[CONTRIBUTION FROM THE CHEMICAL LABORATORY, UNIVERSITY OF TORONTO]

OXYMERCURATION OF BRIDGED CYCLOÖLEFINS

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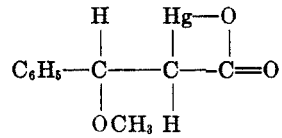
X-ray diffraction studies indicate that addition of the elements of alkoxymercuric salts occurs with inversion at one of the vicinal carbon atoms in alkenes (1). By contrast our studies with 1,4-↑↑-methylene-Δ^5-cyclohexene-2,3-↓↓-dicarboxylic acid (I) and with 1,4-↑↑-ethylene-Δ^5-cyclohexene-2,3-↓↓-dicarboxylic ester (XVIII)[1] seem to show that addition in these compounds occurs directly, *i.e.* without inversion at either carbon atom comprising the alkene linkage.

The configuration of 1,4-↑↑-methylene-Δ^5-cyclohexene-2,3-↓↓-dicarboxylic acid (I) has been demonstrated by Alder and Stein (2) who prepared it by hydrolysis of the adduct from cyclopentadiene and maleic anhydride. When I is boiled with aqueous mercuric acetate the mercuric salt which is formed immediately is slowly transformed into an oxymercurial which is either 5-↓-hydroxy-*anhydro* - [6-↓-hydroxymercuri-2-↓-carboxy] - 1,4 - ↑↑ - methylenecyclohexane-3-↓-carboxylic acid (II) or 5-↓-hydroxy-6-↓-hydroxymercuri-2-↓-carboxy-1,4-↑↑-methylene-cyclohexane-3-↓-carboxylic acid lactone (IIa). When this compound is treated with acetic anhydride an equivalent of water is lost and 5-↓-hydroxy-*anhydro* - [6-↓-hydroxymercuri-2-↓-carboxy] - 1,4 - ↑↑ - methylenecyclohexane - 3-↓-carboxylic acid, γ-lactone (III) is formed. Alternatively III may be formed directly from I by treatment with mercuric acetate in either 2,5-dioxahexane or methanol. It may be noted that this lactonized carboxymercurial is similar in the type with the esterified acetoxymercurial obtained by the addition of mercuric acetate to cyclohexene. Presumably both II and III are preceded in the system by the mercuric salt IV since the initial precipitate in the reaction system forms mercuric oxide when treated with alkali whereas the final precipitate only dissolves in this reagent.

The existence of the lactonized *anhydro*-hydroxymercurial III would seem to require that oxymercuration occurs directly (without inversion) but this conclusion depends on the existence of the mercurial as the monomer III. No evidence has previously been presented to show that *anhydro*-hydroxymercuri-

[1] The use of the prefixes "*exo*" and "*endo*" for specification of configuration in these bridged cycloalkanes and cycloalkenes becomes confusing when more than two substituents must be located, and this situation cannot be ameliorated by introduction of the already-abused terms "*cis*" and "*trans*". Therefore we have elected in this discussion to use arrows which, if the largest cycloalkane ring is considered as flattened, will designate "up" or "down" in respect of this ring. According to our present nomenclature *endo*-norbornene-2,3-dicarboxylic acid (I) becomes 1,4-↑↑-methylene-Δ^5-cyclohexene-2,3-↓↓-dicarboxylic acid, while disodium 5-*endo*-hydroxy-6-*exo*-hydroxymercurinorbornane-2,3-endodicarboxylate (XVI) becomes 5-↓-hydroxy-6-↑-hydroxymercuri-1,4-↑↑-methylenecyclohexane-2,3-↓↓-dicarboxylate. Likewise *endo*-5-chloromercuri-6-hydroxy[2.2.2]bicycloöctane-*trans*-2,3-dicarboxylic acid γ-lactone (XXV) becomes 5-↓-hydroxy-6-↓-chloromercuri-2-↑-carboxy-1,4-↑↑-ethylenecyclohexane-3-↓-carboxylic acid γ-lactone.

carboxylic acids are monomeric but we have found that 3-phenyl-2-methoxy-*anhydro*-2-hydroxymercuripropionic acid,



