559. *Intramolecular Acylation. Part II. The Ring Closure of Some α-Substituted Glutaric Acids.*

By M. F. Ansell and D. H. Hey.

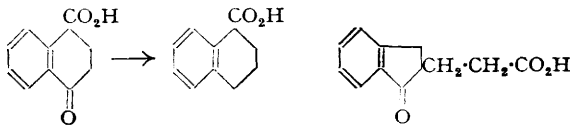
Intramolecular acylation of the nine α-substituted glutaric acids having the formula $R{\cdot}CH(CO_2H){\cdot}CH_2{\cdot}CH_2{\cdot}CO_2H$, $R{\cdot}CH_2{\cdot}CH(CO_2H){\cdot}CH_2{\cdot}CH_2{\cdot}CO_2H$, and $R{\cdot}CH_2{\cdot}CH_2{\cdot}CH(CO_2H){\cdot}CH_2{\cdot}CH_2{\cdot}CO_2H$, in which in each case R is phenyl, α- and β-naphthyl, has been effected by the use of anhydrous hydrogen fluoride, and the constitutions of the ketonic acids thus obtained have been established as follows. Both 1-ketotetralin-4-carboxylic acid (I) and -2-β-propionic acid (IV) have been converted into the corresponding non-ketonic acids (II and V) by Clemmensen reduction and, in addition, (IV) has been converted successively into the lactone of 1-hydroxy-1 : 2 : 3 : 4-tetrahydronaphthalene-2-β-propionic acid (VII) and 4 : 5-benzindan-3-one (VIII). 1-Keto-1 : 2 : 3 : 4-tetrahydrophenanthrene-4-carboxylic (XI) and -2-β-propionic acid (XVIII), 4-keto-1 : 2 : 3 : 4-tetrahydrophenanthrene-1-carboxylic (XXIV) and -3-β-propionic acid (XXVI) have been reduced to the corresponding non-ketonic acids and thence converted into known reference compounds. Both 1- (XV) and 3-keto-4 : 5-benzindane-2-β-propionic acid (XVII) have been converted similarly into 4 : 5-benzindane-2-β-propionic acid (XVI). Further, (XVIII) has been converted successively into the lactone of 1-hydroxy-1 : 2 : 3 : 4-tetrahydrophenanthrene-2-β-propionic acid (XXII) and 1′-keto-1 : 2-*cyclo*pentenophenanthrene (XXI), a compound also obtained by the action of anhydrous hydrogen fluoride on phenanthrene-2-β-propionic acid (XX).

The development of a new method of preparation (Ansell and Hey, *J.*, 1950, 1683) has rendered available a number of α-substituted glutaric acids, which are suitable starting compounds for the preparation of polycyclic systems by intramolecular acylation. The present communication is devoted to a study of the ring closure of the nine α-substituted glutaric acids having the formulæ $R{\cdot}CH(CO_2H){\cdot}CH_2{\cdot}CH_2{\cdot}CO_2H$, $R{\cdot}CH_2{\cdot}CH(CO_2H){\cdot}CH_2{\cdot}CH_2{\cdot}CO_2H$, and $R{\cdot}CH_2{\cdot}CH_2{\cdot}CH(CO_2H){\cdot}CH_2{\cdot}CH_2{\cdot}CO_2H$, where in each case R is phenyl, α- and β-naphthyl. Anhydrous hydrogen fluoride was chosen as the reagent most likely to yield satisfactory results as regards yields, purity of product, and ease of manipulation (cf. Fieser and Hershberg, *J. Amer. Chem. Soc.*, 1939, **61**, 1272), but alternative methods of cyclisation have been employed in some instances, either for purposes of comparison or when the hydrogen fluoride method was unsatisfactory. The results show that it is possible to obtain relatively complex polycyclic systems in a straightforward manner from easily accessible starting compounds, and new routes are thus opened up for the synthesis of a variety of polycyclic structures of current interest. This method, as applied to suitably substituted dicarboxylic acids in general, has received only limited application in the past (cf. von Braun, Bayer, and Cassel, *Ber.*, 1927, **60**, 2602; von Braun and Irmisch, *Ber.*, 1931, **64**, 2461; von Braun and Weissbach, *ibid.*, p. 1785; Manske, *J. Amer. Chem. Soc.*, 1931, **53**, 1104; Ramage and Robinson, *J.*, 1933, 607; Ramage, *J.*, 1938, 397, etc.). The action of anhydrous hydrogen fluoride on some β-substituted glutaric acids has been described in Part I (Hey and Kohn, *J.*, 1949, 3177).

The action of anhydrous aluminium chloride on α-phenylglutaryl chloride in carbon disulphide solution gave 1-ketotetralin-4-carboxylic acid (I) in 60% yield, but when the free acid was treated with anhydrous hydrogen fluoride 71% of the starting material was recovered unchanged and the yield of (I) was reduced to 17%. Since the completion of this work Horning and Finelli (*J. Amer. Chem. Soc.*, 1949, **71**, 3204) have reported the formation of (I) in 57% yield by the action of concentrated sulphuric acid on α-phenylglutaric anhydride. When, however, these workers treated α-phenylglutaric anhydride with aluminium bromide in benzene solution,

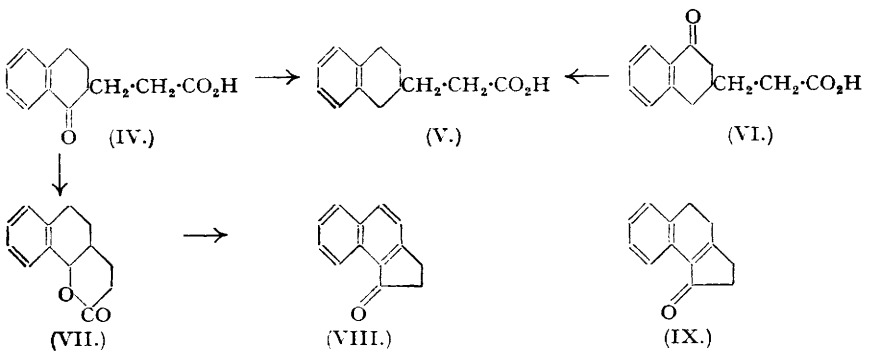
intermolecular acylation took place with formation of γ-benzoyl-α-phenylbutyric acid. The structure of 1-ketotetralin-4-carboxylic acid was confirmed by its conversion, on Clemmensen reduction, into 1 : 2 : 3 : 4-tetrahydro-1-naphthoic acid (II) (Baeyer and Schoder, *Annalen*, 1891, **266**, 184; Newman and O'Leary, *J. Amer. Chem. Soc.*, 1946, **68**, 258). The poor yield of 1-ketotetralin-4-carboxylic acid obtained by the action of anhydrous hydrogen fluoride on α-phenylglutaric acid illustrates the resistance to ring closure encountered by Badger, Campbell, and Cook (*J.*, 1949, 1084) in the case of the α-phenyl nucleus in αβ-diphenylglutaric acid. Other examples in which hydrogen fluoride gives less satisfactory results than aluminium chloride have been reported by Hey and Kohn (*loc. cit.*).

