874. *Aliphatic Acids. Part II.*[1] *Some Aliphatic Epoxy-acids and Related Compounds.*

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The preparation of *erythro*-6,7- and -9,10-dihydroxyoctadecanoic and -13,14-dihydroxydocosanoic acid is described, as is that of the related epoxy-acids by different routes. Reduction of the epoxy-acids, and oxidation and reduction of some related compounds, have been studied.

AFTER the hydroxylation of octadec-*cis*-9-enoic acid by alkaline permanganate [2] this reaction was widely studied,[3,4] and it is now accepted that such a hydroxylation proceeds by *cis*-addition.[5] Although the optimum conditions [4] preclude the large-scale preparation of the dihydroxy-acid, we have evolved a procedure for the preparation of such acids in quantity, the yield being 60—80% depending on the purity of the olefinic acid; it is particularly important that large quantities be handled rapidly. The method has now been applied, with success, to the preparation of *erythro*-6,7-dihydroxyoctadecanoic and *erythro*-13,14-dihydroxydocosanoic acid.

Although *trans*-hydroxylation by the use of peracids [6,7,8] has often been investigated, little attention has been paid to the quantitative aspect. We have followed the uptake of oxygen quantitatively, employing peracetic acid. For octadec-*cis*- and -*trans*-6- and -9-enoic and docos-13-enoic acid, the theoretical amount of oxygen is taken up in 10—15 min. in a strongly exothermic reaction. The epoxy-acids were isolated in 75—95%

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[1] Part I, Cramp, Julietti, McGhie, Rao, and Ross, *J.*, 1960, 4257.

[2] Saytzeff, *J. Russ. Phys. Chem. Soc.*, 1885, **17**, 417.

[3] Grüssner and Hazura, *Monatsh.*, 1889, **10**, 196, and earlier papers; Edmed, *J.*, 1898, 627; Albitzky, *J. Russ. Phys. Chem. Soc.*, 1899, **31**, 76; 1902, **34**, 788, 810; Le Sueur, *J.*, 1901, 1313; Nicolet and Jurist, *J. Amer. Chem. Soc.*, 1922, **44**, 1136; Robinson and Robinson, *J.*, 1925, 175; Hilditch, *J.*, 1926, 1828; Traynard, *Bull. Soc. chim. France*, 1952, **19**, 323.

[4] Lapworth and Mottram, *J.*, 1925, 1628.

[5] Wiberg and Saegebarth, *J. Amer. Chem. Soc.*, 1957, **79**, 2822.

[6] Braun, *J. Amer. Chem. Soc.*, 1929, **51**, 228; Swern, *ibid.*, 1948, **70**, 1235; Swern, *Chem. Rev.*, 1949, **45**, 1; " Organic Reactions," John Wiley, New York, 1953, Vol. VII, p. 378; Böeseken and Belinfante, *Rec. Trav. chim.*, 1926, **45**, 914; Smit, *ibid.*, 1930, **49**, 675; Swern, Findley, and Scanlan, *J. Amer. Chem. Soc.*, 1944, **66**, 1925; Bauer and Bähr, *J. prakt. Chem.*, 1929, **122**, 201; Dorée and Pepper, *J.*, 1942, 477; Findley, Swern, and Scanlan, *J. Amer. Chem. Soc.*, 1945, **67**, 412; Smedley-Maclean and Pearce, *Biochem. J.*, 1931, **25**, 1252; Schmitz and Wallace, *J. Amer. Oil Chemists' Soc.*, 1954, **31**, 363.

[7] Mack and Bickford, *J. Org. Chem.*, 1953, **18**, 686.

[8] Steger and Van Loon, *Rec. Trav. chim.*, 1927, **46**, 703.

yield. The oxiran ring was opened by boiling glacial acetic acid,[7] and after hydrolysis 60—80% yields of the vicinal dihydroxy-acids were obtained. Much time is saved if the dihydroxy-acid is the desired product, since the intermediate epoxy-acid need not be isolated but may be converted directly into the glycol monoester.

The principal drawback in the epoxidation of unsaturated acids by perbenzoic acid, namely, the separation of the epoxy- and benzoic acids, may be overcome by using an ester of the unsaturated acid with subsequent hydrolysis of the epoxy-ester.[8] We have found that it may also be overcome by using monoperphthalic acid, since phthalic acid is virtually insoluble in chloroform or carbon tetrachloride. Monoperphthalic is far superior to perbenzoic acid for the epoxidation of olefinic acids, although this application appears to have been confined so far to epoxidation of octadec-*cis*-11-enoic acid.[9]

The above methods of epoxidation require that very pure olefinic acids be available. This is rarely the case with the naturally occurring acids, particularly octadec-*cis*-9-enoic acid, although comparatively impure olefinic acids are readily hydroxylated to the easily purified dihydroxy-acids. Accordingly, we investigated the possibility of using vicinal dihydroxy-acids as intermediates in the preparation of epoxy-acids.

