

**487. Anodic Syntheses. Part IX.\*** *Unsaturated and Hydroxy-acids. A Direct Stereochemical Connection of Oleic and Elaidic with Erucic and Brassidic Acids.*

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Undec-10-enoic, oleic, elaidic, and *threo*- and *erythro*-9:10-dihydroxystearic acids undergo the Kolbe reaction to give the expected products in 20—50% yields. Anodic cross-coupling of these acids with adipic half-ester occurs readily, and illustrates a convenient method for the synthesis of unsaturated long-chain fatty acids and their dihydroxy-derivatives.

THE success of anodic methods in the synthesis of many saturated fatty acids with both straight and branched chains prompted an examination of similar routes for the preparation of unsaturated acids. Interest in these compounds has been enhanced in recent years by reports that a number of them are growth factors † for various micro-organisms (cf. Pollock, *Nature*, 1948, **161**, 853; Boughton and Pollock, *Biochem. J.*, 1953, **52**, 261), and by the realisation that lipids from tubercle bacilli contain unsaturated branched-chain fatty acids (Polgar and Robinson, *Chem. and Ind.*, 1951, 685; Cason and Sumrell, *J. Biol. Chem.*, 1951, **192**, 405; Cason, Freeman, and Sumrell, *ibid.*, p. 415). Both for biological testing, and for confirmation of the structures provisionally assigned to some of the natural materials, synthetic acids are required of high purity and of known configuration. This paper describes anodic syntheses of erucic and brassidic (*cis*- and *trans*-docos-13-enoic) acids. Erucic acid occurs in the seed fats of the Cruciferae and Tropaeolaceae, and, together with brassidic acid, has been synthesised by Bowman (*J.*, 1950, 177).

By comparison with the anodic reactions of saturated fatty acids, those of unsaturated acids have received little study; and much of the earlier work was carried out under conditions which would not now be regarded as the most suitable for coupling reactions of the Kolbe type. However, previous investigations indicate that normal coupling occurs on electrolysis of olefinic acids provided that the double bond is separated from the carboxyl to be eliminated by at least two carbon atoms (see a summary by Weedon, *Quart. Reviews*, 1952, **6**, 300). Thus hex-4-enoic (Fichter and Holbro, *Helv. Chim. Acta*, 1937, **20**, 333), undec-10-enoic (*Ia*), oleic (*Ib*) (Petersen, *Z. Elektrochem.*, 1912, **18**, 711), petroselenic (octadeca-*cis*-6-enoic) and erucic acids (Ueno and Tamura, *J. Soc. Chem. Ind., Japan*, 1943, **46**, 1213) are reported to undergo anodic coupling, though the geometrical configurations of the products have not been determined, and "crossed" coupling reactions of oct-7-enoic (Ruzicka, Stoll, and Schinz, *Helv. Chim. Acta*, 1928, **11**, 670) and undec-10-enoic acids (Ruzicka, Stoll, Scherrer, Schinz, and Seidel, *ibid.*, 1932, **15**, 1459; Gustbée and Stenhagen, *Sartryck ur Svensk Kemisk Tidskr.*, 1942, **54**, 243) with half-esters have been used to yield terminally unsaturated acids. Since few details are available of a number of these reactions, some of them have been repeated in the present studies.

Electrolysis of undec-10-enoic acid, and of a mixture of the latter with methyl hydrogen adipate (cf. Ruzicka *et al.*, *loc. cit.*, 1932), led to the hydrocarbon (IIa) and pentadec-14-enoic acid (IIIa) in 43 and 22% yield respectively. The structure of (IIIa) was confirmed by ozonolysis to tetradecanedioic acid.

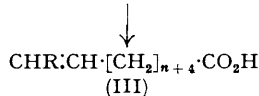
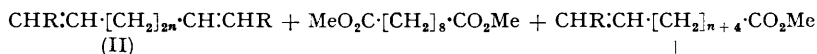
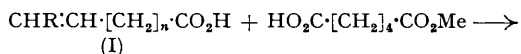
Electrolysis of oleic acid gave (23%) the crystalline tetratriacontadiene (IIb) reported by Petersen (*loc. cit.*), whilst elaidic acid under the same conditions yielded (44%) a previously unknown, higher-melting, isomeric hydrocarbon. That no double bond migration had occurred in either reaction was shown by oxidative degradation of the two dienes (see below). It was therefore concluded that the configurations of the double bonds had been preserved during the electrolyses.

When oleic and elaidic acids were electrolysed in the presence of an excess of methyl

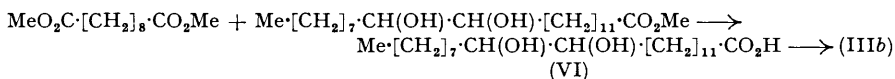
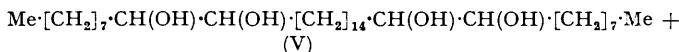
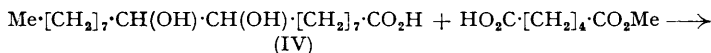
\* Part VIII, *J.*, 1953, 1538.

† The claim (Boer, Jansen, and Kentie, *Nature*, 1946, **158**, 201) that "vaccenic acid" promotes the growth of rats has not been confirmed in later investigations (cf. Gupta, Hilditch, Paul, and Shrivastava, *J.*, 1950, 3484).