The formation of 1-ketoindane-2-β-propionic acid (III) in 30% yield by the action of aluminium chloride on α-benzylglutaric anhydride in nitrobenzene solution has been reported by von Braun and Manz (*Annalen*, 1929, **468**, 258) and it is now shown that the same compound is formed in 81% yield by the action of anhydrous hydrogen fluoride on free α-benzylglutaric acid.



(I.) (II.) (III.)

The action of cold 98% sulphuric acid on α-(2-phenylethyl)glutaric acid gave 1-ketotetralin-2-β-propionic acid (IV) in a yield of 90%, and the yield with anhydrous hydrogen fluoride was 86·5%. The structure of (IV) was established by Clemmensen reduction to tetralin-2-β-propionic acid (V), prepared previously by von Braun, Bayer, and Cassel (*loc. cit.*) by the similar reduction of 1-ketotetralin-3-β-propionic acid (VI).

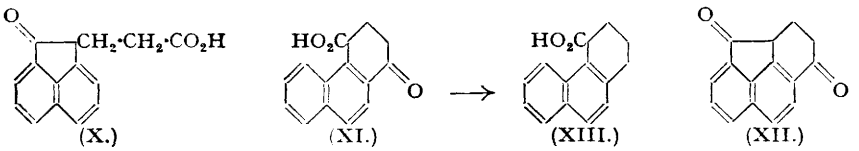


(IV.) (V.) (VI.)

(VII.) (VIII.) (IX.)

An attempt to prepare the 2 : 4-dinitrophenylhydrazone of (IV) by Brady's method (*J.*, 1931, 757) gave the 2 : 4-dinitrophenylhydrazone of the ethyl ester. Esterification of the carboxyl group in keto-acids under Brady's conditions has previously been reported by Cowley and Schuette (*J. Amer. Chem. Soc.*, 1933, **55**, 3465) and by Strain (*ibid.*, 1935, **57**, 758). Reduction of the keto-acid (IV) with sodium amalgam gave the lactone of 1-hydroxytetralin-2-β-propionic acid (VII) which, when heated with phosphoric oxide in xylene solution, gave a non-acidic product which proved to be 4 : 5-benzindan-3-one (VIII) and not the expected 6 : 7-dihydro-compound (IX). An authentic sample of (VIII) was prepared for purposes of comparison by the cyclisation of naphthalene-2-β-propionic acid, obtained in turn by the hydrolysis of ethyl 2-naphthylmethylmalonate, as described by Mayer and Sieglitz (*Ber.*, 1922, **55**, 1835). This cyclisation was effected in 96% yield by using anhydrous hydrogen fluoride (cf. Cook and Hewett, *J.*, 1933, 1111).

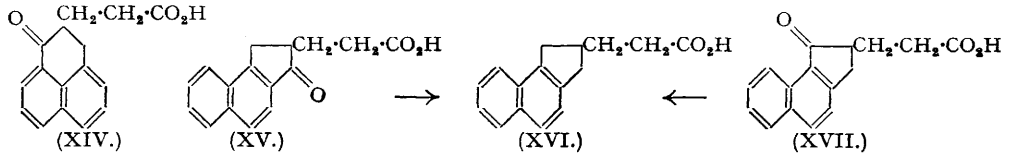
Cyclisation of α-1-naphthylglutaric acid can give rise to three possible products (X, XI, XII)



(X.) (XI.) (XIII.) (XII.)

in addition to a compound containing a seven-membered ring. The product obtained by the use of anhydrous hydrogen fluoride contained only acidic material, which eliminates compound (XII), and the sole product (95% yield) consisted of 1-keto-1 : 2 : 3 : 4-tetrahydrophenanthrene-4-carboxylic acid (XI). Reduction of the product by Huang-Minlon's modification of the Wolff–Kishner reaction (*J. Amer. Chem. Soc.*, 1946, **68**, 2487) gave 1 : 2 : 3 : 4-tetrahydrophenanthrene-4-carboxylic acid (XIII) (m. p. 145—146°), whereas similar reduction of (X) would have given acenaphthene-7-β-propionic acid (m. p. 108·5—109·5°; Bachmann and Sheehan, *ibid.*, 1941, **63**, 204). The structure (XI) was confirmed by the identification of 1 : 2 : 3 : 4-tetrahydrophenanthrene as a by-product of the reduction, and also by the formation of phenanthrene when the 1 : 2 : 3 : 4-tetrahydrophenanthrene-4-carboxylic acid was heated with palladium–charcoal. Attempts to dehydrogenate this acid with sulphur always gave a slightly impure product, but similar dehydrogenation of the methyl ester gave a product from the hydrolysis of which pure phenanthrene-4-carboxylic acid was obtained.

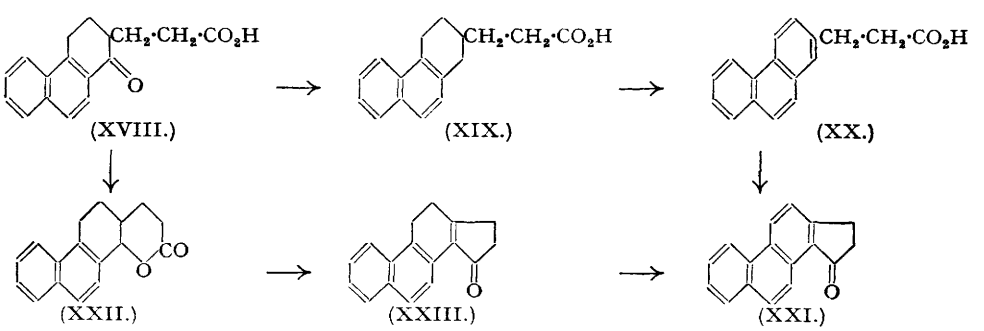
Treatment of α-1-naphthylmethylglutaric acid with anhydrous hydrogen fluoride gave a tar from which a single ketonic product was isolated in the form of its semicarbazone in only 22% yield. This result was unexpected, although Fieser and Jones (*ibid.*, 1942, **64**, 1666) have reported a similar experience with acenaphthene-3-β-propionic acid. This reaction could give rise to 7-ketoperinaphthane-8-β-propionic acid (XIV) and/or 1-keto-4 : 5-benzindane-2-β-propionic acid (XV). The product isolated was proved to be (XV) by the facts that



