lowed by heating on the steam-bath. Inasmuch as 6-retenol is very difficultly soluble in aqueous alkali, these crystals were dissolved in hot, alcoholic potassium hydroxide and reprecipitated by means of concentrated hydrochloric acid. When the finely-divided, red solid thus obtained was boiled with a large volume of dilute potassium hydroxide, the greater portion of the material dissolved to a bright red solution. Acidification of the latter yielded a pale-yellow precipitate which, after filtration and drying, was recrystallized from xylene, giving slightly yellow scales, m. p. 163.5–164.5° (corr.). Mixed with an authentic specimen of 6-retenol, m. p. 162.5–163° (corr.), it melted at 162.5–163° (corr.).

6-Acetoxyretene.—6-Retenol was acetylated by means of acetic anhydride in the presence of anhydrous sodium acetate; white, silky needles from dilute ethanol, m. p. 133–133.5° (corr.). A mixture of this and an authentic specimen of 6-acetoxyretene of m. p. 134–135° (corr.) melted at 133–133.5° (corr.).

6-Retenecarboxylic Acid.—To a solution of 2 g. of 6-acetylretene in 100 cc. of dioxane and 20 cc. of 10% sodium hydroxide, there was added in small portions with shaking an aqueous solution of iodine in potassium iodide.[6] When the iodine color persisted at 60° for two minutes, excess sodium hydroxide was added and the solution was cooled. After dilution, the iodoform was filtered off and the filtrate acidified. A yellow precipitate formed. After drying at 110°, this solid (1.5 g.) was boiled with dilute potassium hydroxide (norite), reprecipitated with dilute acid, dried, and recrystallized from benzene, from which it appeared as small, white needles, m. p. 238–238.5° (corr.). Mixed with an authentic specimen of 6-retenecarboxylic acid of m. p. 238–238.5° (corr.), it melted at 236–237° (corr.).

Summary

1. The structure of 6-acetylretene has been established.

2. The synthesis of 6-retenecarboxylic acid from 6-acetylretene has been simplified by the use of an alkaline iodine–potassium iodide solution as the oxidant.

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[CONTRIBUTION NO. 116 FROM THE EXPERIMENTAL STATION OF E. I. DU PONT DE NEMOURS & COMPANY]

Preparation of Macrocyclic Lactones by Depolymerization[1]

BY E. W. SPANAGEL AND W. H. CAROTHERS

Lactones of the higher ω-hydroxy fatty acids were first successfully synthesized by oxidizing the corresponding cyclic ketones.[2] Preparation by the conventional methods is impossible because the acids tend to react intermolecularly yielding linear polyesters. Once this fact was clearly recognized it became evident[3] (p. 2551) that direct lactonization might be favored by application of the dilution principle first utilized by Ruggli;[4] and Stoll and Rouvé[5] have showed experimentally that this is indeed the case.

A third method for the preparation of large ester rings consists in depolymerizing the corresponding linear polyester. This was first realized with esters of carbonic and oxalic acids.[6] Later it was shown that, by the proper control of temperature and selection of catalysts, excellent results could also be obtained with glycol esters of other dibasic acids.[7]

We have now applied this method to the preparation of several lactones. The possibilities are indicated by the fact that a 70% yield of pure monomer was obtained from the polyester of hydroxytetradecanoic acid. Stoll and Rouvé[5] in a similar case report yields by the dilution method considerably higher than this, but their scale of operation was small (10 g.), the volume large (10 liters) and the time long (six days). Our depolymerization required only three and one-half hours for 32 g. of polyester. It appears therefore that this method has some advantages over the use of high dilution.

One of the objects of the present work was to obtain some lactones which had not been reported previously. Meanwhile Stoll and Rouvé have published a much more extended study[5] of lactonization by the dilution method covering in part the same ground. The overlapping results of the two investigations are in good agreement, but in several cases we are able to report slightly higher melting points than were found by Stoll and Rouvé.

As new compounds we report

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[1] Paper XXVIII on Polymerization and Ring Formation; Paper XXVII, THIS JOURNAL, **57**, 1131 (1935).

[2] Ruzicka and Stoll, *Helv. Chim. Acta*, **11**, 1159 (1928).

[3] Carothers, THIS JOURNAL, **51**, 2548 (1929).

[4] Ruggli, *Ann.*, **392**, 92 (1912).

[5] Stoll and Rouvé, *Helv. Chim. Acta*, **17**, 1283 (1934).

[6] Hill and Carothers, THIS JOURNAL, **55**, 5031 (1933).

[7] Spanagel and Carothers, *ibid.*, **57**, 929 (1935).