The first recorded conversion of an αβ-glycol into the oxide is that of ethylene glycol *via* ethylene chlorohydrin into ethylene oxide by Wurtz;[10] and this procedure has been applied by King[11] to the interconversion (*via* the epoxy-acids) of *erythro*- and *threo*-9,10-dihydroxyoctadecanoic acid. Such a transformation had been previously carried out by Albitzky,[12] employing hydrogen bromide in glacial acetic acid at 100° for interconversion of *erythro*- and *threo*-9,10-dihydroxyoctadecanoic and -13,14-dihydroxydocosanoic acid. The yields of intermediate epoxy-acids isolated were low, owing no doubt to the drastic conditions employed. More recently, Myers[13] has used this route for the interconversion of the isomeric 2,3-dihydroxyoctadecanoic acids, and for their conversion into *cis*- and *trans*-2,3-epoxyoctadecanoic acid. However, no general procedure has been evolved for the conversion of αβ-glycols into epoxides.

The literature contains conflicting reports as to the interaction of vicinal glycols and hydrogen bromide. Albitzky[12] and Stoll *et al.*[14] report the formation of acetoxy-bromides, whereas Baudart[15] and Hunsdiecker[16] claim the isolation of dibromides. Ames and Bowman[17] in a careful investigation found that even at elevated temperatures the prolonged action of hydrogen bromide failed to convert αβ-glycols completely into the corresponding dibromides, although this conversion rapidly occurred in the presence of concentrated sulphuric acid. We have confirmed their report and have found that sulphuric acid may be replaced by phosphoric acid. Moreover, we have observed that vicinal dihydroxy-acids are readily converted by hydrogen bromide in acetic acid at room temperature into acetoxy-bromides; these proved, in agreement with Albitzky,[12] to be viscous oils, but they were converted by alcoholic potassium hydroxide in high yields into the desired epoxy-acids.

Since two Walden inversions are involved, the epoxy-acid will possess the configuration of the dihydroxy-acid from which it was obtained; thus *erythro*-dihydroxy-acids (I) will afford *cis*-epoxides (III), and the isomeric *threo*-dihydroxy-acids (II) are converted into *trans*-epoxides (IV).

This procedure appears to be general for the conversion of vicinal dihydroxy-acids into the related epoxides, and takes place in high yields (78—93%), the results being

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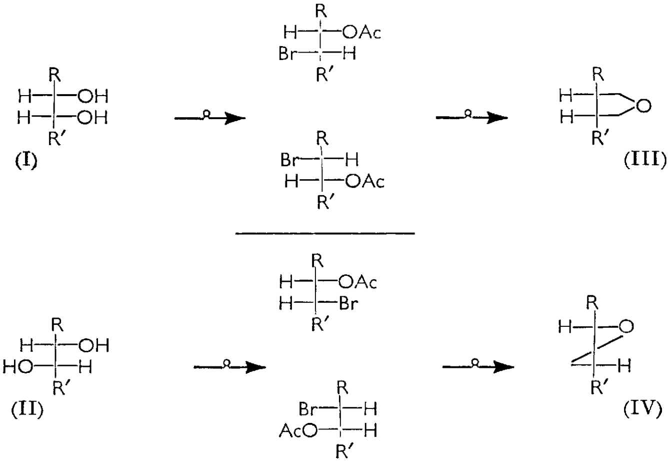
[9] Hofmann, Lucas, and Sax, *J. Biol. Chem.*, 1952, **195**, 473.
[10] Wurtz, *Annalen*, 1859, **110**, 125.
[11] King, *J.*, 1942, 387.
[12] Albitzky, *J. prakt. Chem.*, 1903, **67**, 289, 357.
[13] Myers, *J. Amer. Chem. Soc.*, 1952, **74**, 1390.
[14] Stoll, Hulstkamp, and Rouvé, *Helv. Chim. Acta*, 1948, **31**, 543.
[15] Baudart, *Bull. Soc. chim. France*, 1946, **13**, 87.
[16] Hunsdiecker, *Ber.*, 1943, **76**, 142.
[17] Ames and Bowman, *J.*, 1951, 1079.



summarized in the Table. For comparison the yields of *cis*- and *trans*-9,10-epoxyoctadecanes are included, although these will be reported on in detail in a later paper. The method is a distinct advance since the pure epoxides are formed in high yields from unsaturated acids which need not be in a high state of purity.

Dihydroxyoctadecanoic acid	Epoxide	
erythro-9,10-	*cis*-	93%
threo-9,10-	*trans*-	78%
erythro-6,7-	*cis*-	86%
threo-6,7-	*trans*-	83%

Dihydroxydocosanoic acid	Epoxide	
erythro-13,14-	*cis*-	79%
threo-13,14-	*trans*-	85%
Dihydroxyoctadecane		
erythro-9,10-	*cis*-	79%
threo-9,10-	*trans*-	81%

We next studied some reactions of the dihydroxy- and epoxy-acids. Lithium aluminium hydride reduced the dihydroxy-acids or their methyl esters to the expected triols. We thus obtained both forms of octadecane-1,9,10- and -1,6,7-triol and of docosane-1,13,14-triol. These were also prepared either by oxidation of the unsaturated alcohol with performic acid or of the hydrogen phthalate by alkaline permanganate.

