1093. *Œstrogenic Carboxylic Acids. Part III.* Dibasic Acids.*

By Edward R. Clark.

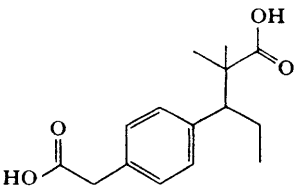
Two dibasic acids and a keto-acid, each of which has some formal resemblance to the natural oestrogens, have been synthesised. None was found to possess significant œstrogenic activity.

Most potent artificial oestrogens possess two oxygen functions. One is always a phenolic hydroxyl, or a derivative thereof, while the second, situated such that the distance between the two is roughly that found in the natural hormone 17β-œstradiol, is usually hydroxyl (aliphatic or aromatic) or carboxyl. Except in the natural steroid hormones, a ketonic or

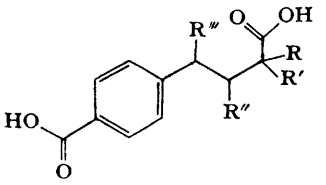
* Part II, E. R. Clark and R. D. Robson, *J.*, 1959, 3714.

secondary alcoholic hydroxyl group is much less effective,[1–4] and we have suggested that low biological activity occasioned by a poor fit between an œstrogen and its receptor may be overcome by replacing a weak hydrogen-bond-forming group (aliphatic hydroxyl or carbonyl) by the more powerfully hydrogen-bonding carboxyl group. Whether any increase in biological activity will result on replacing the phenolic hydroxyl by a carboxyl grouping is not known, though Williams-Ashman, Cassman, and Klavins[5] have suggested that the phenolic hydroxyl may be involved in hydrogen transfer, and hence be essential for activity. Hagerman and Villee[6] do not, however, agree that the phenolic hydroxyl is involved in these biochemical changes, and if their view is correct, it should be possible to obtain an œstrogenic compound possessing two carboxylic acid groups but no phenolic function.

Substitution of carboxyl for aromatic hydroxyl has been carried out in the stilbœstrol and hexœstrol series,[7] but the overall length of the molecules is appreciably increased by such substitution, and size may be responsible for the decreased activity observed. The compounds (I) and (II; R's = Me or Et) do not suffer from this defect, and are able to adopt conformations in which the distances between the two hydrogen-bond-forming groups correspond very



(I)



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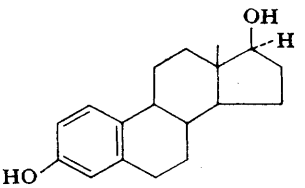


(III)

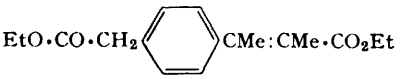
closely to the distance found in 17β-œstradiol (III). Indeed, the dicarboxylic acid (I) may be thought of as an "open-chain" analogue of the highly active allenolic acids.[8]

It was hoped to achieve the synthesis of the dibasic acid (I) *via* the Reformatsky reaction between ethyl *p*-propionylphenylacetate (IV; R = Et) and ethyl α-bromoisobutyrate. Propionylation of ethyl phenylacetate by using propionyl chloride and aluminium chloride

(IV) (V)

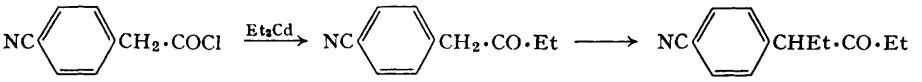
[1] E. R. Clark, *J.*, 1950, 3397.
[2] G. Anner, J. Heer, and K. Miescher, *Helv. Chim. Acta*, 1946, **29**, 1071.
[3] A. H. Nathan and J. A. Hogg, *J. Amer. Chem. Soc.*, 1956, **78**, 6163.
[4] M. Rubin and H. Wishinsky, *J. Amer. Chem. Soc.*, 1946, **68**, 338.
[5] H. G. Williams-Ashman, M. Cassman, and M. Klavins, *Nature*, 1959, **184**, 427.
[6] "Mechanism of Action of Steroid Hormones," ed. Villee and Engel, Pergamon Press, 1961, p. 169.
[7] R. Neher and K. Miescher, *Helv. Chim. Acta*, 1946, **29**, 449.
[8] R. Courrier, A. Horeau, and J. Jacques, *Compt. rend. Soc. Biol.*, 1947, **224**, 1401.