$\underline{O(CH_2)_2O(CH_2)_{10}CO}$

$\underline{O(CH_2)_4O(CH_2)_{10}CO}$ and

$\underline{O(CH_2)_2O(CH_2)_{10}COO(CH_2)_2O(CH_2)_{10}CO}$

The first two are rings of 15 and 17 atoms and their odors are definitely musk-like. These compounds are also of interest because the required hydroxy acids are relatively easily accessible from undecylenic acid through the addition of hydrogen bromide followed by reaction with the sodium derivative of the glycol.

TABLE I

EFFECT OF CATALYST ON YIELDS

Catalyst	Remarks	Crude yield, %	% of distillate dimer	% of distillate monomer
$MgCl_2 \cdot 6H_2O$	No reflux	73	36	64
$MgCl_2 \cdot 6H_2O$	Steam cooled reflux	53	3	97
MgO	No reflux	66	40	60
$MnCl_2 \cdot 4H_2O$	No reflux	63	47	53
$SnCl_2 \cdot 2H_2O$	No reflux	40	75	25
$CoCl_2 \cdot 6H_2O$	No reflux	27	62	48
Mg (powd.)	No reflux	20	83	27

TABLE II

EFFECT OF TEMPERATURE ON YIELDS

Temp., °C.	Time, hours	% crude yield	% dimer
270	2	73	26
260	2	30	12
260	5	58	15
250	2	28	10
250	5	52	12

The greater ease of forming rings of large size compared with intermediate size is again illustrated in the present study by the fact that hydroxytetradecanoic acid gave monomer and dimer in the ratio of 15/1 while for hydroxydecanoic acid the corresponding ratio was 0.17/1. Further evidence of specificity in the catalysis of ester depolymerizations was also found. Whereas in most of the cases previously examined, stannous chloride and various magnesium salts were almost equally effective, in the present work magnesium chloride was much more effective than any other material tested (*cf.* Table I).

Experimental Part

Polyesters were prepared by heating the hydroxy acids at 180–250° for three or four hours in a Claisen flask without added catalyst but with diminished pressure during the last hour.

Depolymerizations were carried out in the vapor heated still already described[7] at a pressure of 1 mm. or less. In some experiments a dephlegmator cooled with steam was inserted at the top of the still. It lowered the rate of distillation and increased the ratio of monomer to dimer.

TABLE III

YIELDS OF LACTONES

Polyester from	Polyester used, g.	Catalyst added	Time of heating to 270° (1 mm.) hrs.	Distillate, %	Distillate isolated as monomer, %	Distillate isolated as dimer, %
10-Hydroxydecanoic acid	20	$MgCl_2 \cdot 6H_2O$	2	65	12	70
13-Hydroxytridecanoic acid	95	$SnCl_2 \cdot 2H_2O$	4	55	Trace (odor)	50
14-Hydroxytetradecanoic acid	32	$MgCl_2 \cdot 6H_2O$	3.5	77	90	6
$HO(CH_2)_2O(CH_2)_{10}COOH$	75	$MgCl_2 \cdot 6H_2O$	4	64	66	6
$HO(CH_2)_3O(CH_2)_{10}COOH$	40	$MgCl_2 \cdot 6H_2O$	4	70	50	0
$HO(CH_2)_4O(CH_2)_{10}COOH$	60	$MgCl_2 \cdot 6H_2O$	3	55	76	0

TABLE IV

PROPERTIES OF LACTONES

Monomeric lactone from	Atoms in monomeric ring	M. p. of monomer, °C.	B. p. of monomer, °C.	Density of monomer d^{33}_4	Refractive index of n^{33}_D	Molecular refraction, MD Obsd.	Molecular refraction, MD Calcd.	Diff. EMD	M. p. of dimer, °C.
10-Hydroxydecanoic acid	11	6.0	113–15/15	0.9926	1.4655	47.40	47.90	−0.50	96[b]
11-Hydroxyundecanoic acid[a,c]	12	3.0	126–7/15	.9812	1.4662	51.97	52.50	− .53	74
13-Hydroxytridecanoic acid	14	....	....	....	....	...	...	...	84[c]
14-Hydroxy-12-oxa-tetradecanoic acid	15	8.0	108–11/1	.9916	1.4645	63.52	63.39	+ .13	106–107
15-Hydroxy-12-oxa-pentadecanoic acid[c]	16	12.0	119–20/2	.9762	1.4622	68.13	67.99	+ .14	.....
16-Hydroxy-12-oxa-hexadecanoic acid	17	−19.0	129–31/1	.9724	1.4646	72.68	72.60	+ .08	.....

[a] *Cf.* Stoll, Rouvé and Stoll-Comte, *Helv. Chim. Acta*, **17**, 1307 (1934). [b] *Cf.* Lycan and Adams, THIS JOURNAL, **51**, 3450 (1929); Carothers and Van Natta, *ibid.*, **55**, 4719 (1933). [c] *Cf.* Stoll and Rouvé, *Helv. Chim. Acta*, **18**, 1087 (1935).

