

Studies on Succinic Acids

I. Preparation of α,α' -Dialkyl- and Tetraalkyl-Substituted Succinic Acids by Kolbe Electrolysis

LENNART EBERSON




Department of Organic Chemistry, Chemical Institute, University of Lund, Sweden

This paper is the first one in a series dealing with problems concerning the stereochemistry of alkyl-substituted succinic acids. The preparation of α,α' -dimethyl-, α,α' -diethyl-, α,α' -diisopropyl-, α,α' -di(*tert.*-butyl)-, α,α' -dineopentyl-, α,α' -dicyclohexyl-, α,α' -dimethyl- α,α' -diethyl-, tetraethyl-, α,α' -diethyl- α,α' -diisopropyl-, $\alpha,\alpha,\alpha',\alpha'$ -bis(ethylene)-, $\alpha,\alpha,\alpha',\alpha'$ -bis(trimethylene)-, and $\alpha,\alpha,\alpha',\alpha'$ -bis(tetramethylene)-succinic acids by Kolbe electrolysis of the corresponding malonic monoesters in methanolic solution and subsequent hydrolysis of the coupled products is described. Treatment with concentrated sulphuric acid at moderate temperatures has been found to be an effective and rapid hydrolysis method for the sterically hindered succinic esters. The melting points of the acids are found to be dependent on the method of determination, generally being appreciably higher when determined with a Kofler apparatus than with the conventional capillary method in an electrically heated block.

The Kolbe electrolysis method has frequently been used for the preparation of α,α' -dialkyl- and tetraalkyl-substituted succinic acids from half esters of mono- and dialkylmalonic acids¹⁻⁶. Most of these electrolyses have been carried out in aqueous solution and a reinvestigation with methanol as solvent seemed desirable, as the conditions for obtaining optimum yields are less critical in this medium⁷. Moreover, the electrolysis of malonic esters containing alkyl groups of more varying type should give a better understanding of the scope and limitations of the reaction.

The electrolyses were carried out in methanolic solution at a smooth platinum anode with a current density of about 0.5 A/cm². The pH of the solution was below 7 and the temperature was kept below 35° by external cooling. The results of the present and earlier investigations are summarized in Table 1.

Table 1. Yield of coupled products.

Substituents in the malonic half ester	Yield (%) of succinate in the present investigation ^a	Yield (%) of succinate and electrolysis medium in earlier investigations
CH ₃ , H	34	40 ^b ; water ¹
C ₂ H ₅ , H	42	46 ^b ; water ¹
<i>iso</i> -C ₃ H ₇ , H	67	
<i>tert.</i> -C ₄ H ₉ , H	85 ^c	
<i>neo</i> -C ₅ H ₁₁ , H	52	
(CH ₃) ₂ SiCH ₃ , H		40; methanol ²
<i>cyclo</i> -C ₆ H ₁₁ , H	63	17; water ³ 33 ^b ; water ¹
CH ₃ , CH ₃		21; methanol-pyridine ⁴ 25; methanol ⁴
CH ₃ , C ₂ H ₅	28 ^c	
C ₂ H ₅ , C ₂ H ₅	32	12 ^b ; water ¹ not stated; water ⁵
C ₂ H ₅ , <i>iso</i> -C ₃ H ₇	22	
<i>n</i> -C ₃ H ₇ , <i>n</i> -C ₃ H ₇		not stated; water ⁶
<i>iso</i> -C ₃ H ₇ , <i>iso</i> -C ₃ H ₇	0	
	12 ^c	
	22 ^c	
	17 ^c	

^a Based on unrecovered malonic diester. ^b Product of unspecified purity. ^c *Trans*-esterification occurred.

The complication that *trans*-esterification occurred with some of the esters investigated was not serious, as no difficulties in the purification of the coupled products were introduced by this reaction, especially as the preparation of the acids was the main purpose.

HYDROLYSIS OF THE SUCCINIC ESTERS

Diethyl α,α' -dimethyl- and α,α' -diethylsuccinate were hydrolyzed by boiling with concentrated hydrochloric acid and 50 % sulphuric acid, respectively, and separated into diastereoisomers by fractionated crystallization from water. Diethyl α,α' -diisopropylsuccinate on hydrolysis with 78 % sulphuric acid exclusively gave the anhydride of the low-melting form of α,α' -diisopropylsuccinic acid. Hydrolysis by warming the ester with concentrated sulphuric acid for a few minutes gave a mixture of the high-melting acid and the anhydride of the low-melting acid. The product from the electrolysis of monoethyl *tert.*-butylmalonate was first purified by distillation *in vacuo* and then separated into two solid diethyl α,α' -di(*tert.*-butyl)-succinates, m.p. 85—87°