yields, however, a mixture of isomers which is not readily separable. Hydrolysis of the mixture of keto-esters yielded a mixture of the *ortho*- and *para*-keto-acids as a viscous oil from which, on prolonged storage in the refrigerator, a small amount of crystalline acid was obtained. Repeated recrystallisation of the mixture failed to separate the constituent isomeric acids as evidenced by peaks in the infrared spectrum at 745 (1,2-disubstituted) and 795 (1,4-disubstituted) cm.$^{-1}$. The *p*-acetyl homologue (IV; R = Me) is much more readily accessible[9] and its reaction with ethyl α-bromoisobutyrate was investigated under a variety of conditions, including the use of zinc and magnesium as the reacting metal, and ether, benzene, and tetrahydrofuran as solvent but none of the expected tertiary alcohol (V; R = R′ = R″ = Me), or its dehydration product, was obtained. Ethyl α-bromopropionate, on the other hand, reacted normally with zinc and ethyl *p*-acetylphenylacetate to yield the unsaturated ester (VI).



(VI)

Our first approach to the synthesis of the dibasic acids of type (II) involved, as intermediate, the cyano-ketone (IX), obtained from *p*-cyanophenylacetic acid. *p*-Cyanophenylacetyl chloride (VII) was converted, though in poor yield, into 1-*p*-cyanophenylbutan-2-one



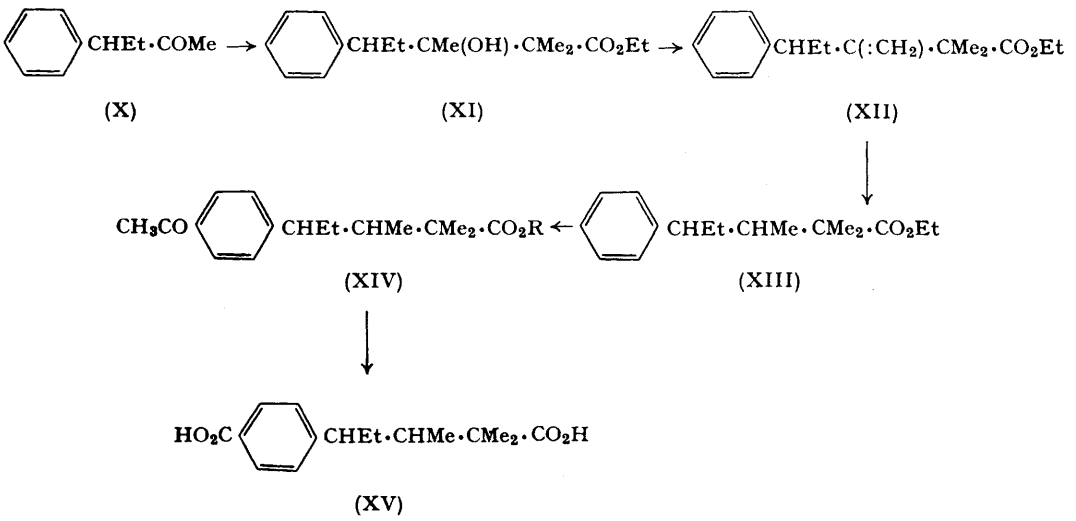
(VII) (VIII) (IX)

(VIII) by reaction with diethylcadmium. Introduction of the ethyl group to produce the required hexanone (IX) was then readily accomplished by using dry sodium ethoxide and ethyl iodide. The 4-*p*-cyanophenylhexan-3-one (IX) appeared to react normally with zinc and ethyl α-bromoacetate but when the reaction mixture was worked up the hexanone was recovered as the only identifiable product. Newman[10] has demonstrated that the recovery of starting ketone in Reformatsky reactions may be due to enolisation of the ketone. This could well be the explanation in this case, where enolisation would be facilitated by the electron attraction of the *para*-cyano-group. This difficulty was readily overcome by first creating the phenyl-substituted branched-chain ester (XIII) and then introducing a suitable group into the *para*-position of the ring.