(XIV.) (XV.) (XVI.) (XVII.)

oxidation gave naphthalene-1 : 2-dicarboxylic acid, isolated as the anhydride, and reduction gave 4 : 5-benzindane-2-β-propionic acid (XVI), a compound also obtained from 3-keto-4 : 5-benzindane-2-β-propionic acid (XVII) as described below. The cyclisation of α-1-naphthylmethylglutaric acid thus appears to provide an example of the formation of a five-membered ring in preference to a six-membered ring, although the product was isolated in only 22% yield from a tarry reaction product which may have contained the isomeric peri-naphthane derivative. The deactivation of the 8-position by the side chain is hardly likely, and, if the perinaphthane derivative is in fact not formed, a more feasible explanation is to be found in steric considerations. In the cyclisation of naphthalene-1-β-propionic acid and its derivatives, in most cases ring closure at the *peri*-position takes place to the exclusion of reaction at the 2-position (cf. Fieser and Novello, *ibid.*, 1940, **62**, 1855), but examples are also known in which reactions at both positions are involved (Fieser and Gates, *ibid.*, p. 2335; Cook and Hewett, *J.*, 1934, 365).

The cyclisation of α-(2-1′-naphthylethyl)glutaric acid to give 1-keto-1 : 2 : 3 : 4-tetrahydrophenanthrene-2-β-propionic acid (XVIII) was accomplished in a yield of 65% with hot 85% sulphuric acid, and in a yield of 92·5% with anhydrous hydrogen fluoride. The structure of the product was established by Clemmensen reduction to 1 : 2 : 3 : 4-tetrahydrophenanthrene-2-β-propionic acid (XIX), followed by dehydrogenation to phenanthrene-2-β-propionic acid (XX)



(XVIII.) (XIX.) (XX.)

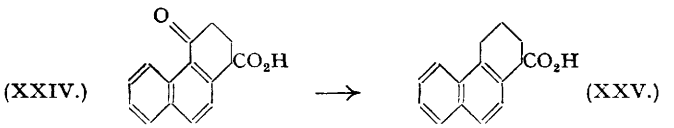
(XXII.) (XXIII.) (XXI.)

which had been prepared previously by Bachmann and Kloetzel (*J. Amer. Chem. Soc.*, 1937, **59**, 2207) by the reduction of phenanthrene-2-β-acrylic acid. The action of anhydrous hydrogen

fluoride on phenanthrene-2-β-propionic acid (XX) gave 1'-keto-1 : 2-*cyclo*pentenophenanthrene (XXI) in a yield of 80%, whereas Bachmann and Kloetzel (*loc. cit.*) have reported that by the action of stannic chloride on phenanthrene-2-β-propionyl chloride the keto*cyclo*pentenophenanthrene is obtained in only 54% yield.

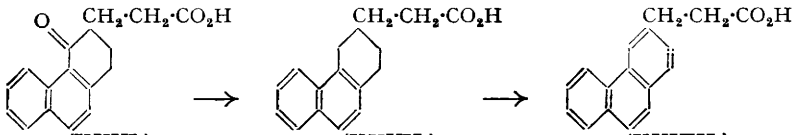
Reduction of 1-keto-1 : 2 : 3 : 4-tetrahydrophenanthrene-2-β-propionic acid (XVIII) with sodium amalgam gave the lactone (XXII) of the 1-hydroxy-acid, which with phosphoric oxide in boiling xylene gave a neutral product; this is considered to be 1'-keto-1 : 2-*cyclo*penteno-3 : 4-dihydrophenanthrene (XXIII), because on dehydrogenation it gave 1'-keto-1 : 2-*cyclo*-pentenophenanthrene (XXI), identical with the product obtained as described above.

The action of anhydrous hydrogen fluoride on α-2-naphthylglutaric acid gave 4-keto-1 : 2 : 3 : 4-tetrahydrophenanthrene-1-carboxylic acid (XXIV) in 71% yield. The structure of the latter was proved by the fact that on reduction by the Huang-Minlon modification of the Wolff–Kishner method both 1 : 2 : 3 : 4-tetrahydrophenanthrene and 1 : 2 : 3 : 4-tetrahydrophenanthrene-1-carboxylic acid (XXV) were obtained.



(XXIV.) (XXV.)

Treatment of α-2-naphthylmethylglutaric acid with anhydrous hydrogen fluoride gave 3-keto-4 : 5-benzindane-2-β-propionic acid (XVII) in 92% yield. Oxidation of the latter gave naphthalene-1 : 2-dicarboxylic acid, whereas Clemmensen reduction gave 4 : 5-benzindane-2-β-propionic acid (XVI), which was also obtained similarly from the isomeric keto-acid (XV) as reported above. Formation of the same end-product from both α-1- and α-2-naphthylmethylglutaric acid provides further evidence that the five-membered ring must be attached to the naphthalene nucleus at the 1- and the 2-positions.



(XXVI.) (XXVII.) (XXVIII.)

The action of anhydrous hydrogen fluoride on α-(2-2'-naphthylethyl)glutaric acid gave 4-keto-1 : 2 : 3 : 4-tetrahydrophenanthrene-3-β-propionic acid (XXVI) in 64% yield. The structure of the latter was proved by Wolff–Kishner reduction to 1 : 2 : 3 : 4-tetrahydrophenanthrene-3-β-propionic acid (XXVII), which in turn was dehydrogenated to give phenanthrene-3-β-propionic acid (XXVIII) (Bachmann and Kloetzel, *loc. cit.*).

Experimental.

In the reactions with anhydrous hydrogen fluoride "Polythene" beakers were used and the reactions were carried out in the open under shelter.