When the reduction by lithium aluminium hydride was carried out in ether both the carboxyl and the oxiran group of the *cis*-epoxy-acids were reduced, whereas with the *trans*-isomers rapid reduction of only the carboxyl took place. For comparison the epoxy-alcohols were prepared by peracid oxidation of the olefinic alcohols, and from the vicinal dihydroxy-alcohols by the method described above.

Both *cis*- and *trans*-epoxy-acids with lithium aluminium hydride in tetrahydrofuran gave the diols formed by the reduction of the carbonyl group and reductive fission of the oxiran ring. Thus, both *cis*- and *trans*-9,10-epoxyoctadecanoic acid afforded a product, m. p. 68—69°, shown to be a mixture of octadecane-1,9- and -1,10-diol. For example, both 9(10)-oxo-octadecanoic acid (the hydration product of octadec-9-ynoic acid) and the 9(10)-hydroxyoctadecanoic acid derived from it by reduction with sodium borohydride, were reduced by lithium aluminium hydride to the same product, m. p. and mixed m. p. 68—69°. Alternatively, oxidation of the reduction product afforded 9(10)-oxo-octadecanoic acid, m. p. 72° (semicarbazone, m. p. 101—103°), identical with an authentic specimen.

Since this work was completed, Fore and Bickford[18] have reported the catalytic reduction of *cis*-9,10-epoxyoctadecyl acetate to octadecane-1,9(10)-diol, m. p. 62—65° (not purified), which on oxidation was converted into 9(10)-oxo-octadecanoic acid and without purification thence by a Beckmann rearrangement into a mixture of nonanedioic

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[18] Fore and Bickford, *J. Org. Chem.*, 1959, **24**, 620.

and decanedioic acid. They concluded that fission of the oxiran ring had taken place in both directions.

The American workers also drew attention to the results of Mack and Bickford,[7] who reported the unidirectional opening of the oxiran ring in the catalytic reduction of *cis*- and *trans*-9,10-epoxyoctadecanoic acid, which afforded solely 10-hydroxyoctadecanoic acid. Since we have shown that hydride reduction of both *cis*- and *trans*-9,10-epoxyoctadecanoic acid afforded *the same* mixture of octadecanediols, we re-investigated the problem. Repetition of the work of Mack and Bickford gave experimental results identical with theirs. The melting point of the hydroxy-acid is in good agreement with that of synthetic 10-hydroxyoctadecanoic acid prepared by ourselves and by others. However, the melting point (71—72°) of the derived oxo-acid is not, since we have in another connection shown it to have m. p. 82—82·5°. We have already drawn attention to discrepancies in the melting points for the semicarbazones of 9- and 10-oxo-octadecanoic acid,[19] synthetic specimens giving semicarbazones, m. p. 110—111° and 117—118° respectively. A melting point of 72° for the oxo-acid and 101—102° for the derived semicarbazone are those obtained for the ~2 : 3 mixture of 9- and 10-oxo-octadecanoic acids obtained by the hydration of octadec-9-ynoic acid.[20] We conclude that hydrogenation of *cis*- and *trans*-9,10-epoxyoctadecanoic acid is not unidirectional as postulated by Mack and Bickford,[7] but leads to a mixture of 9- and 10-hydroxyoctadecanoic acid.

Moreover, we reduced synthetic 10-hydroxyoctadecanoic acid with lithium aluminium hydride to octadecane-1,10-diol, m. p. 70°. Similar reduction of the catalytic reduction product from either *cis*- or *trans*-9,10-epoxyoctadecanoic acid also afforded a product of m. p. 69—70°, but a mixed melting point was depressed by 5—6°.

Under similar conditions both *cis*- and *trans*-6,7-epoxyoctadecanoic acid on catalytic reduction gave 6(7)-hydroxyoctadecanoic acid, m. p. 73—74°, identical with an authentic specimen prepared either by hydroxylation of octadec-*cis*-6-enoic acid or by borohydride reduction of 6(7)-oxo-octadecanoic acid (itself prepared by hydration of octadec-6-ynoic acid). Depending upon the reaction conditions, *cis*- and *trans*-6,7-epoxyoctadecanoic acid, when reduced by lithium aluminium hydride in ether, afforded either *cis*- or *trans*-6,7-epoxyoctadecan-1-ol, m. p. 52—53° and 56—58° respectively, whereas in tetrahydrofuran, or by prolonged reaction in ether, octadecane-1,6(7)-diol, m. p. 69—70°, was isolated. This product was also formed by reduction of 6(7)-hydroxyoctadecanoic acid with lithium aluminium hydride.