To test this approach the readily available benzyl methyl ketone was used as the starting material. From this, 3-phenylpentan-2-one (X) was obtained by using ethyl iodide and dry sodium ethoxide, or, better, sodium isopropoxide solution. The poor yield (28%) when dry sodium ethoxide was used was surprising since Schultz *et al.*[11] obtained 79% alkylation by using powdered sodium hydroxide. The use of the 3-phenylpentan-2-one, instead of the more difficultly accessible 4-phenylhexan-3-one, resulted finally in the synthesis of the dicarboxylic acid (XV) rather than its homologue (II; R = R′ = Me, R″ = R‴ = Et). The presence of a methyl group instead of an ethyl group on the β-carbon might be expected, by analogy with other classes of œstrogens, to have a comparatively small effect on any biological activity possessed by the resulting acid; thus, Dodds *et. al.*[12] found α-methyl-α′-ethylstilbœstrol to have one-third of the œstrogenic activity of diethylstilbœstrol and Heer and Miescher[13]

[9] D. Papa, E. Schwenk, and A. Klingsberg, *J. Amer. Chem. Soc.*, 1946, **68**, 2133.
[10] M. S. Newman, *J. Amer. Chem. Soc.*, 1942, **64**, 2131.
[11] E. M. Schultz, J. B. Bicking, S. Mickey, and F. S. Crossley, *J. Amer. Chem. Soc.*, 1953, **75**, 1072.
[12] E. C. Dodds, L. Golberg, E. I. Grünfeld, W. Lawson, C. M. Saffer, and Sir Robert Robinson, *Proc. Roy. Soc.*, 1944, *A*, **132**, 83.
[13] J. Heer and K. Miescher, *Helv. Chim. Acta*, 1945, **28**, 1506.

found that replacing the ethyl group of bisdehydrodoisynolic acid by methyl led to only a very slight reduction in activity. The Reformatsky reaction between the phenylpentanone (X), ethyl α-bromoisobutyrate, and magnesium proceeded normally to yield a mixture of



the hydroxy-ester (XI) and its dehydration product. Heating with iodine failed to complete the dehydration but phosphorus oxychloride yielded the unsaturated ester (XII). The position of the double bond was demonstrated by the absence of specific absorption in the 240-mμ region of the ultraviolet spectrum and was confirmed by the presence of strong absorption bands at 1636 and 905 cm.$^{-1}$ (C=CH$_2$) in the infrared spectrum. Catalytic hydrogenation over palladium–charcoal readily yielded the saturated ester (XIII), the absence of the double bond being confirmed by the disappearance of the strong absorption bands at 1636 and 905 cm.$^{-1}$ from the infrared spectrum.

The carboxyl group was introduced into the *para*-position of the saturated ester (XIII) *via* the acetyl derivative (XIV; R = Et) which was prepared by a Friedel–Crafts reaction by using acetyl chloride. A strong band in the infrared spectrum at 835 cm.$^{-1}$ established that acetylation had occurred in the *para*-position. Alkaline hydrolysis of the keto-ester (XIV; R = Et) furnished the free keto-acid (XIV; R = H) as a very viscous non-crystalline mass which, on being treated with alkaline hypochlorite, yielded the required dicarboxylic acid (XV).

It is of interest to observe that the infrared spectrum of this dicarboxylic acid (XV) exhibited a single peak (1692 cm.$^{-1}$) in the carbonyl region of the spectrum, corresponding to the aryl carboxylic acid group, no separate absorption band due to the aliphatic carboxyl being present.