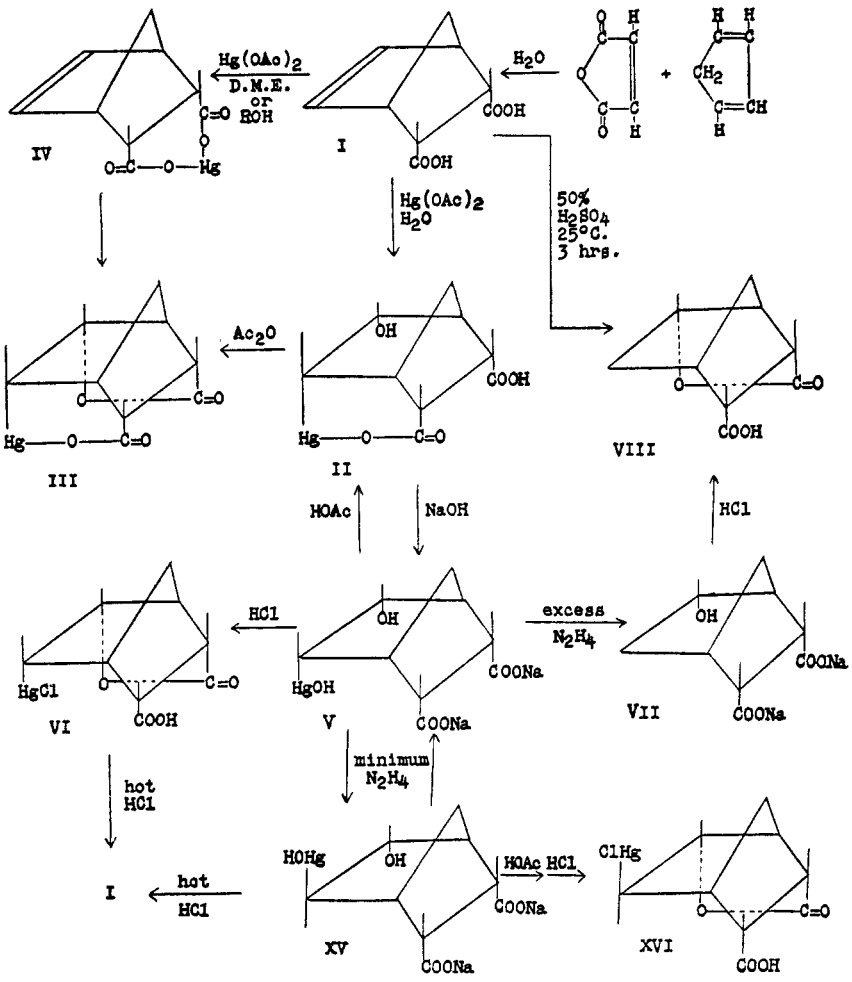
which is obtained from cinnamic acid and mercuric acetate in methanol (3), behaves as a monomer (Rast; Calc'd 379, found 392) in camphor. Compounds like II or III are not soluble in camphor, but sufficient may be dissolved in diphenylmercury for the cryoscopic molecular weight determinations shown in Table I. The cryoscopic constant (K_f = 27.5) has been determined by use of 3-phenyl-2-methoxy-*anhydro*-2-hydroxymercuripropionic acid and then checked against other known compounds listed in the table. Diphenylmercury seems to behave normally as a solvent when the solute concentration is about 5%. The molecular weights of II and III determined in this manner seem to indicate that they are monomeric. Certainly the x-ray diffraction patterns show that they are not polymeric.

When II is converted to its disodium salt V and the alkaline solution is acidified with hydrochloric acid the precipitate must be 5-↓-hydroxy-6-↓-chloromercuri-1,4-↑↑-methylenecyclohexane-2,3-↓↓-dicarboxylic acid, γ-lactone (VI). When either this compound or the alkaline solution from which it is derived is reduced with excess of hydrazine hydrate (4) acidification yields 5-↓-hydroxy-1,4-endomethylene-cyclohexane-2,3-↓↓-dicarboxylic acid γ-lactone, VIII, *via* the

TABLE I

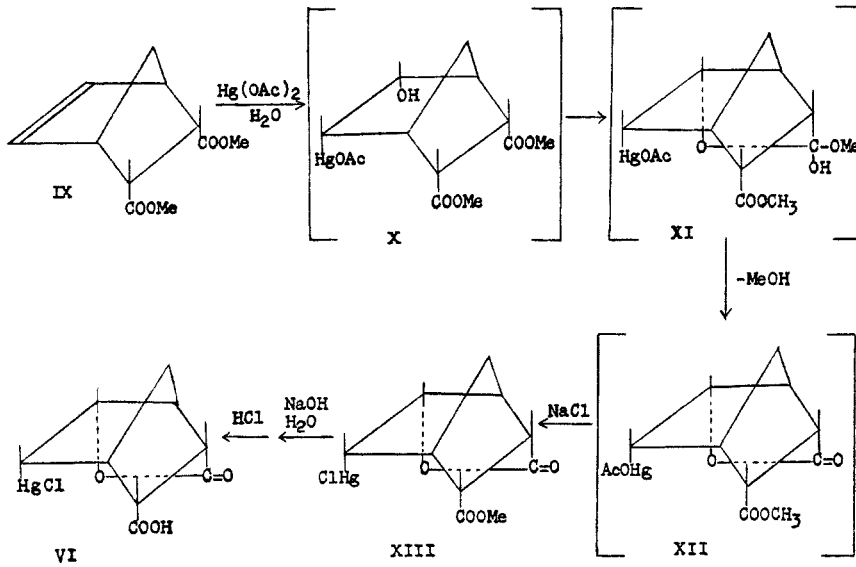
MOLECULAR WEIGHT DETERMINATIONS IN DIPHENYLMERCURY

Substance	Solute / Solvent	Δ_F, °C	Molecular weight	
			Calc'd	Found
Phenylmethoxy-*anhydro*-[hydroxymercuri]propionic acid	0.100	6.7	379	412
	.040	2.9	379	379
α-Methoxycyclohexylmercuric chloride	.145	12.6	349	318
	.123	10.4	349	325
1,2,5,6-Dibenzanthraquinone	.061	5.2	308	322
1,4-Diphenylbutadiene	.052	6.9	206	208
5-↓-Hydroxy-*anhydro*-[6-↓-hydroxymercuri-2-↓-carboxy]-1,4-↑↑-methylenecyclohexane-3-↓-carboxylic acid (II) or IIa	.042	2.7	399	428
	.063	4.1	399	424
	.064	4.6	399	385
	.070	5.0	399	386
5-↓-Hydroxy-*anhydro*-[6-↓-hydroxymercuri-2-↓-carboxy]-1,4-↑↑-methylene-cyclohexane-3-↓-carboxylic acid γ-lactone (III)	.043	3.1	381	382
	.053	3.4	381	425
	.058	3.3	381	485
5-↓-Hydroxy-*anhydro*-[6-↓-hydroxymercuri-2-↓-carboxy]-1,4-↑↑-ethylenecyclohexane-3-↓-carboxylic acid lactone (XXIV)	.012	0.83	395	397
	.019	1.17	395	402
	.020	1.44	395	382



sodium salt, VII. But VIII is the structure assigned by Alder and Stein (2) to the identical compound obtained when 1,4-↑↑-methylene-Δ^5-cyclohexene-2,3-↓↓-dicarboxylic acid (I) is treated with 50% sulfuric acid. Therefore the configuration of the hydroxyl group in the series II–VIII has been demonstrated unless inversion occurs during lactonization. This inversion, involving basal attack by the carboxylate ion on the carbon atom from which the ↑ hydroxyl group would be eliminated by combination with hydronium ion, is unknown among γ-lactones.