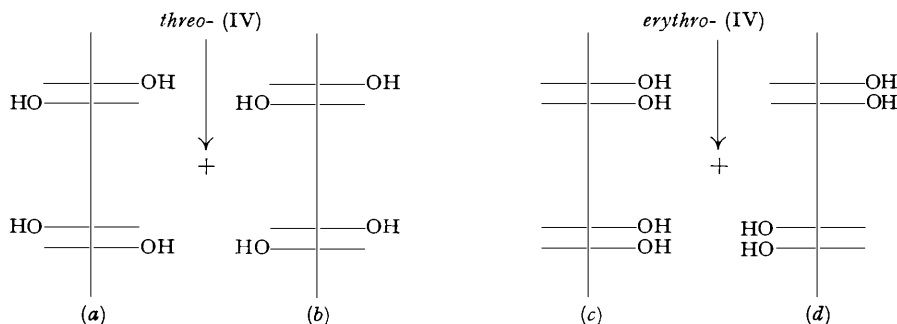
hydrogen adipate the expected mixtures of three products were obtained by both symmetrical and unsymmetrical coupling of the two components. By distillation, and subsequent hydrolysis of the unsymmetrical products, erucic (*cis*-III*b*) and brassidic acid (*trans*-III*b*) respectively were obtained in *ca.* 30% overall yield.



Since *cis*- and *trans*-unsaturated fatty acids may be prepared from the corresponding saturated *erythro*- and *threo*-glycols (Ruzicka, Plattner, and Widner, *Helv. Chim. Acta*, 1942, **25**, 604, 1086; Baudart, *Bull. Soc. chim.*, 1946, **13**, 87; Ames and Bowman, *J.*, 1951, 1079) electrolyses of the 9:10-dihydroxystearic acids (IV) have also been examined.



These intermediates are more easily purified than oleic and elaidic acids, from which they are readily derived. Previously it has been claimed that both ricinoleic (Lübbe, D.R.-P. 624, 331; Kitaura, *Bull. Inst. Phys. Chem. Res.*, Tokyo, 1937, **16**, 765) and ( $\pm$ )-*threo*-9:10-dihydroxystearic acid (Lübbe, *loc. cit.*), unlike  $\alpha$ -hydroxy-acids (von Miller and Hofer, *Ber.*, 1894, **27**, 461), undergo the Kolbe reaction. It has now been shown that electrolyses of the ( $\pm$ )-*threo*- and ( $\pm$ )-*erythro*-forms of (IV) give, in 50 and 20% yields, different diastereoisomers of the tetrol (V). From each of these coupling reactions a mixture of two tetrols would be expected; a ( $\pm$ )-compound formed by symmetrical coupling of the enantiomorphs of *threo*- or *erythro*-(IV), and a *meso*-compound formed by crossed coupling.



[For simplicity each of the ( $\pm$ )-tetrols is represented by only one of its enantiomorphs, (b) and (d).]

These are shown diagrammatically above by projection formulæ (*a*—*d*) of the Fischer type (cf. Hudson, *Adv. Carbohydrate Chem.*, 1948, **3**, 1). Nevertheless in each experiment only one, apparently homogeneous, solid product was isolated. That each solid must, however, be regarded as a mixture of the appropriate pair of isomers was shown in the following manner. Hydroxylation with performic acid (cf. Swern, Billen, and Scanlan, *J. Amer. Chem. Soc.*, 1946, **68**, 1504) of the dienes (II*b*) from oleic and elaidic acids gave (70%) the same solid tetrols as were obtained from electrolyses of ( $\pm$ )-*threo*- and ( $\pm$ )-*erythro*-dihydroxystearic acid respectively. In these hydroxylation experiments equimolar

mixtures of two tetrols [(±)- and *meso*] would, of course, be formed by *trans*-addition to the double bonds (cf. Swern, *Chem. Reviews*, 1949, 45, 1). The possibility (conceivable with the anodic reactions) that only one of the two isomers had been isolated can be ruled out, as the yield is over 50%. The structures of the tetrols were confirmed by oxidative degradation of the mixtures to nonanoic and thapsic acids.

Crossing reactions of *threo*- and *erythro*-dihydroxystearic acids with methyl hydrogen adipate took place normally and, after hydrolysis of the initial products, *threo*- and *erythro*-dihydroxybehenic acids (VI) were isolated (in *ca.* 30% overall yield). These were converted into brassidic and erucic acid respectively by standard procedures (cf. Ames and Bowman, *loc. cit.*) (in 30 and 43% yields based on dihydroxybehenic acid).

It will be apparent that chain extension of an unsaturated fatty acid *via* the dihydroxy-derivative possesses, in general, no merit over the simpler, and more direct, cross-coupling of the parent unsaturated acid; only where the latter is difficult to purify is the alternative process likely to prove superior.