and 36—40°, and a liquid dimethyl ester. The ester with m.p. 85—87° on treatment with concentrated sulphuric acid at 80° for 5 min gave a mixture of high-melting α,α' -di(*tert.*-butyl)-succinic acid and the anhydride of the low-melting diastereoisomer which was converted into the corresponding acid by boiling with 20 % potassium hydroxide. The ester with m.p. 36—40° on treatment with concentrated sulphuric acid gave the anhydride of the low-melting form, while the liquid dimethyl ester gave a mixture of high-melting acid and anhydride of the low-melting acid.

Diethyl α,α' -dineopentylsuccinate and its silicon analogue, diethyl α,α' -bis(trimethylsilylmethyl)-succinate², were readily hydrolyzed by boiling with ethanolic potassium hydroxide, and the acid mixtures obtained were separated into diastereoisomers by fractionated crystallization from suitable solvents.

Murray and Taylor³ separated the solid diethyl esters of α,α' -dicyclohexylsuccinic acid and found that they were difficult to hydrolyze in alkaline media, and instead used heating with a mixture of concentrated sulphuric acid, acetic acid, and water. However, warming with concentrated sulphuric acid for a few minutes again was found to effect hydrolysis. The high-melting ester gave the high-melting acid, whereas the low-melting one gave the anhydride of the low-melting acid. No interconversion of the diastereoisomers was observed, which was the case under the vigorous conditions used by Murray and Taylor.

The α,α' -dimethyl- α,α' -diethyl-, tetraethyl- and α,α' -diethyl- α,α' -diisopropylsuccinates all were very resistant to hydrolysis in alkaline media, but they were easily converted into the corresponding anhydrides by concentrated sulphuric acid at 70—80°. The anhydrides on boiling with strong potassium hydroxide solution and subsequent acidification gave the acids. The $\alpha,\alpha,\alpha',\alpha'$ -bis(ethylene)- and $\alpha,\alpha,\alpha',\alpha'$ -bis(trimethylene)-succinates were hydrolyzed by boiling with 10 % ethanolic potassium hydroxide. The $\alpha,\alpha,\alpha',\alpha'$ -bis(tetramethylene)-succinate required treatment with concentrated sulphuric acid for effecting hydrolysis and then gave $\alpha,\alpha,\alpha',\alpha'$ -bis(tetramethylene)-succinic anhydride, m.p. 62—63°. The anhydride readily dissolved in warm 20 % potassium hydroxide solution and on acidification the corresponding acid was obtained.

DETERMINATION OF THE MELTING POINTS

It is well known that an alkyl-substituted succinic acid decomposes into the corresponding cyclic anhydride and water on heating near its melting point. This phenomenon lowers the melting point and makes it dependent on the rate and time of heating and the method of determination. This is clearly shown in Table 2, which gives melting points for the above acids plus tetramethylsuccinic acid under varying conditions. The first column refers to determination with the Kofler apparatus, the heating block being pre-warmed to about 30° below the melting point before introduction of the sample, and then heated at a rate of about 2°/min. The second and third columns give melting points by the conventional capillary method with open and sealed capillaries, respectively, under the same heating conditions as above. The sealed capillaries were wholly immersed into the electrically heated block to

Table 2. Melting points of alkyl-substituted succinic acids.