Further evidence against such inversion during lactone formation is provided by hydroxymercuration of dimethyl 1,4-↑↑-methylene-Δ^5-cyclohexene-2,3-↓↓-dicarboxylate, IX, in aqueous mercuric acetate. Because the carboxyl groups in IX are not free to form an *anhydro*-hydroxymercuri carboxylate no precipitate appears until, after completion of reaction, aqueous sodium chloride is added. The product thus precipitated is evidently the monomethyl ester of 5-↓-hydroxy-



6-↓-chloromercuri-1,4-↑↑-methylenecyclohexane-2,3-↓↓-dicarboxylic acid lactone, XIII. Its analysis conforms with this composition and when the ester linkage is saponified acidification with hydrochloric acid yields 5-↓-hydroxy-6-↓-chloromercuri-1,4-↑↑-methylenecyclohexane-2,3-↓↓-dicarboxylic acid, γ-lactone (VI).

It is reasonable to assume that XIII is formed by hydroxymercuration of IX *via* the initial addition product dimethyl 5-↓-hydroxy-6-↓-acetoxymercuri-1,4-↑↑-methylenecyclohexane-2,3-↓↓-dicarboxylate, X. Then if the 5-↓-hydroxy groups adds to the 3-↓-carbomethoxy group as is shown in XI elimination of methanol ought to occur with ease. The constraint in the bicyclic structure may be expected to accentuate the known tendency for γ-hydroxy esters to be transformed into γ-lactones (5, 6). The resulting monoester, XII, might be expected to be water soluble until it is converted to the chloromercurial. This explanation, which seems to be the only reasonable one, requires that the hydroxy group be contiguous to the carbomethoxyl group in X. The possibility that lactonization in III or VI occurs with inversion is thus precluded. The hydroxy group must have the configuration shown, since oxymercuration of the diester (IX) and the dicarboxylic acid (I) both lead to the same chloromercurial, VI.

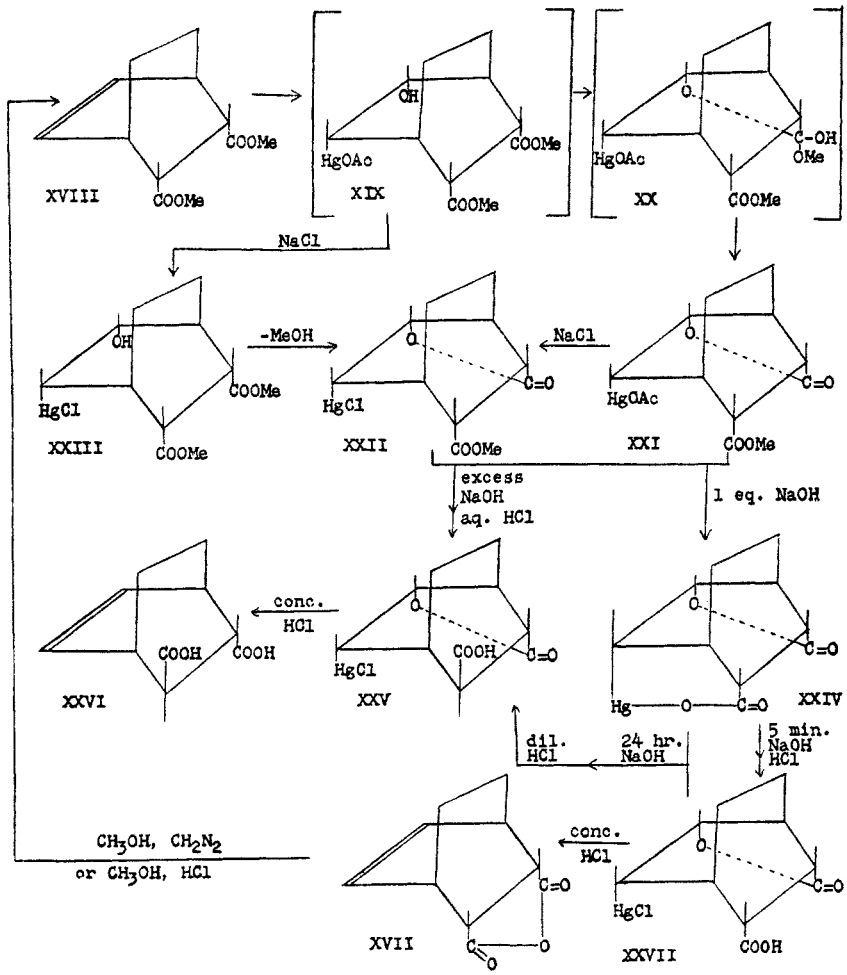
The configuration of the anionomercuri group has been specified (↓) because of *anhydro* cyclic salt formation. In order to demonstrate that the opposite anionomercuri configuration (↑) would not undergo cyclic salt formation with the carboxyl group a solution containing V has been prepared by solution of II in alkali. This solution has been diastereomerically equilibrated (4) by means of the minimum of hydrazine hydrate to a mixture of V and XV and then acidified with acetic acid. The precipitate is 5-↓-hydroxy-*anhydro*-[6-↓-hydroxymercuri-2-↓-carboxy]-1,4-↑↑-methylenecyclohexane-3-↓-carboxylic acid (II) but its