By comparison with the other main routes to long-chain unsaturated fatty acids (*viz.*, the  $\alpha$ -methoxy-ketone route, the acyloin route, and the acetylenic route, cf. *Ann. Reports*, 1949—1951) the anodic procedures possess features which may, in some syntheses, afford distinct advantages: (i) By suitable choice of starting materials a product is obtained which is not contaminated by other monocarboxylic acids of approximately the same molecular weight: the required acid is therefore easily purified. (ii) No laborious separation of the *cis*- and the *trans*-form of the product, or of the *erythro*- and the *threo*-form of its dihydroxy-derivative, is involved. (iii) In the preparation of a *trans*-acid, "elaidinisation" of the *cis*-isomer, with consequent risk of partial migration of the double bond, is avoided. (iv) The geometrical configuration of the product is related to that of the starting material. Thus the configurations long accepted for erucic and brassidic acid (Mascarelli, *Atti R. Accad. Lincei*, 1917, 26, 71) receive additional support from the partial syntheses of these compounds from oleic and elaidic acids.

#### EXPERIMENTAL

M. p.s are corrected, unless stated otherwise. Those below 35° were determined after solidification of the molten substance in a capillary tube.

Except in the electrolysis of undec-10-enoic acid, no allowance has been made for recovered starting material in calculating yields. Yields of unsymmetrical products are based on the mono-acid used in the electrolysis.

*Intermediates.*—Undec-10-enoic acid. Commercial undecenoic acid was distilled and the fraction, b. p. 155—157°/10 mm., m. p. 24.5—25.0°, was collected.

*Oleic acid.* Purification (cf. Smith, *J.*, 1939, 975) of commercial oleic acid, m. p. *ca.* 2°, gave a product, m. p. 12°,  $n_D^{18}$  1.4601 (*idem, loc. cit.*, gives m. p. 13.4°,  $n_D^{20}$  1.4597) [Hydrogen no. (cf. Ogg and Cooper, *Analyt. Chem.*, 1949, 21, 1400), 287. Calc. for 1 double bond, 283].

*Elaidic acid.* (a) Commercial oleic acid was treated with nitrous fumes (cf. Griffiths and Hilditch, *J.*, 1932, 2321). The product, in boiling alcohol, was neutralised with aqueous lithium hydroxide. The lithium salt, which separated on cooling, was collected and fractionally crystallised from 60% aqueous alcohol, giving a solid, m. p. 213—218° (uncorr., sealed capillary), unchanged by further crystallisation. Regeneration of the acid, and one crystallisation from alcohol at 0°, gave elaidic acid, m. p. 42—43° (Mayer, *Annalen*, 1840, 35, 174, gives m. p. 44—45°).

(b) (cf. conversion of *erythro*-9:10-dihydroxystearic acid into oleic acid; Ames and Bowman, *J.*, 1951, 1054). Bromination of *threo*-9:10-dihydroxystearic acid (140 g.), m. p. 93°, and esterification of the product (150 g.), m. p. 20—23° [from methanol at -50° (charcoal)], gave ethyl *erythro*-9:10-dibromostearate (150 g.), a small sample of which was distilled and had b. p. 147—150° (bath-temp.)/10<sup>-4</sup> mm.,  $n_D^{20}$  1.4859 (Found: C, 50.85; H, 8.1. Calc. for C<sub>20</sub>H<sub>38</sub>O<sub>2</sub>Br<sub>2</sub>: C, 51.05; H, 8.15%). Debromination of the dibromo-ester in alcohol with zinc gave ethyl elaidate (92 g.), b. p. 185—187°/0.1 mm.,  $n_D^{25}$  1.4497. Hydrolysis yielded elaidic acid (80 g., 64% overall yield), m. p. 43—44°, raised by one crystallisation from 80% aqueous alcohol to 44.0—44.3°,  $n_D^{50}$  1.4477 (Szalágyi, *Biochem. Z.*, 1914, 66, 152, gives  $n_D^{45}$  1.4499).

9:10-Dihydroxystearic acid. The *threo*-form, m. p. 93°, was prepared from commercial oleic acid and performic acid (cf. Swern, Billen, Findlay, and Scanlan, *J. Amer. Chem. Soc.*, 1945, 67,

1786), and the *erythro*-form, m. p. 131°, by oxidation of sodium oleate with alkaline permanganate (cf. Le Sueur, *J.*, 1901, 1315).

*Methyl hydrogen adipate.* The half ester was prepared from adipic acid and methyl adipate (cf. Swann, Oehler, and Buswell, *Org. Synth.*, Coll. Vol. II, p. 276).

*Apparatus.*—Three cells, "A"—"C," were used. These consisted of cylindrical glass vessels containing two parallel platinum plates, placed *ca.* 3 mm. apart, as electrodes. In cell "A" the electrodes measured 2 × 2.5 cm., in cell "B" 3.5 × 2.5 cm., and in cell "C" 6.5 × 5 cm. Cell "C" (14 × 3") was fitted with two spiral cooling-coils (10 × 1") through which cold water was passed.

*Electrolyses.*—These were carried out with commercial absolute methanol as solvent, to which sufficient sodium had been added to neutralise *ca.* 2% of the total acids used. During the electrolyses the cells were cooled in an ice-bath (internal temperature of cells <50°), and the direction of the current was reversed periodically. At intervals in the symmetrical coupling reactions, and towards the end of the unsymmetrical coupling reactions, it was necessary to interrupt the experiments and remove polymeric deposits from the electrodes. Electrolyses were continued until the electrolyte became slightly alkaline. Before isolation of the products, the cell contents were acidified with either dilute sulphuric acid or glacial acetic acid.