Succinic acid	Melting point, °C, Kofler apparatus	Melting point, °C, open capillary	Melting point, °C, sealed capillary	Melting point, °C, from the literature	Reference
<i>Racem-a,a'</i> -dimethyl-	121—122.5	120—122.5	119.5—122	123—127	8
<i>Meso-a,a'</i> -dimethyl-	197—201	195—197	192 —195	209	8
<i>Racem-a,a'</i> -diethyl-	130—134	132—133	129.5—130.5	131—133	9
<i>Meso-a,a'</i> -diethyl-	204—206	192.5—194	187 —191	194—195	9
<i>Racem-a,a'</i> -diisopropyl-	193—197	166.5—169	163 —164	171	10
<i>Meso-a,a'</i> -diisopropyl-	228—235	221.5—223	214 —216	226—228	10
<i>Racem-a,a'</i> -di-(<i>tert.</i> -butyl)-	159—162	151—152	145 —146.5		
<i>Meso-a,a'</i> -di-(<i>tert.</i> -butyl)-	294—303	310—312	294.5—297.5		
<i>Racem-a,a'</i> -dineopentyl-	182—184	169—171.5	165 —171		
<i>Meso-a,a'</i> -dineopentyl-	274—275	270—271	266 —269		
<i>Racem-a,a'</i> -bis-(trimethylsilylmethyl). ²	164—166	160—162	158 —162		
<i>Meso-a,a'</i> -bis-(trimethylsilylmethyl). ²	245—246	229—232	225 —229		
<i>Racem-a,a'</i> -dicyclohexyl-	151—154	143—146	139 —143.5	147	3
<i>Meso-a,a'</i> -dicyclohexyl-	236—238	219—222	218 —221.5	225	3
Tetramethyl ^a .		176—178	180 —183	192	11
<i>a,a'</i> -dimethyl- <i>a,a'</i> -diethyl-	157—160	142—144	140 —141	147—148	12
Tetraethyl-	140—143	128—129	125.5—126.5	150—151	12
<i>a,a'</i> -diethyl- <i>a,a'</i> -diisopropyl-	123—129	122—125	117.5—122		
<i>a,a,a',a'</i> -bis-(ethylene)-		sublimes	sublimes	256 —275	
<i>a,a,a',a'</i> -bis-(trimethylene)-	201—203	182—185	184 —186		
<i>a,a,a',a'</i> -bis-(tetramethylene)-	202—204	167—174	170 —174	157.7—158.5	13

^a Tetramethylsuccinic acid was prepared from *isobutyric* acid and potassium persulphate according to Fichter and Heer¹⁴.

prevent the decomposition products from distilling to the cold parts of the capillary. The last column gives melting points from the literature, the most recent values having been selected all of which have probably been determined by the capillary method.

The rather large discrepancy between the Kofler and capillary method is readily explained by the fact that the decomposition products can escape almost freely from the unchanged acid in the Kofler apparatus, while this is more difficult in an open capillary and impossible in a sealed one. Even the Kofler method may give melting points differing by as much as 15° for different samples from the same bulk of a substance, dependent on the rate of heating, especially for the tetra-alkylated acids. The values in Table 2 may therefore be too low, and it is possible that other investigators will find still higher melting points. However, the melting point determined in a sealed capillary (which is not a real melting point but a mixed melting point between acid and anhydride under the pressure of acid, anhydride, and water in the vapour phase) was found to be comparatively insensitive to the heating conditions and thus is of value for identification purposes.

Tetraethyl and *a,a'*-diethyl-*a,a'*-diisopropylsuccinic acids in the solid phase slowly pass into their anhydrides on standing even at room temperature, while the low-melting forms of *a,a'*-diisopropyl-, *a,a'*-di-(*tert.*-butyl)-, and *a,a'*-dicyclohexylsuccinic acids, and *a,a'*-dimethyl-*a,a'*-diethyl- and *a,a,a',a'*-bis-(tetramethylene)-succinic acids tend to lose water during recrystallization.

CONFIGURATIONS OF THE DIASTEREISOMERS

The low-melting forms of α,α' -dimethyl- and α,α' -diethylsuccinic acid have previously been shown to be *racemic* by resolution with appropriate alkaloids^{15,16}. In this paper it is shown by means of partial resolution with brucine that the low-melting forms of α,α' -diisopropyl- and α,α' -di(*tert.*-butyl)-succinic acid possess *racemic* configurations; knowledge of the configuration is necessary for the discussion in coming papers of this series. By analogy in melting points, solubility, and especially the behaviour on anhydridization by heat the low-melting forms of α,α' -dineopentyl- and α,α' -bis-(trimethylsilylmethyl)-succinic acid² are tentatively ascribed the *racemic* configuration, as also Murray and Taylor³ have done in the case of α,α' -dicyclohexylsuccinic acid.

Stefl¹⁷ has stated that an α,α' -dimethyl- α,α' -diethylsuccinic acid with m.p. 173° prepared by him was partially resolvable into optically active components by means of brucine. However, the structure of this acid is questionable, as Stefl has shown it to undergo conversion into an anhydride, claimed to be of opposite configuration, which requires the assumption of breaking and recombination of C—C bonds in good yields if actually α,α' -dimethyl- α,α' -diethylsuccinic acid should be involved. It has been shown that optically active compounds which have no possibility to enolize at the asymmetric center, cannot be racemized even under very vigorous conditions¹⁸. The present author has not been able to reproduce this conversion with a sample of the acid prepared by the Kolbe method. No resolution experiments have been attempted, and as only one isomer has been obtained any conclusions regarding the configuration cannot be drawn. The same applies to α,α' -diethyl- α,α' -diisopropylsuccinic acid.

