drogenated to give a mixture of stereoisomeric α-amino-β-hydroxy acids which were separated into *dl*-threonine and *dl-allo*-threonine.

It has been found that oximino-acetoacetic ester reacts with hydrogen at 100 atm. to give a dihydropyrazine, while at 300 atm. pressure ethyl α-amino-β-hydroxybutyrate is the chief product.

The methods given make it possible to obtain *dl*-threonine in a 12 to 14% yield based on acetoacetic ester.[9]

[9] The freedom of *dl*-threonine from *dl-allo*-threonine is not adequately indicated by the m. p. of a sample. The complete separation and estimation of the proportion of the stereo-isomers can be made only through the use of biological assays.

MADISON, WISCONSIN RECEIVED APRIL 11, 1938

[CONTRIBUTION FROM THE DANIEL SIEFF RESEARCH INSTITUTE]

Synthesis of Polycyclic Compounds from Dicyclohexenyl

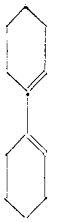
BY CH. WEIZMANN, ERNST BERGMANN AND T. BERLIN

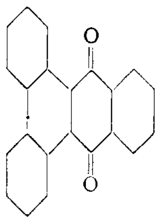
Dicyclohexenyl (I), which is easily accessible through dehydration of cyclohexanone–pinacol, has been used for diene syntheses by Gruber and Adams[1] and by Barnett and Lawrence.[2] Further applications of this synthetic method are reported herein. The condensation product between (I) and maleic anhydride could be dehydrogenated to form phenanthrene-9,10-dicarboxylic acid anhydride,[3] while lead tetraacetate effected dehydrogenation of the middle ring exclusively, giving 1,2,3,4,5,6,7,8-octahydrophenanthrene-9,10-dicarboxylic acid anhydride.[4] With phenylmagnesium bromide, phenanthrene-9,10-dicarboxylic acid anhydride reacted normally, yielding 9-benzoylphenanthrene-10-carboxylic acid.[5] It is isomeric with the *o*-(9-phenanthroyl)-benzoic acid, described by Weizmann and co-workers.[6] Both substances could be cyclized to form the same 1,2,3,4-dibenzanthraquinone (II), when their acid chlorides were heated in decahydronaphthalene solution in the presence of traces of phosphoric oxide.[7] The quinone proved identical with the substance obtained by Clar[8] in a more tedious manner.

Cinnamic acid, on heating with dicyclohexenyl (I), formed the condensation product (III). This, when treated with selenium, was converted into 9-phenylphenanthrene, while dehydrogenation with sulfur resulted in 9-phenylphenanthrene-10-carboxylic acid, which had been obtained before by Koelsch.[9] It is known that selenium in the course of dehydrogenation reactions tends to remove carboxyl groups more than sublimed sulfur.[10]

For the preparation of 9-phenylphenanthrene, the above method seems to be much more convenient than those described by Koelsch[9] and by E. and F. Bergmann.[11]

The reaction of dicyclohexenyl (I) and quinone[2] or α-naphthoquinone, was reinvestigated, our results being slightly different from those of previous authors. The condensation with quinone, carried out in a sealed tube at 140°, gave the true addition product (IV) and a second substance, containing two (or four) hydrogen atoms less (*e. g.*, V). The hydrogen has been transferred to quinone molecules which could be recovered in the form of hydroquinone. The same holds true for the case of α-naphthoquinone. Besides α-naphthohydroquinone, two products have been ob-


I



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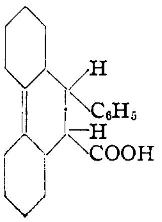
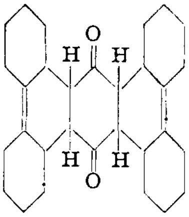
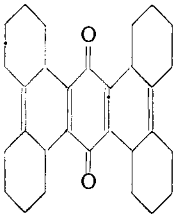


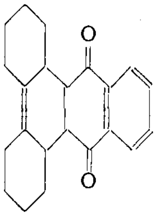
III



IV



V



VI

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[1] Gruber and Adams, THIS JOURNAL, **57**, 2555 (1935).

[2] Barnett and Lawrence, *J. Chem. Soc.*, 1104 (1935).

[3] The same product has been obtained recently through another method by Jeanes and Adams, THIS JOURNAL, **59**, 2608 (1937).