Likewise, catalytic reduction of *cis*- and *trans*-13,14-epoxydocosanoic acid afforded 13(14)-hydroxydocosanoic acid, m. p. 88°, identical with the hydration product of docos-13-ynoic acid. Confirmation was obtained by oxidation to 13(14)-oxodocosanoic acid, m. p. 83—84° (semicarbazone, m. p. 107—108°), showing no depression with the hydration product of docos-13-ynoic acid. Reduction of the epoxy-acids with lithium aluminium hydride in ether gave *cis*- and *trans*-13,14-epoxydocosan-1-ol, m. p. 66—67° and 63—64° respectively, whereas in tetrahydrofuran, or in ether under reflux, docosane-1,13(14)-diol, m. p. 78—79°, was obtained, identical with the hydride reduction product of either 13(14)-oxo- or 13(14)-hydroxy-docosanoic acid.

We wish to emphasize that the oxiran ring of the *trans*-epoxy-acid is much more resistant to reductive fission than that of the *cis*-isomer.

EXPERIMENTAL

erythro-*Dihydroxy Acids*.—Potassium permanganate (30 g.) in water (1 l.) was slowly added to a stirred solution of octadec-*cis*-9-enoic acid (30 g.) in water (3 l.) containing potassium hydroxide (30 g.) at 0—5°. Stirring was continued for a further 15 min., and then were added sodium hydrogen sulphite (30 g.) in water (100 ml.) followed by 17% w/v hydrochloric acid (300 ml.). After a further 5 minutes' stirring, the mixture was set aside, then the aqueous

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[19] Grey, McGhie, and Ross, *J.*, 1960, 1502.

[20] Robinson and Robinson, *J.*, 1926, 2204.

layer which separated was siphoned off and the solid was filtered off, pressed as dry as possible, and heated to boiling with ethyl acetate (400 ml.). The aqueous layer was removed and the hot ethyl acetate solution filtered and concentrated. *erythro*-9,10-Dihydroxyoctadecanoic acid which separated on cooling was filtered off and after being washed with light petroleum (b. p. 60—80°; 300 ml.) had m. p. 127—128°. Recrystallization from ethyl acetate afforded the pure dihydroxy-acid, m. p. 131—132° (50—60%).

By the same procedure, *erythro*-6,7-dihydroxyoctadecanoic acid, m. p. 124—125°, was prepared from octadec-*cis*-6-enoic acid in 65—70% yield.

For the preparation of *erythro*-13,14-dihydroxydocosanoic acid, the permanganate was added at room temperature, and it was advantageous to leave the reaction mixture overnight. Processing as described above afforded *erythro*-13,14-dihydroxydocosanoic acid, m. p. 131—132° (70—75%).

Oxidation of Unsaturated Acids by Peracetic Acid.—The oxidation of octadec-*cis*-9-enoic acid may be regarded as typical. The product may be processed to give either the epoxy- or the dihydroxy-acid.

(a) *Isolation of epoxy-acid.* Octadec-*cis*-9-enoic acid (20 g.) in chloroform (100 ml.) was treated with an excess of peracetic acid solution (15 ml.; 1 ml. = 0·08 g. of active O). Unless cooling was employed the reaction mixture boiled. After 15 min., titration indicated the theoretical uptake of oxygen. The mixture was left for a further 45 min., then the residual peracid was removed by repeated washing with water. Removal of the solvent afforded an oil, which solidified. Crystallization from acetone, at 0°, gave *cis*-9,10-epoxyoctadecanoic acid (16 g.), m. p. 59°.

By this procedure, with the same quantities of reactants, octadec-*trans*-9-enoic acid gave *trans*-9,10-epoxyoctadecanoic acid (15·6 g.), m. p. 55°, octadec-*cis*-6-enoic acid gave *cis*-6,7-epoxyoctadecanoic acid (16·1 g.), m. p. 60—61°, and octadec-*trans*-6-enoic acid gave *trans*-6,7-epoxyoctadecanoic acid (15·3 g.), m. p. 67—68°. Docos-*cis*-13-enoic acid afforded *cis*-13,14-epoxydocosanoic acid (18 g.), m. p. 63·5°, and docos-*trans*-13-enoic acid gave *trans*-13,14-epoxydocosanoic acid (16·2 g.), m. p. 70°.

(b) *Formation of dihydroxy-acid.* The product from procedure (a) (from 100 g. of octadec-*cis*-9-enoic acid) was heated under reflux with glacial acetic acid (500 ml.) (this gave a better product than did 90—100% formic acid) for 90 min. After removal of the excess of acetic acid under reduced pressure, the product was hydrolysed with 20% sodium hydroxide solution (500 ml.) for 1 hr. After acidification, the product was filtered off, dissolved in hot ethyl acetate, and processed as described for the *erythro*-acid, to afford *threo*-9,10-dihydroxyoctadecanoic acid (75 g.), m. p. 94—95°. Similarly octadec-*cis*-6-enoic acid (100 g.) afforded *threo*-6,7-dihydroxyoctadecanoic acid (72 g.), m. p. 118—119°, and docos-*cis*-13-enoic acid (100 g.) gave *threo*-13,14-dihydroxydocosanoic acid (84 g.), m. p. 99—100°.