EXPERIMENTAL

Preparation of the succinic esters

Preparation of the monoethyl malonates. The malonic diester, 0.5 mole, was dissolved in 200 ml of absolute ethanol and a solution of 0.5 mole of potassium hydroxide in 300 ml of absolute ethanol added with good agitation during 5 min. The mixture was allowed to stand over night, whereupon the ethanol was distilled off with gradual addition of water. Unreacted diester was removed by extraction with ether, and the aqueous layer was acidified with concentrated hydrochloric acid. The monoester was extracted with ether and the ether solution thoroughly washed with water. Benzene (about one third of the volume of the solution) was added and finally the solvents were distilled off under reduced pressure at 40–50° to avoid decomposition. By this procedure dry crude monoester was obtained which was sufficiently pure to be directly used in the electrolysis experiments.

Electrolysis of the monoethyl malonates. The electrolysis of a substituted malonic monoester was carried out according to the following procedure: Dry crude monoester, prepared from 0.5 mole of diester according to the above method, was dissolved in 150–200 ml of methanol together with 0.5–1 g of sodium. The mixture was placed in a cell consisting of a 400 ml beaker fitted with a water cooling jacket, a mechanical stirrer, a platinum spiral anode (surface area 3.0 cm²), a platinum net cathode (total surface area ca. 50 cm²), and a thermometer reaching into the liquid. A current of 1.5–2.0 A was passed through the solution until it became neutral. Rapid agitation and passing a rapid stream of tap water through the cooling jacket was necessary to keep the temperature of the electrolyte below 35°.

Table 3. Physical constants and analyses of substituted succinic esters.

Substituents in the succinate	B.p., °C	Pres-sure, mm Hg	M. P., °C	n_D^{20}	d_4^{20}	r_D		% C		% H	
						found	calc.	found	calc.	found	calc.
<i>a,a'</i> -dimethyl	98—99	11		1.4223	0.9988	0.2546	0.2557	59.3	59.4	8.9	9.0
<i>a,a'</i> -diethyl	113—116	11		1.4273	0.9757	0.2633	0.2650	62.6	62.6	9.5	9.6
<i>a,a'</i> -diisopropyl	125—127	11		1.4350	0.9650	0.2704	0.2722	64.8	65.1	10.1	10.1
<i>a,a'</i> -di-(<i>tert.</i> -butyl) ^a			85—87					67.4	67.1	10.5	10.6
<i>a,a'</i> -di-(<i>tert.</i> -butyl) ^a			36—40					66.9	67.1	10.5	10.6
<i>a,a'</i> -di-(<i>tert.</i> -butyl) ^a	111—112	2.5		1.4455	0.9774	0.2726	0.2722	^b 64.8	65.1	^b 10.1	10.1
<i>a,a'</i> -dineopentyl	117—118	2		1.4374	0.9317	0.2818	0.2828	68.7	68.7	10.8	10.9
<i>a,a'</i> -dicyclohexyl ^c			119—121								
<i>a,a'</i> -dicyclohexyl ^c			59—62								
<i>a,a'</i> -dimethyl- <i>a,a'</i> -diethyl	128—132	11		1.4443	1.0004	0.2658	0.2650	^b 63.4	62.6	^b 9.7	9.6
Tetraethyl	122—124	1		1.4595	1.0004	0.2736	0.2777	66.9	67.1	10.6	10.6
<i>a,a'</i> -diethyl- <i>a,a'</i> -diisopropyl	132—135	1.5		1.4607	0.9809	0.2796	0.2828	68.3	68.7	10.8	10.9
<i>a,a,a',a'</i> -bis-(ethylene)	105—112	5		1.4528	1.0814	0.2498	0.2464	^b 60.8	60.6	^b 7.7	7.1
<i>a,a,a',a'</i> -bis-(trimethylene)	108—113	2		1.4603	1.0673	0.2568	0.2545	^b 63.7	63.7	^b 8.4	8.1
<i>a,a,a',a'</i> -bis-(tetramethylene)	159—167	11		1.4730	1.0706	0.2621	0.2589	^b 66.9	66.1	^b 9.0	8.7

^a The separation of these esters is described below.

^b Calculated for dimethyl ester.

^c The crude product was separated into two forms according to Murray and Taylor ³. They found m.p.'s 120° and 60°, respectively.

The reaction product was isolated by dilution of the cell contents with water, distilling off the methanol on a water-bath, and taking up the organic layer in ether. The ether solution was washed with 5 % aqueous sodium carbonate and water and finally dried with anhydrous magnesium sulphate. The ether was distilled off and the residue fractionated *in vacuo*. In most cases also low-boiling material, probably consisting of disproportionation products from intermediate radicals ⁷, was obtained, but it was not further investigated.