1-*Ketotetralin*-4-*carboxylic Acid.*—(*a*) A solution of α-phenylglutaric acid (4·5 g.) (Ansell and Hey, *loc. cit.*) in anhydrous hydrogen fluoride (100 g.) was set aside at 15—20° for 18 hours and then poured on crushed ice. The sticky solid which separated was extracted with ether and washed with water. Evaporation of the dried ethereal extract left a viscous oil (4·4 g.), which was dissolved in alcohol (10 c.c.) and heated at 75° for 1 hour with semicarbazide hydrochloride (4·0 g.) in a mixture of alcohol (30 c.c.) and pyridine (4 c.c.). Fine needle-like crystals rapidly separated. Next morning, filtration gave 1-*ketotetralin*-4-*carboxylic acid semicarbazone* (0·83 g.), m. p. 230° after recrystallisation from ethoxyethanol (Found: C, 58·0; H, 5·4. $C_{12}H_{13}O_3N_3$ requires C, 58·3; H, 5·3%). The mother-liquors from the semicarbazone were made strongly acid with hydrochloric acid and extracted with ether. The ethereal extract was washed with 2N-hydrochloric acid and water. Evaporation of the dried extract left α-phenylglutaric acid (3·2 g.) as an oil which readily solidified and had m. p. and mixed m. p. 82—84° after recrystallisation from ice-cold benzene–light petroleum (b. p. 40—60°). The semicarbazone (0·515 g.) was hydrolysed by boiling it under reflux with 20% hydrochloric acid (100 c.c.) for 30 minutes; the mixture was cooled and extracted with ether. The extract was washed with water, dried, and evaporated, to give 1-*ketotetralin*-4-*carboxylic acid* (0·342 g.) as an oil, which readily solidified. Recrystallisation from benzene–light petroleum (b. p. 40—60°) gave the pure acid in glistening plates, m. p. 94—95° (Found: C, 69·4; H, 5·2. $C_{11}H_{10}O_3$ requires C, 69·5; H, 5·3%). Horning and Finelli (*loc. cit.*), after the completion of this work, recorded m. p. 93—95°.

(*b*) α-Phenylglutaryl chloride was prepared from α-phenylglutaric acid (5·2 g.) and phosphorus pentachloride (10·5 g.) in dry thiophen-free benzene (10 c.c.). After distillation under reduced pressure to remove benzene and phosphorus oxychloride and pentachloride, the residue of α-phenylglutaryl chloride

was dissolved in carbon disulphide (15 c.c.) and added to an ice-cold stirred suspension of anhydrous aluminium chloride (5·5 g.) in carbon disulphide (15 c.c.). After being kept at 0° for 1 hour, the mixture was stirred at room temperature for 2 hours. The carbon disulphide was removed under reduced pressure and the residue cooled to 0° and decomposed with ice and hydrochloric acid. The acid solution was extracted with ether, and the extract washed with 2N-hydrochloric acid and water and dried. Evaporation left a reddish oil (4·5 g.), which was converted into the semicarbazone (3·5 g.; m.p. 228—229°) and thence into the free keto-acid (2·5 g.) as described above. When purified as described above, this had m. p. 94—95° and was identical with that obtained by method (*a*).

1 : 2 : 3 : 4-*Tetrahydro*-1-*naphthoic Acid.*—1-Ketotetralin-4-carboxylic acid (1·0 g.) was added to a suspension of amalgamated zinc (5·0 g.) in a mixture of water (3 c.c.), concentrated hydrochloric acid (9 c.c.), glacial acetic acid (0·3 c.c.), and toluene (5 c.c.). The mixture was boiled under reflux for 24 hours, during which time a further quantity of hydrochloric acid (10 c.c.) was added. The toluene layer was then separated, the aqueous layer extracted with ether, and the combined toluene and ether extracts were washed with water. The residual oil, obtained on removal of the solvents from the dried extract, was distilled to yield 1 : 2 : 3 : 4-tetrahydro-1-naphthoic acid (0·6 g.), b. p. 110—112°/0·5 mm., which immediately solidified. Recrystallisation from ethyl acetate gave the acid in colourless prisms, m. p. 82—84°. Newman and O'Leary (*loc. cit.*) record m. p. 80—81° and Baeyer and Schoder (*loc. cit.*) m. p. 85°.

1-*Ketoindane*-2-*β*-*propionic Acid.*—A solution of α-benzylglutaric acid (5·0 g.) (Ansell and Hey, *loc. cit.*) in anhydrous hydrogen fluoride (100 g.) was kept for 24 hours, and then poured on ice and extracted with ether. After being washed with water and dried (Na_2SO_4), the ethereal solution was evaporated. A slightly yellow solid (4·5 g.) was obtained which, after two crystallisations from benzene–light petroleum (b. p. 40—60°), yielded 1-ketoindane-2-β-propionic acid (3·7 g.) in small, pale yellow, needles, m. p. 106—108°. von Braun and Manz (*loc. cit.*) record m. p. 103—105°.

1-*Ketotetralin*-2-*β*-*propionic Acid.*—(*a*) A solution of α-(2-phenylethyl)glutaric acid (21·0 g.) (Ansell and Hey, *loc. cit.*) in 98% sulphuric acid (110 c.c.) was kept at room temperature for 24 hours and then poured on ice. The precipitated *keto-acid* (17·4 g.; m. p. 96—99°) was collected and washed with water. Recrystallisation from water–dioxan (3 : 1) gave the pure acid in small needles, m. p. 107—108° (Found: C, 71·4; H, 6·2. $C_{13}H_{14}O_3$ requires C, 71·6; H, 6·4%).

(*b*) A solution of α-(2-phenylethyl)glutaric acid (5·0 g.) in anhydrous hydrogen fluoride (100 g.) was kept for 24 hours and then poured on ice. The precipitated acid was quickly filtered off, washed with water, and dried, to give 1-ketotetralin-2-β-propionic acid (4·0 g.; m. p. 105—107°). Recrystallisation from water–dioxan (3 : 1) gave the pure acid, m. p. 107—108°, identical with the compound prepared by method (*a*). Brady's method (*loc. cit.*) gave *ethyl* 1-*ketotetralin*-2-*β*-*propionate* 2 : 4-*dinitrophenylhydrazone*, which crystallised from ethoxyethanol in small needles, m. p. 183·5—184·5° (Found: C, 58·8; H, 5·2. $C_{21}H_{22}O_6N_4$ requires C, 59·2; H, 5·2%).