diastereomer remains in solution as the acetoxymercurial until it is precipitated as 6 - ↑ - chloromercuri - 5 - ↓ - hydroxy - 1,4 - ↑↑ - methylenecyclohexane - 2,3-↓↓-dicarboxylic acid monolactone, XVI. This β-diastereomer shows no tendency toward *anhydro*-mercurial formation, and can easily be contrasted to the γ-lactone of the α-chloromercurial (VI) by mixture melting point. The β-diastereomer is more resistant to decomposition by hydrochloric acid than is the α form but both of them regenerate the lactone (VIII). It is fortunate that the β-diastereomer need not be separated by acid decomposition because the α-diastereomer is also (though not quite so) resistant to the action of hydrochloric acid.

This demonstration of direct addition (without inversion) to an alkene seems to be unequivocal, but it cannot be generalized safely, even among cyclohexanes of "boat" conformation. The norbornylene ring system differs widely from structures containing normal tetrahedral carbon bond angles and bond lengths and so cannot be used reliably as a model for reactions of alkenes. For this reason we have investigated also the oxymercuration of 1,4-↑↑-ethylene-Δ^5-cyclohexene-2,3-↓↓-dicarboxylic acid anhydride (XVII) and its diester (XVIII) because the bicycloöctene ring system which they contain is relatively strainless. The structure of XVII and its synthesis from 1,3-cyclohexadiene and maleic anhydride have been reported by Diels and Alder (7).

Although the anhydride (XVII) and not the acid is stable in the free state the dicarboxylic acid does exist in aqueous solution since it forms a slightly soluble di-mercuric salt when treated with aqueous mercuric acetate. But this salt, unlike that of the 1,4-↑↑-methylene-Δ^5-cyclohexene-2,3-↓↓-dicarboxylic acid (I) is not converted to the oxymercurial even after 96 hours at 100°. Presumably the intra-molecular addition in I is not comparably easy in the 1,4-↑↑-ethylene-Δ^5-cyclohexene-2,3-↓↓-dicarboxylic salt of mercury.

Consequently we have turned to the oxymercuration of dimethyl 1,4-↑↑-ethylene-Δ^5-cyclohexene-2,3-↓↓-dicarboxylate (XVIII) (8) which we have prepared from the anhydride in methanol with diazomethane as well as with hydrogen chloride (9) to ensure that rearrangement does not occur during catalyzed esterification. Treatment of the di-ester XVIII with aqueous mercuric acetate gives two products, one of which partially precipitates during the reaction. According to analysis and chemical behavior this precipitate is 2-↓-carbomethoxy - 5 - ↓ - hydroxy - 6 - ↓ - acetoxymercuri - 1,4 - ↑↑ - ethylenecyclohexane-3-↓-carboxylic acid γ-lactone (XXI). After filtration the remainder of XXI may be precipitated as the chloromercurial XXII by addition of sodium chloride to the filtrate. However it is admixed with dimethyl 5-↓-hydroxy-6-↓-chloromercuri-1,4-↑↑-ethylenecyclohexane-2,3-↓↓-dicarboxylate (XXIII) from which it may be separated by fractional crystallization. The identity of XXIII with respect to XXII is established by heating the former, which loses methanol to yield the latter compound in the manner expected for an γ-hydroxy ester. Evidently dimethyl 1,4-↑↑-ethylene-Δ^5-cyclohexene-2,3-↓↓-dicarboxylate (XVIII) is first hydroxymercurated to XIX which partially loses the elements of methanol *via* XX. No rearrangement of the bicyclic structure has occurred



during these processes since decomposition of the mercurial XXIII by hot dilute hydrochloric acid regenerates the original alkene, XVIII.

The configuration of the mercuri linkage in dimethyl 5-↓-hydroxy-6-↓-chloromercuri-1,4-↑↑-ethylenecyclohexane-2,3-↓↓-dicarboxylate (XXIII) and its lactonic analogs (XXI and XXII) has been proven by treatment of the lactones XXI or XXII with one equivalent of alkali. Slowly there precipitates a compound with analysis corresponding to 5-↓-hydroxy-*anhydro*-[6-↓-hydroxymercuri-2-↓-carboxy] - 1,4 - ↑↑ - ethylenecyclohexane - 3 - ↓ - carboxylic acid, γ - lactone (XXIV). Solution in excess alkali followed by immediate acidification with acetic acid to *p*H 6 regenerates XXIV unchanged. If the acidifying acid is hydrochloric acid (*p*H 3) then 5-↓-hydroxy-6-↓-chloromercuri-1,4-↑↑-ethylenecyclohexane-2,3-↓↓-dicarboxylic acid, γ-lactone (XXVII) is precipitated. Absence of rearrangement is demonstrated by decomposition with concentrated hydrochloric acid which regenerates the original anhydride, XVII.