[4] Haworth and Richardson, *J. Chem. Soc.*, 633 (1935); 348 (1936); Haworth and Sheldrick, *ibid.*, 636 (1935); Haworth and Kelly, *ibid.*, 998 (1936).

[5] It has been described recently by Jeanes and Adams.[3]

[6] Weizmann and co-workers, *J. Chem. Soc.*, 1367 (1935).

[7] This method has been used before by Busso, Thesis, Berlin, 1930.

[8] Clar, *Ber.*, **62**, 350 (1929).

[9] Koelsch, THIS JOURNAL, **56**, 480 (1934).

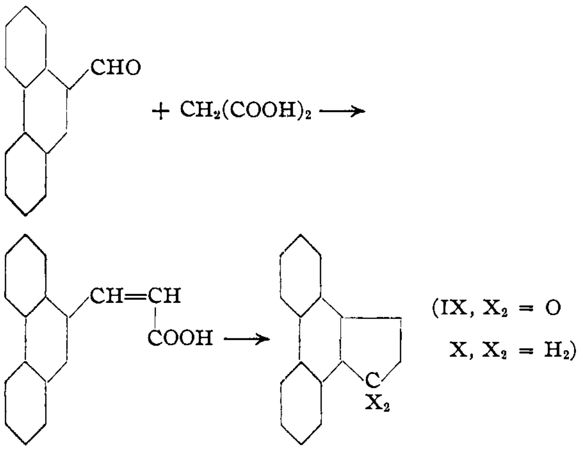
[10] Compare Linstead, "Annual Reports," 1936, pp. 296, 304.

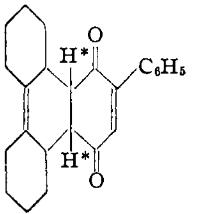
[11] E. and F. Bergmann, THIS JOURNAL, **59**, 1443 (1937).

tained, one had two, the other four, hydrogen atoms less than the expected condensation product (VI), which we were unable to isolate from the mixture. Barnett and Lawrence[2] have isolated it under somewhat different conditions and dehydrogenated it partly into one of our products.

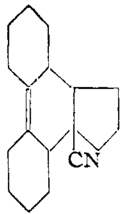
Experiments of Chuang and Han[12] and similar ones carried out in our laboratories have shown that mono-substituted benzoquinones condense with dienes only on the unsubstituted nuclear double bond.[13] Accordingly, phenylquinone gives on condensation with (I) a compound in the molecular ratio 1:1 (VII).[14] When the condensation is carried out in nitrobenzene solution, the product contains two hydrogen atoms less than VII. This is in accordance with similar observations made in our laboratories;[15] undoubtedly the bridge hydrogen atoms H* are removed in this way.

We have tried to synthesize 9,10-cyclopentenophenanthrene, starting with (I). This gave, on heating with 1-cyanocyclopentene-(1), the desired product (VIII), but the yield was so trivial that this way has been abandoned in favor of the following scheme

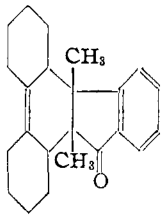




VII



VIII



XI

As the same synthesis has been reported recently by Bachmann and Kloetzel,[16] we give only some additional data in the experimental part of this paper.

2,3-Dimethylindone, finally, on heating with (I), gave a derivative (XI) of 1,2,3,4-dibenzofluorene; the carbonyl group could be reduced by Clemmensen's method; but dehydrogenation of the product so obtained gave no definite results.

Experimental

1,2,3,4-Dibenzoanthraquinone (II).—*o*-(9-Phenanthroyl)-benzoic acid[6] (5 g.) was treated for three hours with thionyl chloride (15 cc.); when its excess was distilled off, the residue crystallized on standing and was recrystallized from butyl acetate. The **chloride**, m. p. 165–66° (dec.), could not be obtained in analytically pure state. *Anal.* Calcd. for $C_{22}H_{15}O_2Cl$: C, 76.7; H, 3.8. Found: C, 79.0, 79.2; H, 4.4, 4.8. For cyclization, the chloride may be used without recrystallization: it (3 g.) was heated with decalin (15 g.) and phosphoric oxide (0.2 g.) for two hours to 180–190° and for one more hour to 210°. Then the solution was washed with dilute soda solution, dried and evaporated. The residue was purified by distillation in a vacuum (b. p. 275° at 1 mm.) and recrystallization from butyl acetate; m. p. 180°; yield 1 g. In some runs the interaction between 9-phenanthrylmagnesium bromide and phthalic anhydride, by which *o*-phenanthroylbenzoic acid is prepared, gave a neutral by-product. According to the analysis, it is **di-(9-phenanthryl)-phthalide.** It crystallizes in glistening prisms from ethyl malonate, m. p. 239°. *Anal.* Calcd. for $C_{36}H_{22}O_2$: C, 88.9; H, 4.5. Found: C, 88.7, 88.8; H, 4.7, 4.7.