Epoxidation of Unsaturated Acids.—The epoxidation of *cis*-9-octadecenoic acid is typical.

(a) *With perbenzoic acid.* Octadec-*cis*-9-enoic acid (30 g.) in chloroform (50 ml.) was treated with an excess of perbenzoic acid in chloroform (300 ml.; 1 ml. = 0·0085 g. of active O). After 48 hr. at 0° the excess of peracid was destroyed by potassium iodide solution, and the liberated iodine was removed with sodium thiosulphate. After being washed, the chloroform solution was evaporated to dryness, and the residue was repeatedly extracted with boiling water to remove benzoic acid. The insoluble oil was removed and crystallized from acetone at 0°, *cis*-9,10-epoxyoctadecanoic acid (12 g.), m. p. 59°, being obtained. Treated similarly, octadec-*trans*-9-enoic acid (15 g.) gave *trans*-9,10-epoxyoctadecanoic acid (10 g.), m. p. 55·5°; octadec-*cis*-6-enoic acid (10 g.) gave *cis*-6,7-epoxyoctadecanoic acid (7·1 g.), m. p. 60°; the *trans*-6-enoic acid (5 g.) gave the *trans*-epoxide (3·6 g.), m. p. 67°; docos-*cis*-13-enoic acid (35 g.) gave *cis*-13,14-epoxydocosanoic acid (25·4 g.), m. p. 63·5°, and its *trans*-isomer (15 g.) gave *trans*-epoxide (12 g.), m. p. 70°.

(b) *With monoperphthalic acid.* The monoperphthalic acid was prepared according to the method given by Fieser.[21]

Octadec-*cis*-9-enoic acid (10 g.) in ether (150 ml.) was treated with ethereal monoperphthalic acid (150 ml.; 1 ml. = 0·006 g. of active O). After 7 days the phthalic acid which had separated was filtered off, the excess of peracid was destroyed with potassium iodide, and the iodine was then removed with sodium thiosulphate. The ethereal solution was washed, and after removal of the ether the residue was digested with chloroform. After cooling in ice for 30 min., the

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[21] Fieser, " Experiments in Organic Chemistry," Heath and Co., Boston, 1955, p. 329.

phthalic acid was filtered off, the chloroform solution was evaporated, and the residue crystallized from acetone at 0°, to give *cis*-9,10-epoxyoctadecanoic acid (8·5 g.), m. p. 59·5°.

Epoxidation of octadec-*trans*-9- and -*cis*- and -*trans*-6-enoic and of docos-*cis*- and *trans*-13-enoic acid under identical conditions afforded the corresponding epoxy-acids, the respective yields being 10, 9·0, 8·4, 8·4, and 8·0 g.

Conversion of Dihydroxy-acids into Epoxy-acids.—The conversion of *erythro*-9,10-dihydroxyoctadecanoic acid is typical. *erythro*-9,10-Dihydroxyoctadecanoic acid (20 g.) was dissolved with shaking in a solution (*d* 1·3; 200 ml.) of hydrogen bromide in glacial acetic acid, shaken for a further 3 hr., and left overnight. The product obtained on dilution with water and exhaustive extraction with light petroleum (b. p. 60—80°) and washing and evaporation of the solvent, was a viscous oil. This was heated with 0·5N-alcoholic potassium hydroxide (200 ml.) for 1 hr. On dilution with water, acidification with 50% acetic acid precipitated a solid, which was filtered off, washed, taken up in benzene, and dried azeotropically. After removal of the benzene, the residue was digested with light petroleum (b. p. 60—80°) and filtered from any insoluble dihydroxy-acid. Removal of the solvent and crystallization of the residue from acetone or acetone–light petroleum (b. p. 40—60°) at 0° gave *cis*-9,10-epoxyoctadecanoic acid (17·5 g.), m. p. 59°, identical with an authentic specimen.

Similarly, *threo*-9,10-dihydroxyoctadecanoic acid (10 g.) afforded *trans*-9,10-epoxyoctadecanoic acid (7·3 g.), m. p. 55°; *erythro*- and *threo*-6,7-dihydroxyoctadecanoic acid (10 g.) yielded *cis*- and *trans*-epoxyoctadecanoic acid (8·1 and 7·8 g.), m. p. 60° and 67° respectively; *erythro*- and *threo*-13,14-dihydroxydocosanoic acid gave *cis*- and *trans*-13,14-epoxydocosanoic acid (7·4 and 8·0 g.), m. p. 63·5° and 70° respectively.