Only one of the two possible racemates of the dicarboxylic acid (XV) was isolated, the only other identifiable product from the haloform reaction being unchanged keto-acid.

Tests for œstrogenic activity were carried out by Dr. Stella R. O'Donnell, using the modification of the Allen-Doisy test described by Emmens, and using the complete absence of leucocytes from the vaginal smears as evidence of œstrus. The diester (VI) and the keto-ester (XIV; R = Et), dissolved in arachis oil, were administered subcutaneously to ovariectomised mice in two equal doses, 24 hours apart. Examination of vaginal smears at 36, 48, and 54 hr. after the last injection demonstrated both compounds to be œstrogenically inactive at a dose of 10 mg. The dicarboxylic acid (XV) was administered as its sodium salt in aqueous solution in four equal doses spread over 2 days. No evidence of vaginal cornification was observed with a dose of 10 mg.

The complete absence of œstrogenic activity from these new compounds at the 10-mg. dose level suggests that mere binding of the molecule to the receptor may not be sufficient and that a phenolic hydroxyl is essential for œstrogenic activity.

Experimental

Infrared spectra were determined on a Perkin-Elmer Infracord Spectrophotometer, model 137. Microanalyses were by Mr. J. A. Stewart of the University microanalytical laboratory.

Ethyl p-*Acetylphenylacetate*.—Ethyl phenylacetate (123 g.) in dry methylene chloride (200 ml.) was added during 5 min. to a mixture of acetyl chloride (225 g.) and anhydrous aluminium chloride (300 g.) in dry methylene chloride (800 ml.) at room temperature. After being stirred at room temperature for 20 hr., the reaction mixture was poured on to ice, the methylene chloride layer separated, the aqueous layer extracted further with methylene dichloride, and the combined methylene chloride solutions washed and dried ($MgSO_4$). The methylene chloride was distilled, dry ethanol (300 ml.) and acetyl chloride (20 ml.) were added to the residue, and the mixture was refluxed for 1 hr. The cooled alcoholic solution was poured into water (2 l.), the organic layer separated, and the aqueous layer extracted with ether. The combined ester and ethereal extract was washed and dried ($MgSO_4$), the ether evaporated, and the residue distilled, using a short fractionating column, until the distillate commenced to solidify in the condenser. The residue in the still solidified when placed in the refrigerator. The crystalline material was filtered from the supernatant oil and washed with ice-cold petroleum (b. p. 40—60°) yielding pale buff-coloured needle crystals (29 g.), m. p. 54—60°. Recrystallisation from petroleum (b. p. 60—80°) yielded ethyl *p*-acetylphenylacetate, m. p. 61—64° (lit.,[9] 67—68°) (Found: C, 69·9; H, 6·7. Calc. for $C_{12}H_{14}O_3$: C, 69·9; H, 6·8%).

Ethyl 4-(*Ethoxycarbonylmethyl*)-αβ-*dimethylcinnamate*.—A solution of ethyl *p*-acetylphenylacetate (19·5 g.) and ethyl α-bromopropionate (13·6 g.) in dry benzene (75 ml.) was slowly added (*ca.* 30 min.) to zinc turnings (4·9 g.) and the mixture stirred and heated on a water-bath (a trace of iodine assisted the start of the reaction). Reflux was continued for a further 1½ hr. and the cooled mixture then poured into 2N-sulphuric acid and ice. The organic layer was separated, washed, and dried ($MgSO_4$). Distillation yielded *ethyl* 4-(*ethoxycarbonylmethyl*)-αβ-*dimethylcinnamate* (9·7 g.), b. p. 142—144°/0·5 mm. (Found: C, 70·15; H, 7·5. $C_{17}H_{22}O_4$ requires C, 70·3; H, 7·6%); $\nu_{max.}$ (liquid film) 1730vs cm.$^{-1}$ (αβ-unsaturated ester).