Yields of coupled products are given in Table 1, and physical constants and analyses in Table 3.

Separation of the esters of a,a'-di-(tert.-butyl)-succinic acid. The crude product, isolated as above, was first purified by distillation, b. p. 102—110°/2 mm, whereby a semi-solid crystal mass was obtained. It was dissolved in boiling 90 % methanol and the solution allowed to cool slowly. The crystals were collected, m. p. 83—85°, m. p. after another recrystallization from the same solvent 85—87° (yield 31 %). The mother liquor was freed from solvent and vacuum-distilled, b. p. 109—112°/2.5 mm. This product was liquid but gradually deposited crystals on standing at 0° for one month, after which time the crystals were filtered on a sintered glassfunnel and sucked as dry as possible, m. p. 33—38°. They were dissolved in petroleum ether, the solution cooled to —80° and the solid rapidly filtered, m. p. 36—40° (yield 15 %).

The mother liquor from the filtration of the crystals with m. p. 33—38° was then very carefully fractionated in an efficient column and a fraction with b. p. 111—112°/2.5 mm was collected, according to analyses consisting of nearly pure dimethyl *a,a'*-di-(*tert.*-butyl)-succinate (yield 39 %).

Hydrolysis of the succinic esters

Melting points of the acids, determined as described above, are given in Table 2. Other melting points in the experimental part were determined with the Kofler apparatus unless otherwise stated. The neutralization equivalent weight of an acid was determined by potentiometric titration in 50 % ethanol (by weight) with standard alkali in the same solvent and was calculated from the most distinct break in the titration curve. The behaviour of these acids on titration will be discussed in a coming paper of this series.

a,a'-Dimethylsuccinic acid. Diethyl *a,a'*-dimethylsuccinate, 10.0 g, was hydrolyzed by boiling with concentrated hydrochloric acid for 8 h. After cooling the crystal mass was filtered off and the mother liquor extracted with ether. The ether was distilled off and the remaining solid combined with the first crystal crop dissolved in hot water. *Meso-a,a'*-dimethylsuccinic acid (4.1 g) crystallized out and was further purified by two recrystallizations from water.

The mother liquor was evaporated to dryness and the residue recrystallized four times from concentrated hydrochloric acid to give almost pure *racem-a,a'*-dimethylsuccinic acid (2.0 g).

a,a'-Diethylsuccinic acid. The diethyl ester was hydrolyzed by boiling with 50 % sulphuric acid over night and the acid mixture separated into *meso* and *racemic* forms according to Schotte and Rosenberg⁹.

a,a'-Diisopropylsuccinic acid. A. Diethyl *a,a'*-diisopropylsuccinate, 10.0 g, was boiled for 20 min with a mixture of concentrated sulphuric acid, 40 ml, and 20 ml of water. During this procedure the mixture became dark, probably due to oxidation. After cooling, it was diluted with water and the organic layer taken up in ether. The ether was distilled off and the residual oil (crude anhydride) dissolved in warm 10 % aqueous potassium hydroxide and finally the acid liberated by acidification with concentrated hydrochloric acid. Crude *racem-a,a'*-diisopropylsuccinic acid (7.8 g) was obtained, which was purified by recrystallization from ethyl acetate. It was necessary to keep the heating time as short as possible to avoid too much anhydridization.

B. Diethyl *a,a'*-diisopropylsuccinate, 10.0 g, was dissolved in 20 ml of concentrated sulphuric acid and warmed on a water-bath for 10 min. After cooling, the mixture was diluted with water and the organic components taken up in ether. The ether solution was extracted twice with 10 % sodium carbonate solution, which then on acidification gave crude *meso-a,a'*-diisopropylsuccinic acid (2.7 g). This acid was purified by recrystallization from hot glacial acetic acid.

The ether solution with the same treatment as above gave *racem-a,a'*-diisopropylsuccinic acid.