Catalysts were explored using polyester (15 g.) from hydroxyundecanoic acid with 0.2 to 0.3 g. of the proposed catalyst at 270° during two hours. The distillate was dissolved in 50 cc. of alcohol and the crystalline dimer which separated on cooling was filtered off and weighed. The accumulated filtrates on distillation were shown to be largely monomer, and in the last column of Table I the indicated yields are based on the assumption that all not dimer was monomer.

The effect of *temperature* is indicated in Table II. In each case 20 g. of polyester from hydroxyundecanoic acid was heated with 0.5 g. of $MgCl_2 \cdot 6H_2O$. The ratio of monomer to dimer rises as the temperature falls, but the rate falls off quite rapidly at the same time.

The results for the depolymerization of polylactone derived from 10-hydroxydecanoic, 13-hydroxytridecanoic, 14-hydroxytetradecanoic acid and the ether acids are listed in Table III. Properties and analyses are indicated in Tables IV and V.

TABLE V

ANALYTICAL DATA

	C	H	Mol. wt.[a]
Lactone of 10-hydroxydecanoic acid			
Calcd. for $C_{10}H_{18}O_2$	70.58	10.58	170
Found	70.31	10.13	162
Dimeric lactone of 13-hydroxytridecanoic acid			
Calcd. for $C_{26}H_{48}O_4$	73.24	11.26	426
Found	73.46	11.30	407, 432
Dimeric lactone of 14-hydroxytetradecanoic acid			
Calcd. for $C_{28}H_{52}O_4$	74.33	11.50	452
Found	74.29	11.79	414
Lactone of 14-hydroxy-12-oxatetradecanoic acid			
Calcd. for $C_{13}H_{24}O_3$	68.42	10.52	228
Found	68.57	10.17	232
Dimeric lactone of 14-hydroxy-12-oxatetradecanoic acid			
Calcd. for $C_{26}H_{48}O_6$	68.42	10.52	456
Found	68.16	10.36	466
Lactone of 15-hydroxy-12-oxapentadecanoic acid			
Calcd. for $C_{14}H_{21}O_3$	69.42	10.74	242
Found	69.76	11.00	234
Lactone of 16-hydroxy-12-oxahexadecanoic acid			
Calcd. for $C_{15}H_{28}O_3$	70.3	10.93	256
Found	70.31	11.01	258

[a] Determinations made in freezing benzene.

Preparation of Materials

11-Hydroxyundecanoic was prepared from undecylenic acid and hydrobromic acid following Ashton and Smith.[8] Our best yields were 72% of the theoretical. Conversion of this to 11-hydroxyundecanoic acid was carried out as follows: a solution of 60 g. (1.5 moles) of sodium hydroxide and 132 g. (0.5 mole) of the bromo acid in one liter of water was refluxed for five hours. The filtered solution was cooled to about 5° for several hours whereupon the sodium salt of the acid separated. It was filtered off and redissolved in hot water. Acidification liberated the hydroxy acid as an oil which crystallized when cooled. One recrystallization from benzene gave 74 g. (72% of the theoretical amount) of fine crystals melting at 70°.

The Ether Hydroxy Acid $HO(CH_2)_2O(CH_2)_{10}COOH$.—One mole of sodium (23 g.) was dissolved in 248 g. of ethylene glycol. The mixture was then heated to 110–115° under reflux and stirred while 133 g. (0.5 mole) of 11-bromoundecanoic acid was added in four portions during one hour. Stirring and heating were continued for four hours and most of the glycol was removed by further heating *in vacuo*. The residue was dissolved in water, acidified, and extracted with ether. The crude acid after crystallization from petroleum ether was obtained as a white powder melting at 48–50°.

Anal. Calcd. for $C_{13}H_{26}O_4$: C, 63.41; H, 10.56; neut. equiv., 246. Found: C, 63.27; H, 10.36; neut. equiv., 244.

The ether hydroxy acid $HO(CH_2)_3O(CH_2)_{10}COOH$ was obtained similarly, m. p. 51°.

Anal. Neutral equivalent calcd. for $C_{14}H_{28}O_4$: 260. Found: 263.

The ether hydroxy acid $HO(CH_2)_4O(CH_2)_{10}COOH$, m. p. 53°.

Anal. Calcd. for $C_{15}H_{30}O_4$: C, 65.69; H, 10.95; neut. equiv., 274. Found: C, 65.39; H, 11.01; neut. equiv., 281.5, 281.3.

Summary

The interchange method for preparing macrocyclic esters is shown to be applicable to the preparation of many-membered lactones and to have advantages in speed and simplicity over the high dilution method.

Three new large cyclic esters are described: the monomeric and dimeric lactones of 14-hydroxy-12-oxatetradecanoic acid and the monomeric lactone of 16-hydroxy-12-oxahexadecanoic acid.

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(8) Ashton and Smith, *J. Chem. Soc.*, 1308 (1934).