*Hydrolyses.*—Unsaturated esters were hydrolysed, in an atmosphere of nitrogen, by being vigorously stirred under reflux for 2 hr. with a 2*N*-solution of sodium hydroxide (2 mols.) in methanol-water (4 : 1).

*Eicosa-1 : 19-diene* [with R. W. KIERSTEAD].—A solution of sodium undec-10-enoate (from 12.0 g. of undec-10-enoic acid and 1.5 g. of sodium) in methanol (60 c.c.) was electrolysed in cell "B." During the reaction the electrolyte was kept slightly acidic by the slow addition of undec-10-enoic acid (12.0 g.) in methanol (20 c.c.) (current, 0.5—0.6 amp.). After the electrolysis, the cell contents were acidified and the products were extracted with ether and separated in the usual way into neutral and acidic fractions. From the latter undec-10-enoic acid (8.3 g.) was recovered. Distillation of the neutral fraction gave eicosa-1 : 19-diene (5.0 g., 43%, based on unrecovered starting material), b. p. 125—130°/0.2 mm.,  $n_D^{20}$  1.4511, m. p. 17—19°, raised to 19.5—20° (uncorr.) by crystallisation from alcohol (Petersen, *Z. Electrochem.*, 1912, 18, 710, gives m. p. 20.3°).

*Pentadec-14-enoic Acid* (cf. Ruzicka, Stoll, Schinz, and Seidel, *Helv. Chim. Acta*, 1932, 15, 1459).—A solution of methyl hydrogen adipate (8.0 g.; 0.05 mol.) in methanol (65 c.c.) was electrolysed in cell "B." During the reaction methyl hydrogen adipate (60 g., 0.39 mol.) and undec-10-enoic acid (24 g., 0.13 mol.) in methanol (40 c.c.) were added slowly, the electrolyte thus being kept slightly acidic (current, 0.5 amp.; faradays passed, *ca.* 1.2 times theoretical, calculated on the basis of the total amount of acids used). After the electrolysis, the cell contents were acidified and evaporated. The residue was extracted with ether, and the extract was washed with aqueous sodium hydroxide (2% w/v), dried, and evaporated. The residue was hydrolysed and the product separated into acidic and neutral fractions. The latter yielded eicosa-1 : 19-diene (1.7 g., 5%), m. p. 18.5—20.0°. The acidic fraction was extracted with light petroleum (b. p. 60—80°; 3 × 70 c.c.), and the extract was evaporated. Four crystallisations of the residue (6.8 g., 22%), m. p. 41.5—45.5°, from aqueous alcohol at 0° gave pentadec-14-enoic acid as plates, m. p. 49.1—49.3° (uncorr.) (Found: equiv., 241. Calc. for C<sub>15</sub>H<sub>28</sub>O<sub>2</sub>: equiv., 240) (Chuit, Boelsing, Hausser, and Malet, *ibid.*, 1927, 10, 113, give m. p. 49.8—50°). From the petroleum-insoluble portion sebacic acid (15 g., 34%) was obtained.

In another experiment the yield of pentadec-14-enoic acid was 30%.

*Tetradecanedioic Acid.*—A slow stream of ozonised oxygen (*ca.* 3% O<sub>3</sub>) was passed through a solution of pentadec-14-enoic acid (0.5 g.) in chloroform (10 c.c.) for 4 hr. The solvent was evaporated and the residue was heated with hydrogen peroxide (10% v/v; 20 c.c.), giving a solid (0.25 g., 47%), m. p. 118—122°. Crystallisation from benzene and finally from aqueous alcohol yielded the diacid, m. p. 125.5—126° (*idem, loc. cit.*, give m. p. 124.8—125.4°), undepressed on admixture with an authentic specimen (prepared by electrolysis of methyl hydrogen suberate and hydrolysis of the resulting diester).

*Tetratriaconta-cis-9 : cis-25-diene.*—Oleic acid (10 g.) in methanol (20 c.c.) was electrolysed in cell "A" (current 0.5 amp.; faradays passed, *ca.* 1.25 times theoretical). During the reaction much insoluble polymer was formed and a colourless oil separated. After the electrolysis, light petroleum (b. p. 60—80°) was added to the cell contents to dissolve the oil, and the warm mixture was then filtered, neutralised, and evaporated. The residue was extracted thoroughly (Soxhlet; 20 hr.) with light petroleum (b. p. 60—80°). Acidification of the insoluble residue yielded crude oleic acid (1.3 g.), m. p. 5—10°. Evaporation of the extract and distillation of

the residue (5.5 g.) gave : (i) Methyl oleate (2.0 g.), b. p. 70—95° (bath-temp.)/10<sup>-4</sup> mm. (ii) An oil (2.0 g., 23%), b. p. 145—150° (bath-temp.)/10<sup>-4</sup> mm., m. p. 18—19°. Two crystallisations at -20° from light petroleum (b. p. 40—60°) gave tetratriaconta-*cis*-9 : *cis*-25-diene as colourless needles, m. p. 21.5—22.0°,  $n_D^{25}$  1.4589 (Found : C, 86.05; H, 14.15. Calc. for C<sub>34</sub>H<sub>66</sub> : C, 86.0; H, 14.0%) (Petersen, *Z. Elektrochem.*, 1912, 18, 1711, gives m. p. 22.5°).