Partial resolution of low-melting a,a'-diisopropylsuccinic acid. Low-melting *a,a'*-diisopropylsuccinic acid, 4.04 g, and brucine, 7.88 g, were dissolved in 250 ml of hot water and the solution filtered warm. After standing for four days at room temperature the crystals formed were filtered off (6.3 g) and recrystallized twice from hot water. The acid was liberated by treatment with dilute hydrochloric acid, dried and recrystallized from ethyl acetate. It showed $[\alpha]_D^{20} = +1.5^\circ$ in absolute ethanolic solution. The rotation was small but significant, as the rotation of the alkaloid is of opposite sign.

a,a'-Di-(*tert.*-butyl)-succinic acid. High-melting diethyl *a,a'*-di-(*tert.*-butyl)-succinate, 5.0 g, was warmed with 10 ml of concentrated sulphuric acid at about 80° for 5 min. The solution was diluted with water and after cooling the crystal mass was filtered off, washed with water and finally dried. It was treated with 25 ml of boiling ethyl acetate, which left the *meso-a,a'*-di-(*tert.*-butyl)-succinic acid undissolved. The acid (1.2 g) was filtered from the hot solution and then recrystallized from boiling glacial acetic acid. (Found: C 62.6; H 9.6; equiv. wt. 116.1. Calc. for $C_{12}H_{22}O_4$: C 62.6; H 9.6; equiv. wt. 115.2.)

The mother liquor was evaporated to dryness leaving behind *racem-a,a'*-di-(*tert.*-butyl)-succinic anhydride (2.5 g), a small sample of which was recrystallized from 80 % aqueous acetone, m. p. 114–115°. (Found: C 67.9; H 9.5. Calc. for $C_{12}H_{20}O_3$: C 67.9; H 9.5.)

Crude anhydride, 2.0 g, was boiled with 20 % aqueous potassium hydroxide until it had completely dissolved, which required about 2 h. Acidification yielded an oil from which the aqueous layer was decanted and replaced by water. The mixture was heated to 80–90° whereby the oil quickly solidified and could be filtered off. It was recrystal-

lized from ethyl acetate or benzene. Care must be exercised in recrystallizing this compound, since prolonged boiling resulted in partial anhydrization. (Found: C 62.8; H 9.6; equiv. wt. 231.0. Calc. for $C_{12}H_{22}O_4$: C 62.6; H 9.6; equiv. wt. 230.3.)

The liquid dimethyl ester on the same treatment gave both *meso* acid and *racemic* anhydride, whereas the low-melting diethyl ester only gave *racemic* anhydride.

Partial resolution of low-melting α,α' -di-(tert.-butyl)-succinic acid. Low-melting α,α' -di-(tert.-butyl)-succinic acid, 8.3 g, and brucine, 14.2 g, were dissolved in 200 ml of boiling water, filtered, and allowed to cool slowly. The salt (11.1 g) was collected and recrystallized once from water. The acid was liberated by treatment with dilute hydrochloric acid and showed after recrystallization from benzene $[\alpha]_D^{20} = +6.1^\circ$ in absolute ethanolic solution. In spite of further recrystallizations of the brucine salt higher rotations could not be achieved.

α,α' -Dineopentylsuccinic acid. Diethyl α,α' -di-neopentylsuccinate, 10.0 g, was boiled with excess of 10 % ethanolic potassium hydroxide over night. The ethanol was distilled off with gradual addition of water, and on acidification a solid was obtained, which was filtered off and dried. The acid mixture was dissolved in boiling ethyl acetate, filtered, and allowed to cool slowly. *Meso- α,α' -dineopentylsuccinic acid* (3.7 g) crystallized out. It was recrystallized once from ethyl acetate. (Found: C 64.9; H 10.1; equiv. wt. 129.5. Calc. for $C_{14}H_{26}O_4$: C 65.1; H 10.1; equiv. wt. 129.2.)

The mother liquor from the above filtration was freed from ethyl acetate and the residue boiled with 15 ml of acetic anhydride for 3 h. The acetic anhydride together with acetic acid formed was distilled off *in vacuo* and the remaining oil dissolved in warm 10 % aqueous potassium hydroxide. On acidification the *racemic* form (3.1 g) was obtained, which was recrystallized from benzene. Before analysis it had to be dried at 105° for 2 h. (Found: C 65.3; H 10.2; equiv. wt. 130.0. Calc. for $C_{14}H_{26}O_4$: C 65.1; H 10.1; equiv. wt. 129.2.)

On anhydrization by heat the two isomers behaved analogously with the two forms of α,α' -bis-(trimethylsilylmethyl)-succinic acid², the high-melting form giving the anhydride of the low-melting acid and the low-melting form its own anhydride.

α,α' -Bis-(trimethylsilylmethyl)-succinic acid. The two forms of these acids have been prepared previously².

