) (0·2 g.) was reduced with sodium borohydride (0·24 g.) in propan-2-ol (30 ml.) for 3 hr. The mixture was worked up as above in (*a*) and a colourless oil (162 mg.) was obtained. Chromatography of this product on Florisil (14 g.) and elution with benzene–ether (10% of ether) gave an oily solid (40 mg.) which after crystallisation from ether

had m. p. 155—159° (5 mg.). It was identical with the reduction product (IX) of the *trans*-keto-lactone (III) (mixed m. p. and infrared spectra). Further elution of the column with benzene–ether and ether alone gave oily material. The total oily product (88 mg.) was catalytically reduced with rhodium–charcoal till the absorption of hydrogen stopped. The hydrogenated compound was chromatographed on Florisil (10 g.). Elution with ether gave the alcohol (VII), m. p. 141—143° (8 mg.), identified by mixed m. p. and infrared spectra.

(*e*) The keto-lactone (IV) (0·25 g.) in propan-2-ol (35 ml.) was stirred at room temperature with sodium borohydride (300 mg.) for 3 hr. The mixture was worked up as above in (*a*). The oily product (0·22 g.) was chromatographed on Florisil (18 g.). Elution with benzene–ether (2·5% of ether) gave a solid (35 mg.) which crystallised from ether–light petroleum in needles, m. p. 111—113° (14 mg.). It was identified as compound (VIII) by mixed m. p. and infrared spectrum. Further elution of the column with ether gave an oily solid (110 mg.) which on crystallisation from ether had m. p. 143—145° (32 mg.) and was identified as the compound (VII) (mixed m. p. and infrared spectrum).

Catalytic Reduction of the Keto-lactone (V).—Compound (V) (50 mg.) in methanol (30 ml.) containing concentrated hydrochloric acid (2 drops) was hydrogenated in the presence of a platinum catalyst. The crude product was chromatographed on Florisil and elution with benzene–ether (2·5% of ether) gave a solid (20 mg.) which separated from ether–light petroleum in crystals, m. p. 110—111°. These were identified as the alcohol (VIII) by mixed m. p. and comparison of infrared spectra.

Similar reduction of compound (V) without addition of mineral acid afforded an oil (no ketonic absorption, strong lactone band) which did not give a crystalline product even after repeated chromatography.

cis-*Decahydro*-5α,8α-*dihydroxynaphthalene*-1α-*carboxylic Acid γ-Lactone* (VII).—(*a*) A solution of the keto-lactone (IV) (0·2 g.) in methanol (30 ml.) containing two drops of concentrated hydrochloric acid took up hydrogen in the presence of platinum dioxide (60 mg.) during 5 hr. The product was chromatographed on Florisil (10 g.). Elution with benzene–ether (10% of ether) afforded the *lactone* (VII) as an oily solid (100 mg.) which after crystallisation from ether–light petroleum had m. p. 143—144° (62 mg.), $\nu_{max.}$ 3590, 3480, 1768 (γ-lactone), 1465, 1380, 1368, 1345, 1323, 1143, 982, 975, and 898 cm.$^{-1}$ (Found: C, 67·2; H, 8·1; O, 24·6. $C_{11}H_{16}O_3$ requires C, 67·3; H, 8·2; O, 24·5%).

(*b*) A solution of the hydroxy-lactone (X) (0·1 g.) in ethyl acetate on hydrogenation with rhodium–charcoal (25 mg.) rapidly absorbed 2 mol. of hydrogen. The product was repeatedly crystallised from ether to give the lactone (VII) (64 mg.), m. p. 142—144°, identified by mixed m. p. and infrared spectrum as identical with the hydrogenation product of the *cis*-keto-lactone (IV).

Oxidation of cis-*Decahydro*-5α,8α-*dihydroxynaphthalene*-1α-*carboxylic Acid γ-Lactone* (VII).—A solution of the alcohol (VII) (35 mg.) in acetone (distilled from potassium permanganate; 10 ml.) at 0° was oxidised in a nitrogen atmosphere with a solution of chromium trioxide in sulphuric acid.[5] The reaction mixture was diluted with water (30 ml.), and the crude product (isolated by extraction with ethyl acetate) on chromatography on Florisil afforded the lactone (IV) (20 mg.), m. p. 85—90°, which after crystallisation from ether–light petroleum had m. p. 97—98°, not depressed on addition of authentic (IV). The infrared spectrum of the oxidation product was identical with that of (IV).

This work has been supported by grants from the National Institutes of Health and the Petroleum Research Fund of the American Chemical Society. We also thank Mrs. Mary Vail for the preparation of starting materials at the University of South Carolina where this work was started.

UNIVERSITY OF NEBRASKA, LINCOLN, 8, NEBR., U.S.A. [*Received, November 5th*, 1962.]