Phenanthrene-9,10-dicarboxylic Acid Anhydride.—Dicyclohexenyl (I, 10 g.) and maleic anhydride (6 g.) were condensed according to Gruber and Adams.[1] The product is purified by trituration with carbon tetrachloride; m. p. 113–115°; yield 5.7 g. This dodecahydro compound (2 g.) is heated with sublimed sulfur (1.63 g.) to 245° for fifteen minutes. The greenish-brown solid is recrystallized from nitrobenzene, m. p. 312°; yield 0.7 g. *Anal.* Calcd. for $C_{16}H_8O_3$: C, 77.4; H, 3.2. Found: C, 76.6; H, 3.7.

Reaction with Phenylmagnesium Bromide.—Phenylmagnesium bromide solution (prepared from 0.05 g. of magnesium and 0.44 g. of bromobenzene) was added to the solution of the above anhydride (0.7 g.) in boiling xylene. The 9-benzoylphenanthrene-10-carboxylic acid, isolated as usual, was recrystallized from tetrachloroethylene, m. p. 218°. It gave the same green color reaction with concentrated sulfuric acid as the above quinone (II) and the isomeric keto acid.

1,2,3,4,5,6,7,8-Octahydrophenanthrene-9,10-dicarboxylic Acid Anhydride.—The dodecahydro product (1 g.) was suspended in glacial acetic acid (25 cc.) at 65° and lead tetraacetate (2.5 g.) added in small portions. The reaction product (0.25 g.) separated spontaneously and was recrystallized from acetic anhydride; long, slender needles, m. p. 305°. *Anal.* Calcd. for $C_{16}H_{16}O_3$: C, 75.0; H, 6.2. Found: C, 74.5; H, 6.7.

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(12) Chuang and Han, *Ber.*, **68**, 876 (1935).

(13) The statement of Adler [*Arkiv Kemi Mineral. Geol.*, **11B**, No. 49.1 (1935)] is in variance with these findings.

(14) The yellow color supports the formula (VII), although isomerization into a hydroquinone may have occurred.

(15) Compare Ch. Weizmann, E. Bergmann and L. Haskelberg, unpublished results: see also Clar, *Ber.*, **65**, 846 (1932); **69**, 1686 (1936).

(16) Bachmann and Kloetzel, THIS JOURNAL, **59**, 2207 (1937).

Dicyclohexenyl (25 g.) and **cinnamic acid** (22 g.) were heated to a temperature of 180° for five hours in a sealed tube. The reaction product (III) was triturated with methyl alcohol and recrystallized from the same solvent; m. p. 221°; yield 31.1 g. *Anal.* Calcd. for $C_{21}H_{26}O_2$: C, 81.3; H, 8.4. Found: C, 80.9; H, 8.7. The **ethyl ester**, prepared from (I) (10 g.) and ethyl cinnamate (11 g.) at 200° (four hours), was obtained as a viscous oil, b. p. 200–210° (0.2 mm.), which crystallized on trituration with methanol. From the same solvent, colorless prisms, m. p. 85–86°, were obtained. *Anal.* Calcd. for $C_{23}H_{30}O_2$: C, 81.7; H, 8.9; OC_2H_5, 13.3. Found: C, 80.3; H, 9.1; OC_2H_5, 14.4. Saponification, yielding the above acid, is accomplished only with enormous difficulty.

In several experiments the condensation product formed from ethyl cinnamate could not be induced to crystallize. Possibly an epimeric form of the above solid ester had been formed, although it was not obtained in a state of analytical purity. *Anal.* Calcd. for $C_{23}H_{30}O_2$: OC_2H_5, 13.3. Found: OC_2H_5, 12.4.