α,α' -Dicyclohexylsuccinic acid. High-melting diethyl α,α' -di-cyclohexylsuccinate, 5.0 g, was heated on a boiling water-bath with 10 ml of concentrated sulphuric acid for 4 min. A longer heating time caused isomerization. Cooling and dilution with water precipitated a solid which was filtered, dried and recrystallized from glacial acetic acid to give 3.1 g of pure *meso- α,α' -dicyclohexylsuccinic acid*.

Low-melting diethyl ester, 5.0 g, was heated on a boiling water-bath with 10 ml of concentrated sulphuric acid for 10 min. After cooling and dilution with water an oil was obtained which was taken up in ether, the ether distilled off, and the residue dissolved in boiling 10 % aqueous potassium hydroxide. Acidification gave an oil which did not solidify when trying the usual methods for effecting crystallization. However, boiling with water for a few minutes caused the oil to crystallize. The acid was collected, dried and recrystallized from benzene to give 2.8 g of *racem- α,α' -dicyclohexylsuccinic acid*. Care was required during this procedure, as prolonged boiling in benzene resulted in anhydrization.

α,α' -Dimethyl- α,α' -diethylsuccinic acid. Dimethyl α,α' -dimethyl- α,α' -diethylsuccinate, 10.0 g, was heated on a boiling water-bath with concentrated sulphuric acid for 15 min. Cooling and dilution with water yielded an oil which was taken up in ether. The ether was distilled off and the residue boiled with 10 % aqueous potassium hydroxide until it had dissolved, which required about 45 min. Acidification gave 7.1 g of *α,α' -dimethyl- α,α' -diethylsuccinic acid*, which was recrystallized from ethyl acetate. (Found: C 59.2; H 9.0; equiv. wt. 203.1. Calc. for $C_{10}H_{18}O_4$: C 59.4; H 9.0; equiv. wt. 202.2.)

Stefl¹⁷ described one liquid and one solid form of α,α' -dimethyl- α,α' -diethylsuccinic anhydride and also found that the liquid form dissolved on boiling with aqueous potassium hydroxide. On acidification an acid with m. p. 173° was obtained. If the liquid anhydride was dissolved in 40 % aqueous potassium hydroxide and the solution kept at reflux temperature for three days it was stated that the solid anhydride was obtained directly on acidification of the reaction mixture. No acid corresponding to this anhydride could be obtained. However, the present author was not able to reproduce this conver-

sion with *a,a'*-dimethyl-*a,a'*-diethylsuccinic anhydride prepared by the Kolbe method. Only *a,a'*-dimethyl-*a,a'*-diethylsuccinic acid with m. p. 155–159° was recovered in 85 % yield.

Tetraethylsuccinic acid. Diethyl tetraethylsuccinate on treatment with concentrated sulphuric acid as described in the foregoing preparation gave tetraethylsuccinic anhydride, m. p. 86–87°, in almost quantitative yield. The anhydride was converted into the acid by boiling with 40 % aqueous potassium hydroxide for 4 h. The yield of crude acid was 95 % and it was recrystallized from ethyl acetate, though with considerable loss due to anhydridization. After standing for about two years the solid acid had transformed into anhydride to an extent of about 30 %.

a,a'-Diethyl-*a,a'*-diisopropylsuccinic acid. Diethyl *a,a'*-diethyl-*a,a'*-diisopropylsuccinate, 10.0 g, was heated on a boiling water-bath with 20 ml of concentrated sulphuric acid for 5 min. Dilution with water produced an oil which was taken up in ether. The ether solution was washed with water and dried with anhydrous magnesium sulphate. The ether was distilled off and the anhydride distilled *in vacuo*, the main fraction (5.1 g) being collected at 140–143°/3 mm. The oil soon solidified and was recrystallized from petroleum ether at –80°, m. p. 44–50°. (Found: C 69.8; H 10.0. Calc. for $C_{14}H_{24}O_4$: C 70.0; H 10.1.)

a,a'-Diethyl-*a,a'*-diisopropylsuccinic anhydride, 2.0 g, was boiled with 20 % ethanolic potassium hydroxide for 2 h. The solution was evaporated to dryness and the residue treated with ice-cold dilute hydrochloric acid. The solid (1.8 g) was filtered, washed with water and rapidly dried in a vacuum-desiccator. A small sample was recrystallized from ethyl acetate as rapidly as possible and then analyzed immediately. (Found: C 65.5; H 10.2; equiv. wt. 261. Calc. for $C_{11}H_{20}O_4$: C 65.1; H 10.1; equiv. wt. 258.4.)