*Tetratriaconta-trans*-9 : *trans*-25-diene.—Elaidic acid (6.8 g.; m. p. 42—43°) in methanol (20 c.c.) was electrolysed in cell "A" (current 0.5 amp.; faradays passed *ca.* 1.25 times theoretical). During the reaction crystals separated; they had m. p. 51—53° (2.5 g., 44%). Crystallisation from alcohol-light petroleum (b. p. 60—80°) gave the *hydrocarbon* as rectangular plates, m. p. 55.5—56° (Found : C, 86.1; H, 13.7%). From the methanolic mother-liquors elaidic acid (0.4 g.) and methyl elaidate (1.5 g.), b. p. 90—110° (bath-temp.)/10<sup>-4</sup> mm.,  $n_D^{16}$  1.4508—1.4521, were isolated. The latter, by hydrogenation and subsequent hydrolysis, was converted into stearic acid, m. p. and mixed m. p. 70°.

*Erucic (Docosa-cis-13-enoic) Acid*.—A mixture of oleic acid (20.7 g., 0.07 mole) and methyl hydrogen adipate (33 g.) in methanol (120 c.c.) was electrolysed in cell "B" (current 1.7 amp.; faradays passed, *ca.* 1.2 times theoretical). Towards the end of the reaction the current tended to drop but was restored at intervals to its former value by the addition of more half-ester (altogether 45.5 g., 0.28 mole, of the latter were used). After the electrolysis, the alkaline cell contents were acidified and then evaporated. The residue, in ether (500 c.c.), was washed with aqueous sodium hydroxide (2% w/v), then with water, and dried (Na<sub>2</sub>SO<sub>4</sub>). Evaporation of the solvent and distillation of the residual oil (38 g.) from a Kon flask gave : (i) Dimethyl sebacate (20.0 g.), b. p. 106—114°/6 × 10<sup>-4</sup> mm.,  $n_D^{25}$  1.4241, which was contaminated with an unsaturated compound but gave sebacic acid (16 g., 57%), m. p. 131.5—133°, on hydrolysis. (ii) A fraction (11.6 g.), b. p. 180—191°/6 × 10<sup>-4</sup> mm.,  $n_D^{20}$  1.4552, consisting largely of methyl erucate. Hydrolysis furnished a solid mixture of sebacic and erucic acids. Extraction with light petroleum (b. p. 60—80°; 40 c.c.), and evaporation of the extract, yielded erucic acid (8.0 g., 34%) as needles, m. p. 29—30°.

Further purification of the erucic acid was effected in the following manner. The acid was converted into its *lithium* salt which after extraction with ether (Soxhlet; 10 hr.) and four crystallisations from 60% aqueous alcohol had m. p. 222—226° (uncorr., sealed capillary), unaltered by further recrystallisation (Found : Li, 2.4. C<sub>22</sub>H<sub>41</sub>O<sub>2</sub>Li requires Li, 2.0%). The salt was shaken with dilute hydrochloric acid and ether; the ethereal layer was washed with water, dried, and evaporated, giving the free acid (3.8 g.), m. p. 31.7—32.2° (Found : equiv., 338.5. Calc. for C<sub>22</sub>H<sub>42</sub>O<sub>2</sub> : equiv., 338.5), raised to 32.5—33° by crystallisation from alcohol at 0° (Found : C, 77.75; H, 12.45. Calc. : C, 78.0; H, 12.5%) (Skellon and Taylor, *J.*, 1952, 1813, give m. p. 33.0°). The *p*-bromophenacyl ester crystallised from alcohol in needles, m. p. 62° (Ames and Bowman, *J.*, 1950, 177, give m. p. 62°).

The residue from the preceding distillation was distilled from a short-path still and yielded tetratriaconta-*cis*-9 : *cis*-25-diene (2.7 g., 16%), b. p. 145—155° (bath-temp.)/10<sup>-4</sup> mm., m. p. 18—19°,  $n_D^{25}$  1.4640.

*Brassicidic (Docos-trans-13-enoic) Acid*.—A mixture of elaidic acid (15 g., 0.053 mole; m. p. 44.0—44.3°) and methyl hydrogen adipate (25 g.) in methanol (90 c.c.) was electrolysed in cell "B" (current 1.7 amp.; faradays passed, *ca.* 1.2 times theoretical). At intervals towards the end of the reaction more half-ester was added (total used 34 g., 0.21 mole). The tetratriaconta-*trans*-9 : *trans*-25-diene (1.3 g.), m. p. 54—55°, which separated during the electrolysis was collected. (A further 0.3 g. was obtained by crystallisation of the high-boiling residues from the distillation of the other products; total yield 13%.) The cell contents were acidified and evaporated and the residue was separated into acidic and neutral fractions in the usual way. From the former elaidic acid (3.0 g.), m. p. 41—42°, was recovered. Distillation of the neutral fraction gave : (i) Liquid (14 g.), b. p. 115—125°/0.8 mm.,  $n_D^{19}$  1.4394, which on hydrolysis yielded sebacic acid (13 g., 60%). (ii) Methyl brassidate (7.1 g.), b. p. 175—185°/0.5 mm., m. p. 27—29° (Keffler and Maiden, *J. Phys. Chem.*, 1936, 40, 905, give m. p. 30.1°),  $n_D^{25}$  1.4495, which was hydrolysed, the resulting acid being extracted with light petroleum (b. p. 60—80°; 150 c.c.). Evaporation of the extract yielded a solid (6.1 g., 34%), m. p. 57—58° (Found : equiv., 344). Crystallisation (charcoal) from alcohol gave brassidic acid (4.1 g.) as rhombs, m. p. 59.8—60.0° (Found : C, 78.1; H, 12.6; equiv., 338. Calc. for C<sub>22</sub>H<sub>42</sub>O<sub>2</sub> : C, 78.0; H, 12.5%; equiv., 338.5) (Sudborough and Gittins, *J.*, 1909, 95, 320, give m. p. 59.5—60°). The *p*-bromophenacyl ester crystallised from alcohol in plates, m. p. 73° (Ames and Bowman, *loc. cit.*, give m. p. 74°).