Tetralin-2-*β*-*propionic Acid.*—1-Ketotetralin-2-β-propionic acid (5·0 g.) was heated under reflux with amalgamated zinc (10·0 g.) in a mixture of water (7·5 c.c.), hydrochloric acid (17·5 c.c.), glacial acetic acid (0·5 c.c.), and toluene (10 c.c.) for 30 hours, during which more hydrochloric acid (18 c.c.) was added. The product was extracted as recorded for 1 : 2 : 3 : 4-tetrahydro-1-naphthoic acid. Distillation of the oil obtained on evaporation of the dried extract gave tetralin-2-β-propionic acid (3·3 g.), b. p. 188—192°/6 mm., which readily solidified. Recrystallisation from light petroleum (b. p. 40—60°) gave colourless needles, m. p. 72—73°. von Braun, Bayer, and Cassel (*loc. cit.*) record m. p. 73°.

Lactone of 1-*Hydroxy*-*tetralin*-2-*β*-*propionic acid.* Sodium amalgam (2%; 200 g.) was added to a solution of 1-ketotetralin-2-β-propionic acid (4·0 g.) in 2% aqueous sodium hydroxide (100 c.c.). The mixture was kept warm for 24 hours and the aqueous solution then decanted from the mercury. The mercury was thoroughly washed with water, and the combined aqueous solutions acidified with hydrochloric acid. The oil which separated solidified and was collected by filtration. After being dried *in vacuo* over sulphuric acid, it was distilled to give the *lactone* (3·2 g.), b. p. 155—157°/0·5 mm., of 1-hydroxy-1 : 2 : 3 : 4-tetrahydronaphthalene-2-β-propionic acid. This readily solidified and crystallised from benzene–light petroleum (b. p. 40—60°) in small rod-shaped crystals, m. p. 142—144° (Found: C, 77·2; H, 6·4. $C_{13}H_{14}O_2$ requires C, 77·2; H, 6·9%).

Conversion of the Lactone into 4 : 5-*Benzindan*-3-*one.*—Phosphoric oxide (0·71 g.) was added to a solution of the above lactone (1·0 g.) in xylene (5 c.c.) and the mixture boiled under reflux for 30 minutes. After removal of the xylene, the tarry residue was distilled (b. p. 120—160°/0·5 mm.) and the solid distillate digested with 5% aqueous potassium hydroxide (20 c.c.) on a water-bath for 1 hour. The neutral product was extracted with ether and washed with water. Evaporation of the dried ethereal extract left an oil (0·36 g.), which readily solidified. Recrystallisation from aqueous acetic acid (charcoal) yielded 4 : 5-benzindan-3-one in long colourless needles, m. p. 102·5—103·5°. A mixed m. p. with an authentic specimen, prepared as described below, showed no depression.

4 : 5-*Benzindan*-3-*one.*—A solution of naphthalene-2-β-propionic acid (0·31 g.) (Mayer and Sieglitz, *loc. cit.*) in anhydrous hydrogen fluoride (20 g.) was kept for 24 hours, after which time all the hydrogen fluoride had evaporated. The residue was dissolved in ether and washed with 5% aqueous sodium carbonate and with water. Evaporation of the dried extract left 4 : 5-benzindan-3-one (0·28 g.) in slightly yellow needles, m. p. 96—99°. Recrystallisation from aqueous acetic acid (charcoal) gave the compound in long colourless needles, m. p. 102·5—103·5°. Mayer and Sieglitz (*loc. cit.*) give m. p. 103°, and Cook and Hewett (*J.*, 1933, 1111) m. p. 102—103°.

1-*Keto*-1 : 2 : 3 : 4-*tetrahydrophenanthrene*-4-*carboxylic Acid.*—A solution of α-1-naphthylglutaric acid (10·0 g.) (Ansell and Hey, *loc. cit.*) in anhydrous hydrogen fluoride (200 g.) was set aside for 24 hours and then poured on ice. The precipitated solid was quickly filtered off, washed with water, and dissolved in 5% aqueous sodium carbonate (100 c.c.). After extraction with ether the solution was treated with

charcoal and filtered. Evaporation of the dried ethereal extract left no residue. The acid precipitated on acidification of the alkaline solution was filtered off, washed with water, and dried (8·8 g.; m. p. 190—198°). Recrystallisation from benzene (800 c.c.) gave 1-*keto*-1 : 2 : 3 : 4-*tetrahydrophenanthrene*-4-*carboxylic acid* (7·3 g.) in rhombohedra, m. p. 198—200° (decomp.) (Found: C, 74·9; H, 5·0. $C_{15}H_{12}O_3$ requires C, 75·0; H, 5·0%). A further 0·8 g., m. p. 190—198°, was obtained on concentration of the mother-liquors.

1 : 2 : 3 : 4-*Tetrahydrophenanthrene*-4-*carboxylic Acid*.—A mixture of the foregoing acid (2·4 g.), potassium hydroxide (1·9 g.), 85% hydrazine hydrate (2 c.c.), and diethylene glycol (15 c.c.) was boiled under reflux for 1½ hours (cf. Huang-Minlon, *loc. cit.*). The solution was then distilled until the internal temperature reached 195°, and then heated under reflux for 4 hours (bath-temp. 220—240°). After cooling, the solution was diluted with water (15 c.c.) and poured into 6N-hydrochloric acid (10 c.c.) The oil which separated was extracted with ether. The extract was washed with 5% aqueous sodium carbonate, and the alkaline washings were acidified with 2N-hydrochloric acid and again extracted with ether. Evaporation (after drying) of the first ethereal extract left 1 : 2 : 3 : 4-tetrahydrophenanthrene (0·4 g.; m. p. 28—30°), identified by the m. p. and mixed m. p. of its picrate with an authentic specimen (m. p. 111·5°) prepared by the method of Bachmann and Struve (*J. Org. Chem.*, 1939, **4**, 472). Evaporation (after drying) of the second ethereal extract left 1 : 2 : 3 : 4-*tetrahydrophenanthrene*-4-*carboxylic acid* (1·5 g.), m. p. 135—145°. Further recrystallisation from light petroleum (b. p. 80—100°) containing a little benzene gave the acid in long thin plates (1·25 g.), m. p. 145—146° (Found: C, 80·0; H, 6·0. $C_{15}H_{14}O_2$ requires C, 79·7; H, 6·2%). The *methyl* ester, prepared by diazomethane, crystallised from ice-cold methyl alcohol in colourless prisms, m. p. 57—58° (Found: C, 80·4; C, 6·6. $C_{16}H_{16}O_2$ requires C, 80·0; H, 6·7%).