On the other hand ageing of the alkaline solution of XXIV (also of XXI or

XXII in excess alkali) causes a prototropic rearrangement of the 2-carboxyl group. An anhydromercurial is not precipitated by acidification to *p*H 6 with acetic acid but acidification with dilute hydrochloric acid precipitates the rearrangement product, 5-↓-hydroxy-6-↓-chloromercuri-2-↑-carboxy-1,4-↑↑-ethylenecyclohexane-3-↓-carboxylic acid, γ-lactone (XXV). The structure of XXV has been demonstrated by decomposition with hydrochloric acid to the known 1,4-↑↑-ethylene-Δ^5-cyclohexene-2,3-↑↓-dicarboxylic acid (XXVI) (2).

The validity of this proof depends as in the former case of the norbornyl derivative III on the molecular weight of the compound shown as the lactonic anhydromercurial XXIV. Only if this is the specified monomer can the positions of the hydroxy and anionomercuri groups designate the addition during hydroxymercuration as direct rather than inverse. However the molecular weight determined cryoscopically in diphenylmercury (Table I) closely approximates to that expected for the monomeric structure. The reliability of this determination has been established by recovery of XXIV from a solidified solution in diphenylmercury.

Since this proof of the direct rather than inverse addition during oxymercuration of these compounds depends also on permanence of the lactone linkage during anhydromercurial formation it has seemed worthwhile to examine the resistance of these lactones in respect of hydrolysis. According to potentiometric titration the lactone linkage is very stable. When 5-↓-hydroxy-6-↓-chloromercuri-1,4-↑↑-ethylenecyclohexane-2,3-↓↓-dicarboxylic acid γ-lactone (XXVII) is is titrated with alkali it consumes the two equivalents expected for neutralization of the free carboxyl group and for conversion of chloromercuri to the hydroxy-

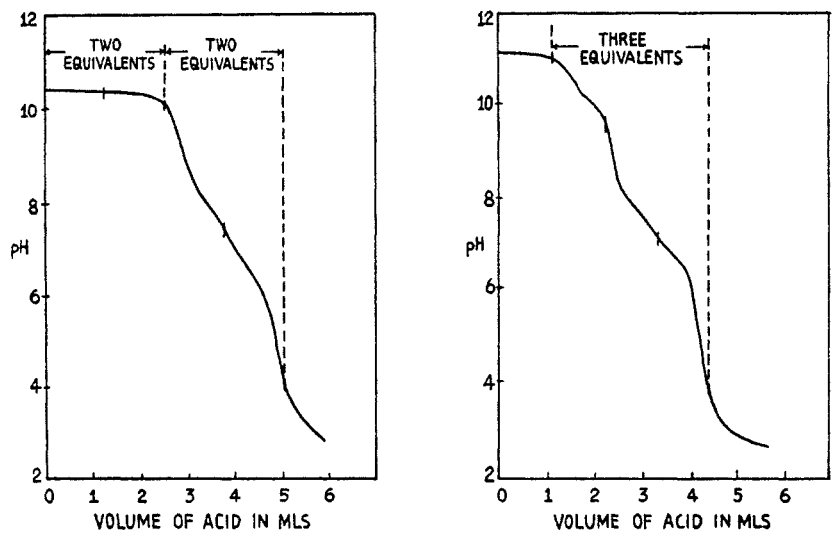


FIG. 1. POTENTIOMETRIC TITRATION OF 0.0553 g. OF XXV DISSOLVED IN 4 EQUIVALENTS OF 0.0815 *N* NaOH AND BACK-TITRATED WITH 0.1010 *N* HCl.

FIG. 2. POTENTIOMETRIC TITRATION OF 0.0484 g. OF XXV DISSOLVED IN 4 EQUIVALENTS OF 0.0815 *N* NaOH, THEN HYDROLYZED AND BACK-TITRATED WITH 0.1010 *N* HCl.

mercuri group. After one day in excess alkali at room temperature XXVII has isomerized to 5-↓-hydroxy-6-↓-chloromercuri-2-↑-carboxy-1,4-↑↑-ethylenecyclohexane-3-↓-carboxylic acid γ-lactone (XXV) but this isomer also consumes only two equivalents of alkali even after treatment with four equivalents of alkali for one day longer (Fig. 1). Only after four hours at 100° with three equivalents of alkali can the lactone ring of XXV be hydrolyzed. The alkaline solution then behaves as if two carboxyl ions and an hydroxymercuri group were present (Fig. 2).

Dimethyl 1,4-↑↑-ethylene-Δ^5-cyclohexene-2,3-↓↓-dicarboxylate has also been treated with mercuric acetate in methanol. The product is designated as dimethyl 6 - ↓ - chloromercuri - 5 - ↓ - methoxy - 1,4 - ↑↑ - ethylenecyclohexane - 2,3 - ↓↓-dicarboxylate by analogy with the products of hydroxymercuration. It is of interest to note that the crude product of this methoxymercuration is very impure unless boron fluoride is used as a catalyst. The impurity seems to be dimethyl 5-↓-acetoxy-6-↓-chloromercuri-1,4-↑↑-ethylenecyclohexane-2,3-↓↓-dicarboxylate. This behavior will be discussed in a forthcoming publication.