The solid acid spontaneously lost water on standing. After one month the m. p. (in a sealed capillary) was 80–105°, the depression being due to the presence of anhydride.

a,a,a',a'-Bis-(ethylene)-succinic acid. Dimethyl *a,a,a',a'*-bis-(ethylene)-succinate, 5.0 g, was boiled with 10 % ethanolic potassium hydroxide over night, the ethanol distilled off and the residue acidified with dilute hydrochloric acid. The solid was collected and recrystallized from 50 % acetic acid to give pure *a,a,a',a'*-bis-(ethylene)-succinic acid (3.1 g). (Found: C 56.3; H 5.8; equiv. wt. 84.5. Calc. for $C_8H_{10}O_4$: C 56.5; H 5.9; equiv. wt. 85.1.)

a,a,a',a'-Bis-(trimethylene)-succinic acid. Dimethyl *a,a,a',a'*-bis-(trimethylene)-succinate, 5.0 g, was boiled with 10 % ethanolic potassium hydroxide over night, the ethanol distilled off and the residue acidified with dilute hydrochloric acid. The solid was filtered and recrystallized from 50 % acetic acid to yield pure *a,a,a',a'*-bis-(trimethylene)-succinic acid (2.3 g). (Found: C 60.5; H 7.2; equiv. wt. 198.0. Calc. for $C_{10}H_{14}O_4$: C 60.6; H 7.1; equiv. wt. 198.2.)

a,a,a',a'-Bis-(tetramethylene)-succinic acid. Dimethyl *a,a,a',a'*-bis-(tetramethylene)-succinate, 5.0 g, was heated on a boiling water-bath together with 10 ml of concentrated sulphuric acid for 5 min. On dilution with water an oil separated which solidified upon cooling. The solid (3.6 g) was filtered and a small sample recrystallized from light petroleum, m. p. 65–66°. According to analyses it consisted of *a,a,a',a'*-bis-(tetramethylene)-succinic anhydride. (Found: C 69.4; H 7.8; Calc. for $C_{12}H_{16}O_3$: C 69.2; H 7.8.)

Crude anhydride, 3.1 g, was dissolved in 20 % aqueous potassium hydroxide by boiling for 15 min. Acidification yielded a solid which was recrystallized from 90 % acetic acid, though with loss due to anhydridization. According to analyses it was *a,a,a',a'*-bis-(tetramethylene)-succinic acid. (Found: C 63.7; H 8.1; equiv. wt. 225.3. Calc. for $C_{12}H_{16}O_4$: C 63.7; H 8.0; equiv. wt. 226.3.)

Overberger *et al.*¹³ found m. p. 63–64° for the anhydride.

The author wishes to express his sincere gratitude to Professor Erik Larsson for his kind interest in this work. A grant from *Doktor P. Håkansson's Stiftelse* is gratefully acknowledged.

REFERENCES

1. Crum Brown, A. and Walker, J. *Ann.* **274** (1893) 41.
2. Ebersson, L. *Acta Chem. Scand.* **10** (1956) 629.
3. Murray, A. K. and Taylor, T. W. *J. J. Chem. Soc.* **1937**, 1450.

4. Alberti, C. *Gazz. Chim. Ital.* **86** (1956) 1195.
5. Walker, J. and Walker, A. P. *J. Chem. Soc.* **87** (1905) 961.
6. Crichton, J. *J. Chem. Soc.* **89** (1906) 929.
7. Weedon, B. C. L. *Quart. Revs. (London)* **6** (1952) 380.
8. Linstead, R. P. and Whalley, M. *J. Chem. Soc.* **1954**, 3722.
9. Schotte, L. and Rosenberg, A. *Arkiv Kemi* **8** (1956) 551.
10. Bone, W. A. and Sprankling, C. H. G. *J. Chem. Soc.* **77** (1900) 654.
11. Ansell, M. F., Hickinbottom, W. J. and Holton, P. G. *J. Chem. Soc.* **1955**, 349.
12. Dox, A. W. *J. Am. Chem. Soc.* **47** (1925) 1471.
13. Overberger, C. G., Bilech, H., Huang, P. T. and Blatter, H. M. *J. Org. Chem.* **20** (1955) 1717.
14. Fichter, F. and Heer, J. *Helv. Chim. Acta* **18** (1935) 1276.
15. Berner, E. and Leonardsen, R. *Ann.* **538** (1939) 1.
16. Wren, H. and Haller, J. W. E. *J. Chem. Soc.* **1937**, 230.
17. Stefl, A. *Über Bernsteinsäure und ihre Homologen* (Diss.) München 1914.
18. Hückel, W. *Theoretische Grundlagen der Organischen Chemie*, Akademische Verlagsgesellschaft, Leipzig 1952.

Received October 1, 1958.