1-p-*Cyanophenylbutan*-2-*one*.—Anhydrous cadmium chloride (15·7 g.) was added to a cold ethereal solution of ethylmagnesium bromide [prepared from ethyl bromide (18·6 g.) and magnesium (4·15 g.)] under an atmosphere of dry nitrogen. The mixture was stirred at room temperature for 1 hr., and then on a water-bath for a further ½ hr. The ether was distilled rapidly, dry benzene (30 ml.) added, and distillation continued until all the ether was removed. Dry benzene (80 ml.) was added, the mixture cooled, and a solution of *p*-cyanophenylacetyl chloride[14] (20·4 g.) in dry benzene (50 ml.) added rapidly. The mixture was stirred and heated on a water-bath for 3 hr., allowed to cool, and poured on to ice and dilute sulphuric acid. The benzene layer was separated, the aqueous layer extracted with ether, and the combined benzene–ether solution washed and dried (K_2CO_3). Distillation yielded an oil, b. p. 120—135°/0·9 mm., from which a solid (A) separated. The solid was filtered off and the liquid redistilled, b. p. 123—129°/0·5 mm., $\nu_{max.}$ (liquid film) 2235s (C≡N), 1717vs cm.$^{-1}$ (saturated ketone). The oil yielded 1-p-*cyanophenylbutan*-2-*one* 2,4-*dinitrophenylhydrazone*, m. p. 118—118·5° (Found: C, 57·65; H, 4·5; N, 20·1. $C_{17}H_{15}N_5O_4$ requires C, 57·8; H, 4·25; N, 19·8%). When the oil was kept for several weeks it deposited needle crystals of 1-p-*cyanophenylbutan*-2-*one* (3·4 g.), m. p. 33—35° (Found: C, 75·75; H, 6·3; N, 8·25. $C_{11}H_{11}NO$ requires C, 76·3; H, 6·3; N, 8·1%); $\nu_{max.}$ (Nujol mull) 2232s and 1709vs cm.$^{-1}$. The solid (A) was recrystallised from 45% ethanol, yielding *ethyl* p-*cyanophenylacetate*, m. p. 94—96° (Found: C, 70·05; H, 5·75; N, 7·45. $C_{11}H_{11}O_2N$ requires C, 70·0; H, 5·8; N, 7·4%); $\nu_{max.}$ (Nujol mull) 2237s (C≡N) and 1736vs cm.$^{-1}$ (saturated aliphatic ester).

4-p-*Cyanophenylhexan*-3-*one*.—Dry sodium ethoxide [prepared from sodium (0·46 g.) in the usual way] was mixed with molten 1-*p*-cyanophenylbutan-2-one (3·4 g.). A viscous dark mass was formed and stirring was continued for 10 min. to ensure complete interaction. Ethyl iodide (9·6 g.) was then added as rapidly as possible, and the mixture stirred at room temperature for 15 min. and then with heating on a steam-bath for 1 hr. The excess of ethyl iodide was distilled off, water added to the reaction mixture, and the organic material extracted into ether. The

[14] R. Jaeger and Sir Robert Robinson, *J.*, 1941, 744.

ethereal extract was washed with water, thiosulphate solution, and water, and dried ($CaSO_4$). Distillation yielded the required 4-p-*cyanophenylhexan-3-one* (2·25 g.), b. p. 121—125°/0·6 mm. (Found: C, 77·6; H, 7·5; N, 6·95. $C_{13}H_{15}ON$ requires C, 77·6; H, 7·5; N, 7·0%); $\nu_{max.}$ (liquid film) 2237s (aryl C≡N), 1717vs (saturated C=O), 1608s, 1502s (aromatic ring), and 828s cm.$^{-1}$ (1,4-disubstituted ring).