EXPERIMENTAL[2]

5-↓-Hydroxy-anhydro-[6-↓-hydroxymercuri-2-↓-carboxy]-1,4-↑↑-methylenecyclohexane-3-↓-carboxylic acid (II) or IIa. To 9.1 g. (0.05 mole) of 1,4-↑↑-methylene-Δ^5-cyclohexene-2,3-↓↓-dicarboxylic acid (I) (2) in 75 ml. of water was added a solution of 15.9 g. (0.05 mole) of mercuric acetate in 75 ml. of water. A voluminous precipitate appeared at once. This system was boiled for two hours, then chilled and filtered. A test with aqueous alkali showed that the filtrate contained no salts of mercury. The filtered precipitate was washed with 100 ml. of water, 100 ml. of absolute ethanol, and 50 ml. of ether; 19.9 g. (100%). The melting point (235° decomp.) was not distinctive or reliable, so characterization was made by x-ray diffraction: [10] 5.85; [7] 8.31, 7.47, 4.20; [6] 4.54, 4.45; [4] 3.73; [3] 3.27, 2.86; [2] 3.08, 2.73, 2.52; [1] 5.08, 4.83, 3.42, 3.34, 2.95, 2.70, 2.61; [0.5] 2.38, 2.19, 2.01, 1.93.

The compound is soluble in 10% aqueous sodium hydroxide (2.5 ml. per g.) from which it may be recovered by acidification to *p*H 6 with dilute acetic acid. Also it is soluble in aqueous ammonia, concentrated hydrochloric acid, and warm aqueous sodium chloride. It is insoluble in molten camphor, borneol, and naphthalene but is soluble in molten diphenylmercury.

Anal. Calc'd for $C_9H_{10}HgO_5$: C, 27.1; H, 2.52; Hg, 50.3.
Found: C, 27.1; H, 2.68; Hg, 50.7.

5-↓-Hydroxy-1,4-methylenecyclohexane-2,3-↓↓-dicarboxylic acid γ-lactone (VIII). A solution of 8.00 g. (0.02 mole) of 5-↓-hydroxy-*anhydro*-[6-↓-hydroxymercuri-2-↓-carboxy]-1,4-↑↑-methylenecyclohexane-3-↓-carboxylic acid (II) in 50 ml. of 3.2% of aqueous sodium hydroxide (0.04 mole) was boiled under reflux for eight hours with 2.5 ml. (0.044 mole) of 85% hydrazine hydrate. The metallic mercury (3.90 g., 97%) was filtered off and the filtrate evaporated to a volume of 15 ml. Upon acidification with concentrated hydrochloric acid no precipitate appeared at *p*H 7 but 1.65 g. (45%), m.p. 196–199°, precipitated at *p*H 3. Crystallization from boiling water raised this m.p. to 201.5–202.5° and a mixture melting point with an authentic sample (2) was not lowered.

[2] Melting points have been corrected against reliable standards. X-ray diffraction intensities [I/I_1] have been reported for at least five strongest lines using Cu K_α (Ni filtered) radiation with spacings expressed in Angstroms. The elemental analyses for hydrogen recorded here are usually high because the analyst did not use gold foil in his combustion tube.

The x-ray powder pattern was determined: [10] 5.54; [7] 6.41; [5] 4.81; 3.75; [4] 4.48, 4.12, 3.01, 2.79; [2] 5.06, 3.39, 2.70, 2.59, 2.43, 2.06.

The acidified filtrate later precipitated 0.10 g. of 1,4-↑↑-methylene-Δ^5-cyclohexene-2,3-↓↓-dicarboxylic acid (I), m.p. 172–174°, identified by mixture melting point.

5-↓-Hydroxy-6-↓-chloromercuri-1,4-↑↑-methylenecyclohexane-2,3-↓↓-dicarboxylic acid,γ-lactone (VI). *A. Direct treatment with hydrochloric acid.* Treatment of 1.0 g. (0.0025 mole) of II with 10 ml. of 22% aqueous hydrochloric acid at 100° for 20 minutes gave a colorless solution which precipitated 0.78 g. of indefinite melting point upon cooling. Crystallization from 6 ml. of hot water gave 0.45 g. (42%) of VI, m.p. 191–193°. A further crop from the mother liquors melted at 179–181°, 0.22 g. (50%). A mixture melting point showed that it was 1,4-methylene-Δ^5-cyclohexene-2,3-dicarboxylic acid (I).

B. From alkaline solution. Two grams (0.003 mole) of II in 20 ml. (0.025 mole) of 5% aqueous sodium hydroxide gave a colorless solution from which nothing was precipitated by addition of 12% hydrochloric acid to *p*H 7. Further acidification to *p*H 3 precipitated 0.8 g. (40%), m.p. 193.5–195.5° (decomp.). This melting point was not raised by crystallization from absolute ethanol (20 ml. per g.); mixture melting point with the product by procedure *A* was not lowered.

Anal. Calc'd for $C_9H_9ClHgO_4$: C, 25.9; H, 2.18; Hg, 48.1.

Found: C, 25.7; Hg, 2.54; H, 47.7.

5-↓-Hydroxy-6-↑-chloromercuri-1,4-↑↑-methylenecyclohexane-2,3-↓↓-dicarboxylic acid, γ-lactone (XVI). A solution of 8 g. (0.02 mole) of II and 4.0 g. (0.10 mole) of sodium hydroxide in 80 ml. of water was boiled under reflux with 0.10 ml. (0.0016 mole) of 85% hydrazine hydrate for 140 minutes and then chilled. Metallic mercury (1.86 g., 46%) was filtered off and the filtrate was acidified to *p*H 3.6 with 12% hydrochloric acid. During 30 minutes 1.40 g. (17%) of the β-diastereomer (XVI) precipitated, m.p. 211–214°. This product, containing mercury and chlorine, was crystallized from absolute ethanol (60 ml. per g.), 0.47 g., m.p. 214.2–215.2°. The diffraction pattern was determined: [10] 11.13, 8.72; [9] 9.69; [3] 5.73, 3.57, 2.85; [2] 6.55, 5.30, 4.44, 4.15; [1] 7.37, 6.10, 5.06, 4.67, 3.91, 3.83, 3.42, 3.16.