Reduction of Dihydroxy-acids by Lithium Aluminium Hydride.—*erythro*-9,10-Dihydroxyoctadecanoic acid or its methyl ester (10 g.) was dissolved or suspended in anhydrous tetrahydrofuran or ether (100 ml.), and added to a stirred slurry of lithium aluminium hydride (5 g.) in ether (150 ml.). The mixture was stirred for 60 min. under reflux after the addition was complete (in the case of the *erythro*- and *threo*-13,14-dihydroxydocosanoic acid or their methyl esters, the reaction time was extended to 3 hr.). The excess of hydride was destroyed by dropwise addition of moist ether, and the mixture was then acidified with 0·1N-sulphuric acid. The organic layer was washed with distilled water, alkali, and finally water. After removal of the solvent the solid residue was dried azeotropically with benzene and crystallized from hexane–acetone, affording *erythro*-octadecane-1,9,10-triol (8 g.), m. p. 128—129°.

Similarly *threo*-9,10-dihydroxyoctadecanoic acid or its methyl ester (5 g.) afforded *threo*-octadecane-1,9,10-triol (4·5 g.), m. p. 82·5°; *erythro*- and *threo*-6,7-dihydroxyoctadecanoic acid or their methyl esters (5 g.) afforded erythro- (3·6 g.), m. p. 131—132° (Found: C, 71·7; H, 12·5. $C_{18}H_{38}O_3$ requires C, 71·5; H, 12·7%), and threo-*octadecane*-1,6,7-*triol* (3·2 g.), m. p. 85—87° (Found: C, 71·7; H, 12·5%); and *erythro*- and *threo*-13,14-dihydroxydocosanoic acid or their methyl esters (2·5 g.) afforded erythro- (1·6 g.), m. p. 128—129° (Found: C, 73·45; H, 12·9. $C_{22}H_{46}O_3$ requires C, 73·7; H, 12·9%), and threo-*docosane*-1,13,14-*triol* (1·9 g.), m. p. 90° (Found: C, 73·6; H, 12·9%).

For comparison these four triols were also prepared by oxidation of the hydrogen phthalate of the unsaturated alcohols with alkaline permanganate, or by epoxidation of the alcohols followed by hydrolysis of the epoxide ring. The unsaturated alcohols were prepared by reduction of the corresponding unsaturated acids or their methyl esters.

Preparation of Octadec-cis-6-*en*-1-*ol.*—This may be regarded as typical of the method adopted.

Octadec-*cis*-6-enoic acid (2 g.) in dry ether (80 ml.) was added in 15 min. to a stirred slurry of lithium aluminium hydride (1 g.) in dry ether (20 ml.). Stirring was continued for a further 45 min. The usual procedure gave an oil, which crystallized from light petroleum (b. p. 40—60°) at 0°, yielding needles of *octadec*-cis-6-*en*-1-*ol* (1·3 g.), m. p. 29—30° (Found: C, 80·2; H, 13·1. $C_{18}H_{36}O$ requires C, 80·5; H, 13·3%).

Octadec-trans-6-*en*-1-*ol* (1·8 g. from 2·5 g.) had m. p. 42—43° (Found: C, 80·3; H, 13·2%); docos-*cis*-13-en-1-ol (3·0 g. from 5·0 g.) had m. p. 34—35°, crystallizing from light petroleum (b. p. 40—60°) at 0° (characterized as the dibromide, m. p. 44—45°); *docos*-trans-13-*en*-1-*ol* (3·1 g. from 5·0 g.), m. p. 50—51°, crystallized in needles from light petroleum (b. p. 40—60°) (Found: C, 81·2; H, 13·8. $C_{22}H_{44}O$ requires C, 81·4; H, 13·7%).

The hydrogen phthalates of the unsaturated alcohols were prepared in the usual manner by using pyridine and phthalic anhydride.

Octadec-*cis*-6-enyl hydrogen phthalate had m. p. 30—32°, and the *trans*-isomer m. p. 42—44°; docos-*cis*-13-enyl hydrogen phthalate had m. p. 35—37°, and the *trans*-isomer m. p. 57—58°.

Oxidation of Hydrogen Phthalates by Alkaline Permanganate.—Octadec-*cis*-6-enyl hydrogen phthalate (1 g.) in 1·2% aqueous sodium hydroxide (250 ml.) was treated, with stirring, with potassium permanganate (1 g.) in water (100 ml.). After 15 minutes' stirring, the excess of permanganate was decomposed with sodium hydrogen sulphite, and the whole was acidified with 17% hydrochloric acid and extracted with ether. After being washed, the ether extracts were evaporated and the oily residue was hydrolysed by 3N-sodium hydroxide (20 ml.) at 100° for 1 hr. The alkaline solution was diluted with water and extracted with hot ethyl acetate. The ethyl acetate solution was washed and concentrated, whereupon small needles of *erythro*-octadecane-1,6,7-triol (0·35 g.; m. p. 131—132°) separated. This was identical with the reduction product from *erythro*-6,7-dihydroxyoctadecanoic acid.

Similarly was obtained *threo*-octadecane-1,6,7-triol (0·15 g. from 1 g.), m. p. 85—86°, identical with a specimen prepared by hydride reduction of *threo*-6,7-dihydroxyoctadecanoic acid.