Dehydrogenation of 1 : 2 : 3 : 4-*Tetrahydrophenanthrene*-4-*carboxylic Acid*.—The tetrahydro-acid (0·5 g.) was heated to 200° with 10% palladium–charcoal (0·1 g.) for 15 minutes. A further 0·1 g. of catalyst was then added and heating continued at 240° for a further 7½ hours. During this time 100 c.c. of gas was evolved. The reaction mixture was thoroughly extracted with ether, and after filtration the ethereal extract was washed with 5% aqueous sodium carbonate. Acidification of the alkaline solution yielded only a trace of material, but evaporation of the dried ethereal extract gave phenanthrene (0·3 g.), identified by the m. p. and mixed m. p. of its picrate (m. p. 143—144° from alcohol).

Dehydrogenation of Methyl 1 : 2 : 3 : 4-*Tetrahydrophenanthrene*-4-*carboxylate*.—A mixture of the ester (0·2 g.) and sulphur (0·533 g.) was heated at 240—250° for 3 hours. The reaction mixture was then hydrolysed by boiling aqueous sodium hydroxide (10 c.c.; 20%) for 2 hours. After extraction with ether, the solution was treated with charcoal and filtered. Acidification of the filtrate gave phenanthrene-4-carboxylic acid (0·02 g.), m. p. 167—169°. Recrystallisation from aqueous acetic acid gave the pure acid, m. p. 169—171°. Fieser, Fieser, and Hershberg (*J. Amer. Chem. Soc.*, 1936, **58**, 2325) record m. p. 171·5—173°, and Kruber (*Ber.*, 1934, **67**, 1000) records m. p. 170—171°.

1-*Keto*-4 : 5-*benzindane*-2-*β*-*propionic Acid*.—A solution of α-1-naphthylmethylglutaric acid (5·0 g.) (Ansell and Hey, *loc. cit.*) in anhydrous hydrogen fluoride (100 g.) was kept for 24 hours and then poured on ice. A dark greenish-brown oil separated, which was extracted with ether and washed with water. Evaporation of the dried ethereal extract left a dark oil, which was dissolved in hot alcohol (30 c.c.) (charcoal), and the solution was cooled and filtered. The resulting pale yellow solution was heated at 75° for 1 hour with a solution of semicarbazide hydrochloride (3·0 g.) in a mixture of alcohol (10 c.c.) and pyridine (4 c.c.). A pale yellow, highly insoluble semicarbazone rapidly separated, which after cooling was filtered off and dried (1·7 g.; m. p. 240—244°). The free ketone was regenerated by boiling the semicarbazone with 20% hydrochloric acid (150 c.c.) for 1½ hours and then extracted with ether. After being washed with water and dried, the ethereal solution was evaporated to give 1-*keto*-4 : 5-*benzindane*-2-*β*-*propionic acid* (1·0 g.) as an oil, which readily solidified and then had m. p. 97—100°. Recrystallisation from benzene–light petroleum (b. p. 40—60°), in the presence of activated alumina, yielded the pure acid in clusters of small needles, m. p. 103·5—104·5° (Found: C, 75·3; H, 5·3. $C_{16}H_{14}O_3$ requires C, 75·6; H, 5·5%).

4 : 5-*Benzindane*-2-*β*-*propionic Acid*.—The above keto-acid (0·8 g.), amalgamated zinc (2·5 g.), water (2 c.c.), concentrated hydrochloric acid (5 c.c.), glacial acetic acid (2 drops), and toluene (2·5 c.c.) were boiled under reflux for 24 hours, during which a further quantity (3 c.c.) of hydrochloric acid was added, and then extracted as for 1 : 2 : 3 : 4-tetrahydro-1-naphthoic acid. The oil obtained on evaporation of the dried extracts was distilled at 0·1 mm. (bath-temp. 220°) to give 4 : 5-benzindane-2-β-propionic acid (0·3 g.) as an oil, which readily solidified. Recrystallisation from benzene–light petroleum (b. p. 60—80°) gave the acid in clusters of small needles, m. p. 106—107°, raised to 107—108° on admixture with an authentic specimen (m. p. 107—108°) obtained by the reduction of 3-keto-4 : 5-benzindane-2-β-propionic acid (see below).

Oxidation of 1-*Keto*-4 : 5-*benzindane*-2-*β*-*propionic Acid*.—A cold saturated aqueous solution of potassium permanganate was added to a solution of 1-keto-4 : 5-benzindane-2-β-propionic acid (0·4 g.) in 10% aqueous sodium hydroxide (10 c.c.) until the violet colour persisted. It was then decolourised by the addition of sodium sulphite, the precipitated manganese dioxide filtered off, and dilute sulphuric acid added. After being boiled for a short time to remove sulphur dioxide, the solution was cooled and extracted with ether. Evaporation of the ethereal extract left an oil, from which the anhydride of naphthalene-1 : 2-dicarboxylic acid sublimed under reduced pressure at 180—200° (bath-temp.). Recrystallisation from light petroleum (b. p. 60—80°) gave the anhydride in small needles, m. p. 165—167. A mixed m. p. with the anhydride (m. p. 167—168°) obtained by the oxidation of 3-keto-4 : 5-benzindane-2-β-propionic acid (see below) showed no depression.

1-*Keto*-1 : 2 : 3 : 4-*tetrahydrophenanthrene*-2-*β*-*propionic Acid*.—(*a*) A solution of α-(2-1′-naphthylethyl)glutaric acid (1·0 g.) (Ansell and Hey, *loc. cit.*) in 85% sulphuric acid (4 c.c.) was heated on a water-bath for 1 hour, cooled, and poured on ice. The precipitated acid was filtered off, washed with water, and

dried to give 1-*keto*-1 : 2 : 3 : 4-*tetrahydrophenanthrene*-2-β-*propionic acid* (0·75 g.), m. p. 142—145°. Recrystallisation from dioxan–water (1 : 3) gave the pure acid in small colourless needles, m. p. 143—146° (Found: C, 75·7; H, 5·8. $C_{17}H_{16}O_3$ requires C, 76·1; H, 6·0%). (*b*) A solution of α-(2-1′-naphthylethyl)glutaric acid (3·0 g.) in anhydrous hydrogen fluoride (60 g.) was kept for 24 hours and then poured on ice. The precipitated solid was collected, washed with water, and dried, to give 1-keto-1 : 2 : 3 : 4-tetrahydrophenanthrene-2-β-propionic acid (2·6 g.), m. p. 143—146°, identical with that prepared by method (*a*).