Anal. Calc'd for $C_9H_9ClHgO_4$: C, 25.9; H, 2.78.

Found: C, 26.3; H, 2.77.

In an alternative procedure the filtrate obtained by removal of mercury was acidified to *p*H 6.0 with glacial acetic acid. Then a solution of 3.18 g. of mercuric acetate in 25 ml. of water was added. The precipitate (0.3 g., 7%) melted with decomposition at 235° and gave an x-ray diffraction pattern characteristic of II.

The filtrate was treated with 1 g. of sodium chloride in 10 ml. of water. During 10 minutes a precipitate formed, 1.64 g. (10%), m.p. 215–216°. This product was identical (mixture melting point) with that isolated in the preceding experiment as XVI.

After 0.083 g. (0.0002 mole) of this product was boiled in 3 ml. of 20% hydrochloric acid for three hours and then was brought to *p*H 10 with 15% aqueous alkali, the mercury was removed as the oxide (0.041 g., 95%) by centrifugation. The supernatant layer was concentrated to 0.5-ml. volume and then acidified. The product, 0.028 g. (77%), was 1,4-methylene-Δ^5-cyclohexane-2,3-dicarboxylic acid (I), m.p. 179.5–181°. A mixture melting point with the authentic compound was not depressed.

5-↓-Hydroxy-anhydro-[6-↓-hydroxymercuri-2-↓-carboxy]-1,4-↑↑-methylenecyclohexane-3-↓-carboxylic acid, γ-lactone (III). *A. By oxymercuration of* I. A suspension of 3.18 g. (0.01 mole) of mercuric acetate in 20 ml. of anhydrous 2,5-dioxahexane was shaken with 1.82 g. (0.01 mole) of 1,4-methylene-Δ^5-cyclohexene-2,3-dicarboxylic acid (I) at 25° for ten minutes. A voluminous gel was formed (a mercuric salt) which became granular after 3–4 hours. A test portion then would dissolve in alkali rather than precipitate mercuric oxide. Filtration of the dioxahexane suspension gave 3.67 g. (98%) of III, decomposition temperature about 250°.

B. By dehydration of II. To 2.0 g. (0.005 mole) of II was added 15 ml. of acetic anhydride and the system was boiled for three hours under reflux and cooled. Filtration gave 1.85 g. (93%) of III with poor melting point of 253° (decomp.).

Anal. Calc'd for $C_9H_8HgO_4$: C, 28.4; H, 2.11.
Found: C, 28.3; H, 2.43.

The products by procedures *A* and *B* showed no depression on mixture melting point but this criterion was not very definitive. However both samples gave identical x-ray diffraction patterns: [10] 3.35; [8] 6.70; [6] 5.98, 5.43, 4.90, 4.41; [5] 2.87, 2.80, 2.70; [4] 2.40, 2.27; [3] 2.52; [2] 2.62, 4.15.

When III was boiled under reflux in aqueous suspension for four hours it did not revert to II.

5-↓-Hydroxy-6-↓-chloromercuri-2-↓-carbomethoxy-1,4-↑↑-methylenecyclohexane-3-↓-carboxylic acid, γ-lactone (XIII). To 10.5 g. (0.05 mole) of dimethyl 1,4-↑↑-methylene-Δ^5-cyclohexane-2,3-↓↓-dicarboxylate (IX) (10) was added a solution of 15.9 g. (0.05 mole) of mercuric acetate in 160 ml. of water. After four hours of shaking the system was filtered into 100 ml. of 5% aqueous sodium chloride. Filtration removed 20.7 g. (95%) of the ester-lactone, XIII, m.p. 209–213°. This crude product was thoroughly extracted with dimethylformamide (1 ml. per g.). The filtered extract was diluted with 1.5 volumes of chloroform and the slight precipitate was filtered off immediately. The filtrate, diluted with another volume of chloroform, precipitated 50% of the original weight, m.p. 222–223°. Repetition of this purification raised the melting point to 223–223.5°. The x-ray diffraction pattern was determined: [10] 9.351, 4.667; [9] 3.645, 2.938; [8] 5.901; [7] 2.440; [6] 6.505, 2.050; [5] 3.798, 3.504; [4] 4.392, 3.324, 3.195, 3.097, 2.864, 2.620, 2.279; [2] 5.368, 2.673, 2.205, 1.951; [1] 4.168, 2.125, 1.861, 1.677, 1.612.

Anal. Calc'd for $C_{10}H_{11}ClHgO_4$: C, 27.9; H, 2.58; Hg, 46.5.
Found: C, 28.2; H, 2.78; Hg, 46.6.

A solution of 2.30 g. (0.005 mole) of XIII and 2.0 g. (0.05 mole) of sodium hydroxide in 60 ml. of 1:1 methanol-water was boiled 16 hours under reflux, then cooled and filtered. When the filtrate was acidified to *p*H 5.5 with acetic acid 1.73 g. of II, m.p. 238° (approx., decomp.), was precipitated. Its identity was confirmed by mixture melting point and x-ray diffraction pattern. Alternatively identification was made by acidification with hydrochloric acid, yielding VI, identified in the same manner.

Dimethyl 1,4-↑↑-ethylene-Δ^5-cyclohexene-2,3-↓↓-dicarboxylate (XVIII). *A. From diazomethane.* A solution of 6.0 g. (0.034 mole) of 1,4-↑↑-ethylene-Δ^5-cyclohexene-2,3-↓↓-dicarboxylic acid anhydride (XVII) in 180 ml. of methanol was cooled to 0° and treated with excess of ethereous diazomethane solution. The solvent was partially evaporated and 6.9 g. (90%), m.p. 69–70.5°, crystallized out. One purification from petroleum ether (b.p. 60–70°, 3 ml. per g.) raised the melting point to 69.5–71°.