Oxidation of Unsaturated Alcohols with Performic Acid.—Octadec-*cis*-6-en-1-ol (3 g.) in formic acid (18 ml.) was treated, with stirring, with hydrogen peroxide (100-vol.; 3 ml.). The temperature rose and was kept at 40° for 2 hr. Removal of the solvent yielded a brown oil, which was hydrolysed with 3N-sodium hydroxide (50 ml.) for 1 hr. at 100°. Acidification with 17% hydrochloric acid gave a pale yellow solid, which was filtered off, washed, and dried azeotropically with benzene. Crystallization from ethyl acetate afforded small plates of *threo*-octadecane-1,6,7-triol (2 g.), m. p. 85—86°.

Similarly octadec-*trans*-6-en-1-ol (3 g.) afforded leaflets of the *erythro*-triol (2·4 g.), m. p. 131—132°.

erythro- and *threo*-Docosane-1,13,14-triol were prepared similarly. The *erythro*-triol (0·75 g. from 1 g.) had m. p. 128—129°, and the *threo*-triol (0·6 g. from 1 g.) had m. p. 90°.

Reduction of Epoxy-acids by Lithium Aluminium Hydride.—(a) *In ether. cis*-9,10-Epoxyoctadecanoic acid or its methyl ester (10 g.) in anhydrous ether (100 ml.) was added to a stirred slurry of lithium aluminium hydride (5 g.) in ether (500 ml.). After 15 min., the excess of hydride was destroyed by acetone, and the whole was acidified with 0·1N-sulphuric acid. Evaporation of the washed and dried (Na_2SO_4) ethereal layer left an oil, which readily solidified. This was crystallised from acetone at 0° to give octadecane-1,9(10)-diol (6·9 g.), m. p. 69—70° (Found: C, 75·9; H, 13·2. Calc. for $C_{18}H_{38}O_2$: C, 75·5; H, 13·4%).

Similarly, *cis*-6,7-epoxyoctadecanoic acid (10 g.) afforded a *diol* (6·5 g.), m. p. 69—70° (Found: C, 75·7; H, 13·0%); also *cis*-13,14-epoxydocosanoic acid (2 g.) gave *docosane*-1,13(14)-*diol* (1·5 g.), m. p. 78—79° (Found: C, 77·3; H, 13·3. $C_{22}H_{46}O_2$ requires C, 77·2; H, 13·5%).

Under identical conditions the *trans*-epoxy-acids afforded the epoxy-alcohols, namely, *trans*-9,10-epoxyoctadecan-1-ol (4 g. from 5 g.), m. p. 49—50° (from alcohol) (Found: C, 75·9; H, 12·7. Calc. for $C_{18}H_{36}O_2$: C, 76·0; H, 12·8%), trans-6,7-*epoxyoctadecan*-1-*ol* (1·7 g. from 2·0 g.), m. p. 56—58° (from hexane) (Found: C, 76·1; H, 13·0%), and trans-13,14-*epoxydocosan*-1-*ol* (4 g. from 5 g.), m. p. 63—64° (from alcohol) (Found: C, 77·8; H, 10·6. $C_{22}H_{41}O_2$ requires C, 77·6; H, 10·6%).

The last two epoxy-alcohols were also prepared by epoxidation of the corresponding *trans*-unsaturated alcohols with peracetic or perbenzoic acid. These products were identical with those prepared by reduction of the *trans*-epoxy-acids with lithium aluminium hydride.

(b) *In tetrahydrofuran. cis*- or *trans*-9,10-Epoxyoctadecanoic acid or its methyl ester (2 g.) in tetrahydrofuran (100 ml.) was added in 15 min. to a stirred suspension of lithium aluminium hydride (2 g.) in tetrahydrofuran (100 ml.). The mixture was heated under reflux for 90 min. The product, isolated as in (a), had m. p. 69—70° (Found: C, 75·6; H, 13·1. Calc. for $C_{18}H_{38}O_2$: C, 75·5; H, 13·4%).

Likewise, *cis*- and *trans*-6,7-epoxyoctadecanoic acid (2 g.) afforded the diol (1·3 g.), m. p. 68—70° (Found: C, 76·8; H, 13·2%), and *cis*- and *trans*-13,14-epoxydocosanoic acid (2·5 g.) gave a diol (1·8 g.), m. p. 78—79° (Found: C, 77·4; H, 13·4%).

Reduction of Hydroxy- and Keto-acids by Lithium Aluminium Hydride.—9(10)-Hydroxy- or 9(10)-oxo-octadecanoic acid (5 g.) in ether (100 ml.) was added in 15 min. to a stirred slurry of lithium aluminium hydride (5 g.) in ether (200 ml.). After a further 60 minutes' stirring the product was isolated as usual, being octadecane-1,9(10)-diol (4 g.), m. p. 70° (from ethanol). It was identical with a specimen prepared by the hydride reduction of *cis*-9,10-epoxyoctadecanoic acid. A mixed m. p. determination with the product obtained from *cis*-9,10-epoxyoctadecanoic acid by catalytic reduction followed by hydride reduction showed a depression of 5—6°.