*Tetratriaconta-threo*-9 : 10-threo-25 : 26-*tetrol*.—(a) A warm (45—55°) solution of *threo*-

9 : 10-dihydroxystearic acid (31.6 g.) in methanol (140 c.c.) was electrolysed in cell " C " (a current of 1.2 amps. was used initially but this fell to 0.5 amp. when the product began to separate; total faradays passed, *ca.* 4.5 times theoretical). The cell contents were cooled to 20° and the product (13.7 g., 50%), m. p. 120.5—123°, was collected. Crystallisation from alcohol gave the microcrystalline tetrol (9.7 g.), m. p. 124—124.5° (Found: C, 75.45; H, 13.0. Calc. for C<sub>34</sub>H<sub>70</sub>O<sub>4</sub>: C, 75.4; H, 13.0%) (D.R.-P. 624,331 gives m. p. 121°).

Neutralisation and evaporation of the methanolic mother-liquors gave a semi-solid (11.0 g.) from which no pure product could be isolated.

(b) A mixture of tetratriaconta-*cis*-9 : *cis*-25-diene (0.5 g.), aqueous hydrogen peroxide (25—30%; *ca.* 15% excess) and formic acid (98—100%; 6 c.c.) was stirred vigorously at 40° for 4 days (cf. Swern, Billen, and Scanlan, *J. Amer. Chem. Soc.*, 1946, **68**, 1504). Water (35 c.c.) was added and the solid precipitate was collected, washed with water, and hydrolysed by hot aqueous-methanolic 2*N*-sodium hydroxide for 2 hr. The resulting mixture was concentrated and acidified with 2*N*-sulphuric acid. The solid (0.37 g., 70%) was collected and had m. p. 119—121°. Crystallisation from alcohol gave the tetrol, m. p. 123—124° (57%), undepressed on admixture with a specimen from (a).

*Tetratriaconta-erythro-9 : 10-erythro-25 : 26-tetrol.*—(a) *erythro-9 : 10-Dihydroxystearic acid* (20 g.) in methanol (360 c.c.) was electrolysed in cell " C " (current 1.4 amp.; faradays passed, *ca.* 11 times theoretical). The product (3.3 g., 20%), which separated during the reaction, was collected and had m. p. 162—163°. Crystallisation from alcohol gave the microcrystalline *tetrol*, m. p. 163.5—164° (Found: C, 75.7; H, 13.1. C<sub>34</sub>H<sub>70</sub>O<sub>4</sub> requires C, 75.4; H, 13.0%). Evaporation of the methanolic mother-liquors gave a solid (13.5 g.) from which no pure product could be isolated.

(b) A solution of performic acid [prepared from 98—100% formic acid (7.0 c.c.) and 25—30% hydrogen peroxide (0.24 c.c.)] was added to tetratriaconta-*trans*-9 : *trans*-25-diene (0.35 g.) in chloroform (20 c.c.). The mixture was warmed to 40°, acetone (1 c.c.) was added, and the resulting homogeneous solution was stirred at 40° for 20 hr. (a further 0.2 c.c. of hydrogen peroxide was added after 12 hr.). Evaporation of the solvents, hydrolysis of the residue and isolation of the product in the usual way gave a solid (0.3 g., 75%), m. p. 157.5—160.5°. Two crystallisations from alcohol-ethyl acetate gave the tetrol, m. p. 164°, undepressed on admixture with a specimen from (a).

Attempts to hydroxylate the diene in heterogeneous media by the method described above for the *cis-cis*-isomer were unsuccessful, the starting material being recovered unchanged even after 4 days.

*Oxidation of the Tetrols.*—(a) Freshly prepared lead tetra-acetate (24.1 g., 0.054 mole) was added during 1.5 hr. in small portions to a well-stirred solution of the tetrol, m. p. 124° (15 g., 0.028 mole) in benzene (450 c.c.) and acetic acid (" AnalaR; " 38 c.c.) which was kept at 65° in an atmosphere of nitrogen. The mixture was stirred at 65° for a further 3 hr. and then cooled. The tetra-acetate-free solution was decanted from the lead acetate, and the latter was washed with warm benzene (40 c.c.). The benzene solutions were combined, washed with water until free from acetic acid, dried (Na<sub>2</sub>SO<sub>4</sub>), and evaporated under reduced pressure (Dufton column). A portion (4 g.) of the residue (15 g.) was distilled, giving nonanal (1.1 g., 51%), b. p. 60—64°/7 mm., *n*<sub>D</sub><sup>20</sup> 1.4235. The 2 : 4-dinitrophenylhydrazone (formed in 84% yield) had m. p. 105.5°, undepressed on admixture with an authentic specimen (Huber, *J. Amer. Chem. Soc.*, 1951, **73**, 2730, gives m. p. 105—106°).