1 : 2 : 3 : 4-*Tetrahydrophenanthrene*-2-β-*propionic Acid*.—The foregoing acid (4·0 g.), amalgamated zinc (10·0 g.), water (7·5 c.c.), hydrochloric acid (17·5 c.c.), glacial acetic acid (0·5 c.c.), and toluene (10 c.c.) were boiled under reflux for 24 hours, during which a further quantity of hydrochloric acid (18 c.c.) was added. The mixture was then extracted as for 1 : 2 : 3 : 4-tetrahydro-1-naphthoic acid. Distillation of the oil obtained on evaporation of the extracts gave 1 : 2 : 3 : 4-*tetrahydrophenanthrene*-2-β-*propionic acid* (2·2 g.), b. p. 191—196°/0·008 mm., which immediately solidified. Recrystallisation from benzene gave the compound in clusters of small needles, m. p. 148·5—149·5° (Found: C, 80·5; H, 7·2. $C_{17}H_{18}O_2$ requires C, 80·3; H, 7·1%).

Phenanthrene-2-β-*propionic Acid*.—A mixture of 1 : 2 : 3 : 4-tetrahydrophenanthrene-2-β-propionic acid (0·508 g.) and sulphur (0·128 g.) was heated at 220—250° for 2 hours. When cold, the reaction mixture was digested with 5% aqueous sodium hydroxide (30 c.c.), treated with charcoal, and filtered. Acidification of the filtrate gave crude phenanthrene-2-β-propionic acid (0·22 g.), m. p. 160—176°. Two recrystallisations from aqueous acetic acid gave the pure acid in small needles, m. p. 177—177·5°. Bachmann and Kloetzel (*loc. cit.*) record m. p. 177—177·5°.

1′-*Keto*-1 : 2-cyclo*pentenophenanthrene*.—A solution of phenanthrene-2-β-propionic acid (0·15 g.) in anhydrous hydrogen fluoride (20 g.) was kept for 24 hours, after which all the hydrogen fluoride had evaporated. The residue was extracted with ether and washed with 5% aqueous sodium carbonate and water. Evaporation of the dried ethereal solution left needles of 1′-keto-1 : 2-*cyclo*pentenophenanthrene (0·111 g.,), m. p. 181—184°. Sublimation at 200° (bath-temp.)/0·3 mm., followed by recrystallisation from acetic acid, raised the m. p. to 183—184°. Bachmann and Kloetzel (*loc. cit.*) record m. p. 184°.

Lactone of 1-*Hydroxy*-1 : 2 : 3 : 4-*tetrahydrophenanthrene*-2-β-*propionic Acid*.—Sodium amalgam (2%; 100 g.) was added to a solution of 1-keto-1 : 2 : 3 : 4-tetrahydrophenanthrene-2-β-propionic acid (2·0 g.) in 2% aqueous sodium hydroxide (50 c.c.). The mixture was kept warm for 24 hours and the aqueous layer decanted from the mercury. The mercury was thoroughly washed with water and the combined aqueous solutions acidified, an oil separating. After decantation of the aqueous layer the oil was treated with ether, whereupon it solidified. The solid product, together with a small amount of material obtained on evaporation of the ethereal solution, was distilled to give the 1-*hydroxy*-1 : 2 : 3 : 4-*tetrahydrophenanthrene*-2-β-*propionic acid lactone* (1·3 g.), b. p. 215—220°/0·15 mm., which immediately solidified. Recrystallisation from benzene gave the lactone in clusters of small needles, m. p. 147—148° (Found: C, 80·8; H, 6·2. $C_{17}H_{16}O_2$ requires C, 81·0; H, 6·3%).

1′-*Keto*-3 : 4-*dihydro*-1 : 2-cyclo*pentenophenanthrene*.—Phosphoric oxide (1·4 g.) was added to a solution of the above lactone (2·5 g.) in xylene (10 c.c.), and the mixture was boiled under reflux for 1 hour. The xylene was removed under reduced pressure and the residue digested with 5% aqueous sodium hydroxide (50 c.c.) for 1 hour on a water-bath. The neutral product was extracted with ether and washed with water. Evaporation of the dried ethereal extract left a brown oil which solidified. Sublimation at 170—180°/0·3 mm. gave 1′-*keto*-3 : 4-*dihydro*-1 : 2-cyclo*pentenophenanthrene* (0·5 g.), which crystallised from benzene in colourless needles, m. p. 165—166° (Found: C, 86·9; H, 6·0. $C_{17}H_{14}O$ requires C, 87·2; H, 6·0%).

Dehydrogenation of 1′-*Keto*-3 : 4-*dihydro*-1 : 2-cyclo*pentenophenanthrene*.—The ketone (0·055 g.) and sulphur (0·0075 g.) were heated at 230—240° (bath-temp.) for 1½ hours. From the reaction mixture 1′-keto-1 : 2-*cyclo*pentenophenanthrene was isolated by sublimation at 200°/0·3 mm. Recrystallisation from aqueous acetic acid gave the compound as pale yellow needles, m. p. 181—184°. A mixed m. p. with 1′-keto-1 : 2-*cyclo*pentenophenanthrene, m. p. 183—184°, prepared from phenanthrene-2-β-propionic acid as described above, showed no depression.

4-*Keto*-1 : 2 : 3 : 4-*tetrahydrophenanthrene*-1-*carboxylic Acid*.—A solution of α-2-naphthylglutaric acid (3·5 g.) (Ansell and Hey, *loc. cit.*) in anhydrous hydrogen fluoride (70 g.) was kept for 24 hours and then poured on ice. The viscous oil which separated was extracted with ether and washed with water. Evaporation of the dried ethereal extract left an oil (3·0 g.), which was converted into the semicarbazone by heating its solution in alcohol (7 c.c.) at 75° for 1 hour with a solution of semicarbazide hydrochloride (3·0 g.) in a mixture of alcohol (10 c.c.) and pyridine (3 c.c.). The colourless highly insoluble semicarbazone, which rapidly separated, was collected and the free ketone, regenerated by boiling 20% hydrochloric acid (200 c.c.) under reflux (1 hour), was extracted with ether. Evaporation of the dried ethereal solution gave 4-*keto*-1 : 2 : 3 : 4-*tetrahydrophenanthrene*-1-*carboxylic acid* (2·3 g.) as an oil, which solidified. Recrystallisation from benzene–light petroleum (b. p. 60—80°) gave the acid in slightly yellow prisms, m. p. 146·5—148·5° (Found: C, 74·7; H, 5·0. $C_{15}H_{12}O_3$ requires C, 75·0; H, 5·0%).