Similarly, 6(7)-hydroxy- or 6(7)-oxo-octadecanoic acid afforded a diol, m. p. 69—70°; also 13(14)-hydroxy- or 13(14)-oxo-docosanoic acid gave a diol, m. p. 78—79°.

Catalytic Reduction of cis- *and* trans-*Epoxy-acids.*—*cis*-9,10-Epoxyoctadecanoic acid (5 g.) in acetic acid (60 ml.) was hydrogenated at room temperature in the presence of 10% palladium-charcoal (1·5 g.) for 24 hr. (or for 1 hr. at 80°). The product, isolated in the usual way and crystallized from acetone, had m. p. 81° (2·5 g.) (Found: C, 71·9; H, 12·0. Calc. for $C_{18}H_{36}O_3$: C, 72·0; H, 12·1%).

trans-9,10-Epoxyoctadecanoic acid (2 g.) was hydrogenated as for the *cis*-isomer, but for 48 hr. at 5 atm. The crude material (1·95 g.) had m. p. 70°, which on several crystallizations was raised to 81° (0·9 g.); it was identical with the product from the *cis*-isomer.

The hydrogenation product (0·5 g.) in acetic acid (30 ml.) was oxidized with chromium trioxide (0·25 g.) in water (3 ml.) for 2 hr. at 60°. The usual procedure gave a product (0·26 g.), m. p. 71° (Found: C, 72·6; H, 11·5. Calc. for $C_{18}H_{34}O_3$: C, 72·4; H, 11·5%); the semicarbazone had m. p. 101—102° (Found: C, 64·2; H, 10·6; N, 11·7. Calc. for $C_{19}H_{37}O_3N_3$: C, 64·2; H, 10·5; N, 11·8%). These values confirm the product as a mixture of 9- and 10-oxo-octadecanoic acid containing 58% of 10-oxo-octadecanoic acid. Further, the product was identical with a sample prepared by hydration of octadec-9-ynoic acid, which is known to form a semicarbazone of m. p. 101—102°.

By the procedure used for *cis*-9,10-epoxyoctadecanoic acid, *cis*-6,7-epoxyoctadecanoic acid (5 g.) afforded 6(7)-*hydroxyoctadecanoic acid* (2·1 g.), m. p. 73—74° (Found: C, 72·1; H, 12·2. $C_{18}H_{36}O_3$ requires C, 72·0; H, 12·1%). Hydrogenation of *trans*-6,7-epoxyoctadecanoic acid (5 g.), as described for *trans*-9,10-epoxyoctadecanoic acid, afforded the same product (1·9 g.), m. p. 73—74°. A mixed m. p. with the hydration product of octadec-6-ynoic acid (with formic acid) showed no depression. Oxidation gave 6(7)-oxo-octadecanoic acid, m. p. 75—76° (semicarbazone, m. p. 115—116°), identical with a specimen prepared by hydration of octadec-6-ynoic acid; the latter keto-acid had m. p. 74—76° and gave a semicarbazone, m. p. 115—116°.

Similarly, *cis*- and *trans*-13,14-epoxydocosanoic acid (5 g.) afforded the same 13(14)-hydroxydocosanoic acid, m. p. 89—90° (2·1 and 1·3 g. respectively) (Found: C, 74·0; H, 12·3. Calc. for $C_{22}H_{44}O_3$: C, 74·1; H, 12·4%). Comparison with authentic 13(14)-hydroxydocosanoic acid, m. p. 89—90°, showed them to be identical, whereas oxidation afforded 13(14)-oxodocosanoic acid, m. p. 84° (semicarbazone, m. p. 107—108°), which was identical with the hydration product of docos-13-ynoic acid, m. p. 84° (semicarbazone, m. p. 107—108°).

Oxidation of Octadecane-1,10-*diol.*—To the diol (2·5 g.) in acetic acid (100 ml.) was added chromic acid (2·5 g.) in water (10 ml.) at 40°, during 45 min. After a further 3 hr., any excess of oxidant was destroyed by the addition of sodium hydrogen sulphite solution. Subsequent dilution with water afforded a greenish solid, which was dissolved in dilute sodium carbonate solution, boiled therein for 10 min. and filtered from insoluble material. Acidification afforded a white solid (2·0 g.), which crystallized from ethyl acetate, giving 10-oxo-octadecanoic acid, m. p. 81—82° (semicarbazone, m. p. 118—119°).

Similar treatment of the product (2·5 g.) obtained from *cis*-9,10-epoxyoctadecanoic acid by catalytic reduction followed by hydride reduction afforded a product (2·1 g.), m. p. 71° (semicarbazone, m. p. 101—102°). These are the values for a 2 : 3 mixture of 9/10-oxo-octadecanoic acid.

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