9-Phenylphenanthrene.—The condensation product (III, 2 g.) was heated with selenium powder (4 g.) for twenty-four hours to 300–320° in a sealed tube. The reaction product was extracted with ether and the solution, after washing with soda, distilled at 0.6 mm. The clear yellow oil so obtained crystallized spontaneously; after trituration with methyl alcohol, it was recrystallized from light petroleum (b. p. 40–80°); leaflets, m. p. and mixed m. p. with an authentic sample, 113°. For further identification it was converted into its dihydro derivative, m. p. 84°, by addition of lithium metal and subsequent hydrolysis. *Anal.* Calcd. for $C_{20}H_{16}$: C, 93.8; H, 6.2. Found: C, 94.0; H, 6.4.

9-Phenylphenanthrene-10-carboxylic Acid.—The condensation product (III, 5 g.) was heated with sulfur (5 g.) for ten minutes at 260°. The reaction product was dissolved in sodium hydroxide solution, filtered and acidified. The oil obtained was taken up with ether; after evaporation of this solvent, it solidified and was recrystallized from benzene, m. p. 189°, as given by Koelsch.[9] *Anal.* Calcd. for $C_{21}H_{14}O_2$: C, 84.0; H, 4.7. Found: C, 83.8, 84.3; H, 5.1, 5.2.

Dicyclohexenyl (I, 5 g.) and **benzoquinone** (1.7 g.; 0.5 mol) were heated at 140° for five hours in a sealed tube. On trituration with methyl ethyl ketone, the reaction product separated white crystals, from ligroin, m. p. 247°, yield 1.7 g., which according to the analysis were eicositetrahydrotetrabenzanthraquinone (IV). *Anal.* Calcd. for $C_{30}H_{40}O_2$: C, 83.3; H, 9.2. Found: C, 83.2, 83.0; H, 9.1, 9.0. The residue of the methyl ethyl ketone mother liquor was distilled *in vacuo* and could be divided into two fractions: (a) b. p. 145° at 8 mm., from xylene leaflets, m. p. 176°, which according to analysis and mixed m. p. were hydroquinone. (*Anal.* Calcd. for $C_6H_6O_2$: C, 65.5; H, 5.5. Found: C, 64.7; H, 5.8); (b) b. p. 260–290° at 2 mm., oil, solidifying on trituration with propyl alcohol; from ligroin, m. p. 297° (*Anal.* Calcd. for $C_{30}H_{36}O_2$: C, 84.1; H, 8.4; for $C_{30}H_{38}O_2$: C, 83.7; H, 8.8. Found: C, 83.8; H, 9.3). The product, m. p. 315° (dec.), obtained by Barnett and Lawrence[2] has not been observed, it should not be identical with our substance, m. p. 297°; as the analytical figures reported by the British authors point definitely to the formula $C_{30}H_{40}O_2$. Possibly it is stereoisomeric with the above substance, m. p. 247°.

Dicyclohexenyl (I, 7.2 g.) and **α-naphthoquinone** (7 g.) condensed at 150° (three hours, sealed tube). The solid was triturated with acetone and then separated by a very tedious fractional crystallization from butyl acetate, into two substances: (a) orange-yellow prisms, m. p. 254°, apparently identical with the decahydro-1,2,3,4-dibenzanthraquinone of Barnett and Lawrence (*Anal.* Calcd. for $C_{22}H_{22}O_2$: C, 83.0; H, 6.9. Found: C, 82.4; H, 7.2); (b) golden needles, m. p. 238–239°, octahydro-1,2,3,4-dibenzanthraquinone (*Anal.* Calcd. for $C_{22}H_{20}O_2$: C, 83.5; H, 6.3. Found: C, 83.3, 83.6; H, 6.6, 6.8).

The acetonic mother liquor of the crude product was evaporated and the residue recrystallized from toluene. A mixture of the above two substances and of fluffy needles was obtained, which were separated mechanically. The needles, after recrystallization from toluene, melted at 181° and were according to this and to the analysis α-naphthohydroquinone. *Anal.* Calcd. for $C_{10}H_8O_2$: C, 75.0; H, 5.0. Found: C, 74.8; H, 5.5.

Dicyclohexenyl (I, 3 g.) and **1-cyanocyclopentene-(1)**[17] (1.7 g.) were heated at 150–160° for eight hours in a sealed tube. Even after that prolonged heating, only part of the material had reacted, giving VIII, distilling at a bath temperature of 210–220° (1.5 mm.). *Anal.* Calcd. for $C_{18}H_{25}N$: C, 84.7; H, 9.8. Found: C, 84.0, 84.9; H, 9.5, 10.0.