1 : 2 : 3 : 4-*Tetrahydrophenanthrene*-1-*carboxylic Acid*.—4-Keto-1 : 2 : 3 : 4-tetrahydrophenanthrene-1-carboxylic (1·2 g.) was reduced as was the 1-keto-4-carboxylic acid. A mixture of 1 : 2 : 3 : 4-tetrahydrophenanthrene (0·3 g.), identified as picrate, and 1 : 2 : 3 : 4-*tetrahydrophenanthrene*-1-*carboxylic acid* (0·7 g.) was obtained. The latter compound crystallised from benzene in colourless needles, m. p. 160—162° (Found: C, 79·9; H, 6·4. $C_{15}H_{14}O_2$ requires C, 79·7; H, 6·2%). The *methyl* ester, prepared by diazomethane, crystallised from ice-cold methyl alcohol in colourless needles, m. p. 55—55·5° (Found: C, 80·2; H, 6·6. $C_{16}H_{16}O_2$ requires C, 80·0; H, 6·7%).

3-*Keto*-4 : 5-*benzindane*-2-β-*propionic Acid*.—A solution of α-2-naphthylmethylglutaric acid (5·0 g.) (Ansell and Hey, *loc. cit.*) in anhydrous hydrogen fluoride (100 g.) was kept for 24 hours and then poured

on ice. An oil separated which on stirring solidified, and was filtered off, washed, and dried, to give 3-*keto*-4 : 5-*benzindane*-2-*β*-*propionic acid* (4·3 g.), m. p. 133—141°. Recrystallisation from benzene gave the acid, m. p. 141—142° (Found : C, 75·1; H, 5·3. $C_{16}H_{14}O_3$ requires C, 75·5; H, 5·5%).

4 : 5-*Benzindane*-2-*β*-*propionic Acid*.—The foregoing acid (2·0 g.), amalgamated zinc (5·0 g.), water (3·5 c.c.), hydrochloric acid (9 c.c.), glacial acetic acid (6 drops), and toluene (5 c.c.) were boiled under reflux for 24 hours, during which a further quantity of hydrochloric acid (10 c.c.) was added. The mixture was then extracted as for 1 : 2 : 3 : 4-tetrahydro-1-naphthoic acid. Distillation of the oil obtained on evaporation of the dried extracts gave 4 : 5-*benzindane*-2-*β*-*propionic acid* (1·5 g.), b. p. 196°/0·07 mm., which immediately solidified. Recrystallisation from benzene gave the acid in clusters of colourless needles, m. p. 107·5—108·5° (Found : C, 80·3; H, 6·5. $C_{16}H_{16}O_2$ requires C, 80·0; H, 6·7%).

Oxidation of 3-*Keto*-4 : 5-*benzindane*-2-*β*-*propionic Acid*.—3-Keto-4 : 5-benzindane-2-*β*-propionic acid (0·5 g.) was heated at 60—70° for 24 hours with a solution of potassium ferricyanide (30 g.) and potassium hydroxide (5·5 g.) in water (100 c.c.). When cold the solution was filtered and acidified. The precipitated acid was collected and sublimed at 180—200° under reduced pressure, to give the naphthalene-1 : 2-dicarboxylic anhydride (0·09 g.) in small needles, m. p. 164—168°. Resublimation, followed by recrystallisation from benzene–light petroleum (b. p. 60—80°), raised the m. p. of the anhydride to 167—168°. Freund and Fleischer (*Annalen*, 1913, **399**, 213) record m. p. 168—169° and Kruber (*Ber.*, 1932, **65**, 1388) records m. p. 163—164° for this anhydride.

4-*Keto*-1 : 2 : 3 : 4-*tetrahydrophenanthrene*-3-*β*-*propionic Acid*.—A solution of *α*-(2-2′-naphthylethyl)-glutaric acid (6·0 g.) (Ansell and Hey, *loc. cit.*) in anhydrous hydrogen fluoride (100 g.) was kept for 24 hours, and then poured on ice. The precipitated solid was filtered, washed with water, and dried, to give 4-*keto*-1 : 2 : 3 : 4-*tetrahydrophenanthrene*-3-*β*-*propionic acid* (5·6 g.), m. p. 138—146°. Further recrystallisation from aqueous alcohol gave small needles (3·6 g.), m. p. 152—153° (Found : C, 76·3; H, 5·7. $C_{17}H_{16}O_3$ requires C, 76·1; H, 6·0%).

1 : 2 : 3 : 4-*Tetrahydrophenanthrene*-3-*β*-*propionic Acid*.—4-Keto-1 : 2 : 3 : 4-tetrahydrophenanthrene-3-*β*-propionic acid (2·7 g.) was reduced as for the 1-keto-4-carboxylic acid, with 85% hydrazine hydrate (2·0 c.c.), potassium hydroxide (1·9 g.), and diethylene glycol (15 c.c.). The reduction product was dissolved in ether, the ethereal solution extracted with 5% aqueous sodium carbonate solution, and 1 : 2 : 3 : 4-*tetrahydrophenanthrene*-3-*β*-*propionic acid* (2·2 g.) precipitated by acidification of the alkaline solution. Recrystallisation from benzene–light petroleum (b. p. 60—80°) gave the acid in small needles, m. p. 157—158° (Found : C, 80·1; H, 7·1. $C_{17}H_{18}O_2$ requires C, 80·3; H, 7·1%).

Phenanthrene-3-*β*-*propionic Acid*.—A mixture of the above tetrahydro-acid (0·355 g.) and sulphur (0·09 g.) was heated at 220—250° for 2 hours. When cold the reaction mixture was digested with 5% aqueous sodium hydroxide solution (30 c.c.), treated with charcoal, and filtered. Acidification of the filtrate gave crude phenanthrene-3-*β*-propionic acid (0·254 g.), which after crystallisation from aqueous acetic acid, followed by 2 recrystallisations from benzene, was obtained in glistening plates, m. p. 161—163°. Bachmann and Kloetzel (*loc. cit.*) record m. p. 158·5—159·5°. The methyl ester, prepared by diazomethane, crystallised from ice-cold methyl alcohol in plates, m. p. 60—61°. Bachmann and Kloetzel (*loc. cit.*) record m. p. 63—64° for this ester.

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