Potassium permanganate (11.0 g.) was added in small portions during 3.5 hr. to a well-stirred and cooled (15°) suspension of the remainder of the crude product in water (90 c.c.) and sulphuric acid (9.4 c.c.) (cf. Ruhoff, *Org. Synth.*, 1936, **16**, 39). The resulting mixture was treated with sulphur dioxide until all the manganese dioxide had reacted. The organic layer was separated and extracted with light petroleum (b. p. 60—80°; 60 c.c.). Crystallisation of the residue (2.4 g., 43%), m. p. 117—120°, from benzene gave thapsic acid, m. p. 123—123.5°, undepressed on admixture with an authentic specimen. Distillation of the petroleum extract yielded nonanoic acid (2.3 g., 35%), b. p. 140—142°/16 mm., m. p. 8—10°, *n*<sub>D</sub><sup>20</sup> 1.4319. The *p*-toluidide crystallised from alcohol in needles, m. p. 83.5—84° (Robertson, *J.*, 1919, **115**, 1221, gives m. p. 84°).

(b) Similar oxidation of the tetrol, m. p. 164°, (2.0 g.) gave nonanal (48%) (2 : 4-dinitrophenylhydrazone) and thapsic acid (34%).

*threo-13 : 14-Dihydroxybehenic (Dihydroxydocosanoic) Acid.*—A solution of *threo-9 : 10-dihydroxystearic acid* (60 g., 0.19 mole) and methyl hydrogen adipate (122 g., 0.76 mole) in methanol (710 c.c.) was electrolysed in cell " C " (current 4.3 amp.). After 6 hr. a solid separated

from the electrolyte; the current fell markedly but was restored to its former value by the addition of more half-ester (30 g., 0.2 mole) (faradays passed, *ca.* 1.5 times theoretical). After the electrolysis, the solid was collected, giving tetratriaconta-*threo*-9 : 10-*threo*-25 : 26-tetrol (7 g., 14%). The filtrate was neutralised with dilute hydrochloric acid and then evaporated. The residue was extracted with ether. On acidification of the insoluble residue *threo*-9 : 10-dihydroxystearic acid (6.0 g.) was recovered. The ethereal extract was washed with aqueous sodium hydroxide (2% w/v), dried, and evaporated. Distillation gave dimethyl sebacate (59 g., 54%), b. p. 110—120°/0.07 mm.,  $n_D^{20}$  1.4377. The high-boiling residue was hydrolysed with methanolic sodium hydroxide (10% w/v), and the acidic product was isolated, washed twice with boiling water, dried, and extracted with warm benzene (125 c.c.). The sodium salt of the residual acid (21 g., 30%), m. p. 99—100°, was extracted with benzene (Soxhlet; 12 hr.). Regeneration of the free acid and crystallisation from methanol gave *threo*-13 : 14-dihydroxybehenic acid (17 g., 24%) as plates, m. p. 100.5—101° (Found: C, 71.05; H, 12.0%; equiv., 374. Calc. for  $C_{22}H_{44}O_4$ : C, 70.9; H, 11.9%; equiv., 373) (Dorée and Pepper, *J.*, 1942, 477, give m. p. 101°).

*erythro*-13 : 14-Dihydroxybehenic Acid.—A solution of *erythro*-9 : 10-dihydroxystearic acid (34.5 g., 0.11 mole) and methyl hydrogen adipate (64 g., 0.40 mole) in methanol (500 c.c.) was electrolysed in cell "C." At intervals more half-ester (total used 85 g.; 0.52 mole) was added (current, 3—4 amp.; faradays passed, *ca.* 1.5 times theoretical). After the electrolysis tetratriaconta-*erythro*-9 : 10-*erythro*-25 : 26-tetrol (4.5 g., 15%), which had separated during the reaction from the warm (40°) electrolyte, was collected. When kept at 20° the filtrate deposited a solid which was collected and crystallised from methanol, giving methyl *erythro*-13 : 14-dihydroxybehenate (12.0 g., 29%), m. p. 107—107.5° (Found: C, 71.45; H, 12.15. Calc. for  $C_{23}H_{46}O_4$ : C, 71.45; H, 12.0%). Hydrolysis with ethanolic sodium hydroxide (10% w/v) gave the dihydroxy-acid (10.2 g.) as hexagonal plates, m. p. 128.5—129.5°, raised to 130° by crystallisation from methanol (Found: C, 71.15; H, 12.1%; equiv., 374. Calc. for  $C_{22}H_{44}O_4$ : C, 70.9; H, 11.9%; equiv., 373) (Albitski, *J. Russ. Phys. Chem. Soc.*, 1902, 34, 788, gives m. p. 130—131°).

From the methanolic mother-liquors, after removal of the crystalline dihydroxy-ester, *erythro*-9 : 10-dihydroxystearic acid (4.7 g.), dimethyl sebacate (60 g., 54%), and *erythro*-13 : 14-dihydroxybehenic acid (2.4 g., total yield 33%) were obtained by procedures similar to those outlined in the preceding experiment.