Phenanthrene-9-aldehyde and its Acetal.—A mixture of 9-phenanthrylmagnesium bromide (from 3.25 g. of magnesium and 32.5 g. of 9-bromophenanthrene)[18] and ethyl orthoformate (37.5 g.) was refluxed for two hours and after removal of the solvents heated for six more hours on the water-bath, poured out into a mixture of ice and ammonium chloride and taken up with ether. The **acetal** boiled at 175° (0.75 mm.) (*Anal.* Calcd. for $C_{19}H_{20}O_2$: C, 81.4; H, 7.1. Found: C, 81.8; H, 7.4) and was heated with dilute hydrochloric acid for six hours at 150° in an oil-bath.[19] On cooling, the desired aldehyde crystallized spontaneously; it was purified by distillation; b. p. 200° (1.5 mm.); from methanol, m. p. 98°, yield 13 g.[20]

β-9-Phenanthryl-acrylic acid (from glacial acetic acid, needles, m. p. 255°) and β-9-phenanthrylpropionic acid (from 75% acetic acid, m. p. 178°) were prepared according to Bachmann and Kloetzel.[16] Cyclization by means of phosphoric oxide afforded 4,5,6,7-dibenzohydrindone-(1), which could not be isolated by the above-mentioned authors. Their method gave a mixture of 4,5,6,7-dibenzohydrindone-(1) (IX) and 5,6-benzo-2,3-dihydro-1-benzonaphthenone.

4,5,6,7-Dibenzo-1-hydrindone (IX).—β-(9-Phenanthryl)-propionic acid (5 g.) was dissolved in toluene (75 cc.) at 100° and phosphoric oxide (30 g.) added. The mixture was heated at 130° for two hours and decomposed with ice water and ether. The ethereal solution, on evaporation, left a solid residue, which was distilled at 0.01 mm., b. p. 190°. The yellow distillate solidified on trituration

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[17] A. H. Cook and Linstead, *J. Chem. Soc.*, 956 (1934).

[18] Bachmann, THIS JOURNAL, **56**, 1363 (1934).

[19] Compare Schlenk and Bergmann, *Ann.*, **479**, 55 (1930).

[20] Mosettig and van de Kamp, THIS JOURNAL, **55**, 2995 (1933); and Shoppee, *J. Chem. Soc.*, 37 (1933), have prepared the aldehyde by different methods. Compare, recently, Hewett, *ibid.*, 193 (1938).

with acetone and was recrystallized from propyl alcohol: beautiful needles, m. p. 164°; yield 1.5 g. *Anal.* Calcd. for $C_{17}H_{12}O$: C, 87.9; H, 5.2. Found: C, 88.0; H, 5.4.

9,10-Cyclopentenophenanthrene (X).—The ketone (1.5 g.) was reduced with amalgamated zinc wool (15 g.) and hydrochloric acid and the reaction product again purified by distillation in a high vacuum (0.02 mm.). At 180–190°, a yellowish oil distilled which crystallized spontaneously; from isopropyl alcohol as bent, long needles; m. p. 154°, yield 1.3 g. *Anal.* Calcd. for $C_{17}H_{14}$: C, 93.6; H, 6.4. Found: C, 93.0; H, 6.9. To the constitutional proof given by Bachmann and Kloetzel, nothing has to be added.

Dicyclohexenyl (I, 1.3 g.) and **phenylquinone**[21] (1.3 g.) were heated for four hours at 120–150° in a sealed tube. The product was distilled *in vacuo*, some unchanged dicyclohexenyl distilling over first (b. p. 130–140° at 9 mm.). The reaction product of b. p. 260–280° (1.25 mm.) solidified on standing with light petroleum (b. p. 40–80°) and was recrystallized from ligroin. At the beginning, black clusters of a quinhydrone appeared, then the yellow prisms of the condensation product (VII); after repeated crystallization from xylene, their m. p. was 207–208°. Concd. sulfuric acid gives a dark red solution. *Anal.* Calcd. for $C_{24}H_{26}O_2$: C, 83.2; H, 7.5. Found: C, 82.9, 82.8; H, 7.9, 7.6.