3-Phenylpentan-2-one.—(*a*) Benzyl methyl ketone (80 g.) was added to dry powdered sodium ethoxide (prepared from 13·8 g. of metallic sodium) in an atmosphere of dry nitrogen, and with cooling in ice. The mixture was stirred to form a smooth paste (*ca.* 20 min.), cooled in salt–ice, and ethyl iodide (94 g.) added as rapidly as possible consistent with control of the reaction. The mixture was stirred and heated on a water-bath for 90 min., and worked up as described for 4-*p*-cyanophenylhexan-3-one above. Distillation yielded 3-phenylpentan-2-one (27 g.), b. p. 107—109°/16 mm. (Found: C, 81·45; H, 9·05. Calc. for $C_{11}H_{14}O$: C, 81·5; H, 8·7%); the semicarbazone had m. p. 195—196° (lit.,[11] 190—191°) (Found: C, 65·85; H, 7·9; N, 19·1. Calc. for $C_{12}H_{17}N_3O$: C, 65·8; H, 7·8; N, 19·2%).

(*b*) Benzyl methyl ketone (117 g.) was added to a stirred solution of sodium isopropoxide [prepared from sodium (20 g.) and dry isopropyl alcohol (500 ml.)] at 50°. Ethyl iodide (150 g.) was added over 10 min. and the reaction mixture stirred overnight. The isopropyl alcohol and excess of ethyl iodide were distilled off, the residue was allowed to cool, and water added. The product was isolated as above, yielding the required ketone (70 g.), b. p. 88—90°/7 mm. (Found: C, 81·1; H, 8·7%).

Ethyl 2,2-Dimethyl-3-methylene-4-phenylhexanoate.—Magnesium turnings (9·1 g.) were activated by reaction with ethyl iodide (4·5 ml.), washed thoroughly with dry ether, and finally left covered with dry ether (50 ml.). Approximately one-half of a mixture of 3-phenylpentan-2-one (48·6 g.), ethyl α-bromoisobutyrate (58·5 g.), and dry benzene (120 ml.) was added to the activated magnesium and the mixture stirred and heated on a water-bath until the reaction commenced (*ca.* 2½ hr.). The heat was removed and the remainder of the ketone–bromo-ester mixture added at such a speed that rapid reflux was maintained. The reaction mixture was then heated on the water-bath (3 hr.), cooled, and poured on to ice and hydrochloric acid. The organic layer was separated and the aqueous layer extracted with ether. The combined benzene–ether solution was washed with water, dilute sodium carbonate solution, and water, and dried ($MgSO_4$). Distillation gave a mixture of hydroxy- and unsaturated esters (42·3 g.), b. p. 107—135°/1 mm.

The mixture (38 g.) was mixed with phosphorus oxychloride (8 ml.) and dry benzene (200 ml.) and heated on a water-bath for 2 hr. The mixture was allowed to cool, then washed with water, dilute sodium carbonate solution, and water, and dried ($MgSO_4$). Distillation yielded the required *unsaturated ester* (28·9 g.), b. p. 107—109°/1 mm. (Found: C, 78·25; H, 9·2. $C_{17}H_{24}O_2$ requires C, 78·5; H, 9·2%); $\nu_{max.}$ (liquid film) *inter al.* 1721vs (COOR), 1636m (C=CH_2), 1590m, 1577w, 1488m (aromatic ring), 1250vs, 1151vs, 1133vs, 1026s, 905s (=CH_2), 758m, and 700s (monosubstituted benzene) cm.$^{-1}$; $\lambda_{max.}$ (EtOH) 259 mμ (ε = 370).

Ethyl 2,2,3-Trimethyl-4-phenylhexanoate.—The unsaturated ester (15·4 g.) dissolved in 96% ethanol (150 ml.) was hydrogenated at atmospheric temperature and pressure in the presence of 5% palladium–charcoal (1 g.) as catalyst. Uptake of hydrogen was complete (98% theory) in 3—4 hr. The catalyst was filtered off and the solution distilled to yield the required *saturated ester* (13·7 g.), b. p. 111—113°/1 mm. (Found: C, 77·55; H, 10·15. $C_{17}H_{26}O_2$ requires C, 77·8; H, 10·0%); $\nu_{max.}$ (liquid film) *inter al.* 1721vs (COOR), 1590m, 1572w, 1488m (aromatic ring), 1250vs, 1170vs, 1136vs (ester), 1015s, 770s, 738s, and 700vs (monosubstituted benzene) cm.$^{-1}$.