*Oxidation of the 13 : 14-Dihydroxybehenic Acids* (cf. Huber, *loc. cit.*).—(a) Oxidation of the *threo*-compound (1.0 g.) with periodic acid and steam-distillation of the product gave nonanal. The 2 : 4-dinitrophenylhydrazone (formed in 23% overall yield) crystallised from alcohol in needles, m. p. 103—104°, undepressed on admixture with an authentic specimen.

Permanganate oxidation of the residue from the steam-distillation yielded a solid (0.32 g., 49%), m. p. 104—107°, which was crystallised several times from benzene and gave brassylic (tridecanedioic) acid, m. p. 112.5—113.5° (Found: equiv., 124. Calc. for  $C_{13}H_{24}O_4$ : equiv., 122) (Chuit, *Helv. Chim. Acta*, 1926, 9, 264, gives m. p. 113—113.2°).

(b) Similar degradation of the *erythro*-compound (2.0 g.) gave nonanal 2 : 4-dinitrophenylhydrazone (0.86 g., 37%) and brassylic acid (0.46 g., 35%) (Found: equiv., 124).

*Brassicidic Acid* (cf. Ames and Bowman, *J.*, 1951, 1804).—Concentrated sulphuric acid (20 c.c.) was added in small portions to a cooled mixture of *threo*-13 : 14-dihydroxybehenic acid (2.5 g.) in a solution of hydrogen bromide in acetic acid (20% w/v; *d* 1.3; 21 c.c.). The mixture was kept for 21 hr. and then heated at 100° for 8 hr. Half way through the latter period more hydrogen bromide-acetic acid (2 c.c.) was added. The mixture was poured into water, and the product was isolated with light petroleum (b. p. 60—80°), giving a pale yellow acid (3.2 g.), which was esterified by heating it with alcohol, sulphuric acid, and benzene, the water formed being removed by azeotropic distillation. The resulting crude ester, in light petroleum (b. p. 40—60°; 100 c.c.) was poured on to a column of alumina (7 × 1") and eluted with the same solvent (400 c.c.). Evaporation of the eluate gave a solid (1.83 g., 52%), m. p. 35.5—37°, which was crystallised twice from alcohol at 0°, yielding *ethyl erythro*-13 : 14-dibromobehenate, m. p. 37—37.5° (Found: C, 55.1; H, 8.85.  $C_{24}H_{46}O_2Br_2$  requires C, 54.85; H, 8.8%).

A well-stirred mixture of the dibromo-ester (1.2 g.), alcohol (12 c.c.), and activated zinc dust (2.3 g.) was boiled under reflux for 1½ hr. in an atmosphere of nitrogen. The mixture was filtered and the solid was washed well with light petroleum (b. p. 60—80°). The filtrate was diluted with water and the product was isolated with light petroleum (b. p. 60—80°). Distillation yielded *ethyl brassidate* (0.54 g., 70%), b. p. 145—150°/5 × 10<sup>-5</sup> mm., m. p. 23.7—24°.

$n_D^{24}$  1.4612, which after two crystallisations from acetone at  $-15^\circ$  was obtained as rhombs, m. p.  $24.5^\circ$  (Found: C, 78.1; H, 12.8. Calc. for  $C_{24}H_{46}O_2$ : C, 78.6; H, 12.65%) (Keffler and Maiden, *loc. cit.*, give m. p.  $25.0^\circ$ ). Hydrolysis with ethanolic sodium hydroxide, and isolation of the acidic fraction, gave a solid (82%), m. p.  $57.5-58.5^\circ$ . Crystallisation from alcohol yielded brassidic acid as plates, m. p.  $59.5-60^\circ$  (Found: C, 77.85; H, 12.6%; equiv., 341. Calc. for  $C_{22}H_{42}O_2$ : C, 78.0; H, 12.5%; equiv., 339). The *p*-bromophenacyl ester had m. p.  $73^\circ$ .

*Erucic Acid*.—*erythro*-13:14-Dihydroxybehenic acid (6.0 g.) was converted into *threo*-13:14-dibromobehenic acid (5.7 g.) which was esterified, giving the *ethyl ester* (4.3 g., 51%), b. p.  $125-130/10^{-4}$  mm.,  $n_D^{20}$  1.4826 (Found: C, 54.85; H, 8.95.  $C_{24}H_{46}O_2Br_2$  requires C, 54.75; H, 8.8%).

Debromination of the ester (3.8 g.) in alcohol with zinc gave ethyl erucate (2.4 g., 91%), b. p.  $110-115/10^{-4}$  mm.,  $n_D^{21}$  1.4550 (Found: C, 79.05; H, 12.8. Calc. for  $C_{24}H_{46}O_2$ : C, 78.6; H, 12.65%). Hydrolysis and isolation of the acidic product gave erucic acid (1.73 g., 93%), as needles m. p.  $32-32.5^\circ$ , raised to  $33^\circ$  by crystallisation from methanol at  $0^\circ$  (Found: C, 77.8; H, 12.55. Calc. for  $C_{22}H_{42}O_2$ : C, 78.0; H, 12.5%).

The m. p.s of both specimens of synthetic erucic acid reported above were undepressed on admixture with an authentic sample of the natural acid, for which the authors are indebted to Dr. J. H. Skellon.

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