When the same condensation was carried out in nitrobenzene as diluent (6.5 cc.) (four hours of boiling), a dark resin was obtained, which was distilled twice *in vacuo* (b. p. 250–270° at 1.25 mm.), and then triturated with a mixture of methanol and acetone. From isopropyl alcohol it formed clusters, m. p. 140–141°, which gave the same color reaction with concd. sulfuric acid as the above product, but contained two hydrogen atoms less. *Anal.* Calcd. for $C_{24}H_{24}O_2$: C, 83.7; H, 7.0. Found: C, 83.5; H, 7.0.

Dicyclohexenyl (I, 4 cc.) and **2,3-dimethylindone**[22] (3 g.) were heated at 200° in toluene solution (10 cc.) for eight hours. Part of the reactants was recovered unchanged, the condensation product (XI) distilling at 165–175° (0.1 mm.). It formed a yellowish, extremely viscous oil, which could not be induced to crystallize. *Anal.* Calcd. for $C_{23}H_{28}O$: C, 86.3; H, 8.8. Found: C, 85.7, 85.8; H, 9.1, 9.2.

Clemmensen Reduction.—The condensation product (5 g.) was reduced with amalgamated zinc wool (50 g.) and half-concentrated hydrochloric acid. The reaction product was a colorless oil, which had the constant b. p. 240–245° (0.1 mm.); yield 2.3 g. *Anal.* Calcd. for $C_{23}H_{30}$: C, 90.2; H, 9.8. Found: C, 89.7; H, 10.3. The dehydrogenation, carried out at 300° (twenty-four hours) gave traces of a crystalline substance, from bromobenzene prisms, m. p. above 300°, and an oil, which was converted into the picrate in benzene solution; from propyl alcohol brownish-yellow clusters of needles, m. p. 210°. Due to the scarcity of material, the constitution of these two substances was not dealt with.

Summary

The condensation has been studied between dicyclohexenyl and maleic anhydride, cinnamic acid, benzoquinone, naphthoquinone, phenylquinone, 1-cyanocyclopentene-(1), and 2,3-dimethylindone, respectively. Several reactions of the condensation products have been investigated.

REHOVOTH, PALESTINE

RECEIVED MARCH 12, 1938

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[21] Kvalnes, THIS JOURNAL, **56**, 2478 (1934).

[22] Burton and Shoppee, *J. Chem. Soc.*, 1156 (1935).

[CONTRIBUTION FROM THE SCHOOL OF CHEMISTRY AND PHYSICS OF THE PENNSYLVANIA STATE COLLEGE]

Sterols. XXXIII. 3,11-Dihydroxy-12-ketocholanic Acid and Derivatives

BY RUSSELL E. MARKER AND ELMER J. LAWSON

Within the last year the presence of hydroxyl or carbonyl groups at C_{11} has been postulated repeatedly in certain naturally occurring steroids. The arguments for assigning hydroxyl or ketonic groups to this position have been chiefly steric, based on the lack of reactivity of the functional groups. Thus digoxigenin,[1] sarmentogenin,[2] the cortical substances[3] of Reichstein, Kendall, and Wintersteiner and Pfiffner, and uranetriol[4] from mares' pregnancy urine have been supposed to have hydroxyl or ketonic groups at C_{11}. Since the position of the unreactive functional group in these compounds has in every case been established by indirect evidence, it is highly desirable to prepare substances known to have functional groups in the 11-position.

In order to synthesize uranetriol, we have attempted to prepare 3(α),11-dihydroxycholanic acid. While the synthesis of this substance has not been accomplished, we wish to report certain experiments in this direction. We have prepared 3(α),11-dihydroxy-12-ketocholanic acid by bromination and subsequent hydrolysis of 3(α)-hydroxy-12-ketocholanic acid. This synthesis is similar to the synthesis of 11-hydroxy-12-ketocholanic acid from 12-ketocholanic acid by Wieland and Dane.[5]

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[1] Smith, *J. Chem. Soc.*, 1305 (1935).

[2] Tschesche and Bohle, *Ber.*, **69**, 783 (1936).

[3] See Reichstein in Ruzicka and Stepp. "Ergebnisse der vitamin- und Hormonforschung," 1938, p. 334.

[4] Marker, Kamm, Oakwood, Wittle and Lawson, THIS JOURNAL, **60**, 1061 (1938).

[5] Wieland and Dane, *Z. physiol. Chem.*, **216**, 97 (1933).