Ethyl 4-p-Acetylphenyl-2,2,3-trimethylhexanoate.—Ethyl 2,2,3-trimethyl-4-phenylhexanoate (14·9 g.) dissolved in methylene chloride (30 ml.) was added at room temperature, during 7 min., to a stirred solution of acetyl chloride (0·5 ml.) and aluminium chloride (23·9 g.) in methylene chloride (170 ml.). The mixture was stirred for a further 15 min. after completion of the addition and was then poured on ice and dilute hydrochloric acid. The organic layer was separated, the aqueous layer further extracted with methylene chloride, and the combined organic solution washed with water, dilute sodium carbonate solution, and water, and dried ($MgSO_4$). Distillation yielded the required *keto-ester* (10·9 g.), b. p. 161—163°/0·9 mm. (Found: C, 74·95; H, 9·3. $C_{19}H_{28}O_3$ requires C, 75·0; H, 9·3%); $\nu_{max.}$ (liquid film) *inter al.* 1715vs (CO_2R), 1672vs (ArC=O), 1595s, 1560w, 1453m, 1407m, 1388m, 1353m, 1264vs, 1179m, 1170m, 1138s, 1015s, 956m, and 835m cm.$^{-1}$ (1,4-disubstituted benzene).

4-p-Carboxyphenyl-2,2,3-trimethylhexanoic Acid.—Ethyl 4-*p*-acetylphenyl-2,2,3-trimethylhexanoate (7·7 g.) was hydrolysed by prolonged heating (16 hr.) with 10% aqueous alcoholic

potassium hydroxide solution (100 ml.). The keto-acid (6·6 g.) was obtained as a non-crystalline solid; $\nu_{max.}$ (CCl_4 solution) 2600m (carboxylic OH), 1704s (COOH), and 1675vs (ArC=O); (Nujol mull) 827s (1,4-disubstituted benzene) cm.$^{-1}$.

Potassium hydroxide (17 g.) was dissolved in water (55 ml.), and crushed ice (55 g.) added. The mixture was cooled in an ice–salt bath and chlorine (8—9·5 g.) passed in, the temperature being kept below 0°. To the resulting solution, rapidly warmed to *ca.* 40°, was added dropwise, with stirring, a solution of the derived keto-acid (6·6 g.) in 10% aqueous potassium hydroxide. The heat of reaction caused a further increase in temperature to 60—65° and this temperature was maintained for 2 hr. after completion of the addition. The mixture was then set aside overnight, excess of hypochlorite destroyed with sodium hydrogen sulphite solution, and the resulting solution acidified with hydrochloric acid. The white precipitate so formed was filtered off, dried, and extracted with hot acetone. Evaporation of the acetone extract yielded a pale yellow solid (4·9 g.). Repeated crystallisation from 50% aqueous ethanol yielded one stereoisomer of the required *dicarboxylic acid* (2·6 g.), m. p. 210·5—211·5° (Found: C, 68·9; H, 7·7%; Equiv., 134. $C_{16}H_{22}O_4$ requires C, 69·0; H, 7·95%; Equiv., 139); $\nu_{max.}$ (Nujol mull) *inter al.* 2660m (OH), 1692s (ArCOOH), 1613m, 1575w (aromatic ring), 1422w, 1290s (C–O and OH), and 940m (OH) cm.$^{-1}$; $\lambda_{max.}$ (ethanol) 240 mμ ($\varepsilon = 14{,}200$).

Department of Pharmacology, The School of Medicine,
Leeds, 2.

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