B. From methanolic hydrogen chloride. A solution of 2.65 g. (0.015 mole) of the anhydride XVII in 25 ml. of anhydrous methanol was saturated at 0° with dry hydrogen chloride. After eight hour's reflux most of the solvent then was evaporated; 2.33 g. (69%), m.p. 63–66°. After purification from petroleum ether a mixture melting point with the product by procedure *A* was not lowered.

Dimethyl 6-↓-chloromercuri-5-↓-methoxy-1,4-↑↑-ethylenecyclohexane-2,3-↓↓-dicarboxylate. A solution of 1.12 g. (0.005 mole) of XVIII in 10 ml. of anhydrous methanol was treated with 1.59 g. (0.005 mole) of mercuric acetate in 15 ml. of methanol. After four hours this sytem was filtered into 20 ml. of 5% aqueous sodium chloride at 0°, 1.50 g. (62%), m.p. 132–148°. Repeated crystallization from methanol (8 ml. per g.) raised the melting point to 160–162°. An otherwise identical reaction including 0.0005 mole of boron fluoride etherate gave a crude product, m.p. 148–154°, which was purified more easily than the first crude product.

Anal. Calc'd for $C_{13}H_{19}ClHgO_5$: C, 31.7; H, 3.81; OCH_3, 18.9.
Found: C, 31.3; H, 3.76; OCH_3, 18.7.

The x-ray diffraction pattern was: [10] 11.53; [9] 8.66, 7.96, 6.86, 4.73; [6] 3.46; [5] 4.12, 3.78; [4] 3.08; [3] 2.90.

2-↓-Carbomethoxy-5-↓-hydroxy-6-↓-acetoxymercuri-1,4-↑↑-ethylenecyclohexane-3-↓-carboxylic acid, γ-lactone (XXI). To a suspension of 2.24 g. (0.01 mole) of dimethyl 1,4-↑↑-ethylene-Δ^5-cyclohexene-2,3-↓↓-dicarboxylate (XVIII) in 5 ml. of water was added 3.18

g. (0.01 mole) of mercuric acetate in 15 ml. of water. After shaking eight hours the precipitate was filtered, 2.87 g. (61%), m.p. 172–175°. Crystallization from methanol (4 ml. per g.) or chloroform-petroleum ether (b.p. 60–70°, 5 ml. of 1:1.5 mixture per g.) raised the melting point to 188.5–189.5°. The x-ray diffraction pattern was: [10] 10.77; [9] 4.55; [8] 6.60; [6] 4.27; [2] 3.56; [1] 4.02, 3.82, 2.83, 2.67.

Anal. Calc'd for $C_{13}H_{16}HgO_6$: C, 33.3; H, 3.44; OCH_3, 6.62.
Found: C, 33.6; H, 3.55; OCH_3, 6.68.

2-↓-Carbomethoxy-5-↓-hydroxy-6-↓-chloromercuri-1,4-↑↑-ethylenecyclohexane-3-↓-carboxylic acid, γ-lactone (XXII). The aqueous filtrate from which crude XXI was filtered (as described above) was added to 10 ml. of 5% aqueous sodium chloride, 1.24 g. (27%), m.p. 130–160°. Crystallization from methanol (15 ml. per g.) raised this melting point to 212.5–214°. The x-ray diffraction pattern of XXII was: [10] 9.44, 6.96; [9] 4.62, 4.11; [5] 5.62, 3.92; [3] 3.26; [2] 3.51, 3.02, 2.86. The identical product was obtained by treatment of a methanolic solution of XXI with aqueous sodium chloride.

Anal. Calc'd for $C_{11}H_{13}ClHgO_4$: C, 29.7; H, 2.94; OCH_3, 6.96.
Found: C, 29.5; H, 2.93; OCH_3, 6.92.

Dimethyl 5-↓-hydroxy-6-↓-chloromercuri-1,4-↑↑-ethylenecyclohexane-2,3-↓↓-dicarboxylate (XXIII). Further fractional crystallization of the combined liquors from which pure XXII was isolated yielded 0.25 g. (5%, m.p. 141.5–142°. It is estimated that 15–20% was present. The x-ray diffraction pattern was: [10] 6.75; [8] 9.82; [6] 4.11; [5] 13.67, 7.43; [4] 4.25; [3] 3.70; [2] 5.25, 5.05, 4.51, 3.86.

Anal. Calc'd for $C_{12}H_{17}ClHgO_5$: C, 30.2; H, 3.58; OCH_3, 13.0.
Found: C, 30.5; H, 3.78; OCH_3, 13.2.

When this compound was heated above its melting point it resolidified and then melted at 210–212°. A mixture melting point with XXII was not depressed.

5-↓-Hydroxy-anhydro-[6-↓-hydroxymercuri-2-↓-carboxy]-1,4-↑↑-ethylenecyclohexane-3-↓-carboxylic acid, γ-lactone (XXIV). A solution of 1.27 g. (0.0026 mole) of XXI in 10.4 ml. (0.0026 mole) of 1% aqueous sodium hydroxide was filtered and allowed to stand for one day at 25°. The precipitate was filtered off and washed with 2.0 ml. each of water, ethanol, and ethyl ether; 0.70 g. (68%), m.p. 243° (decomp.) determined by insertion at 230° with a heating rate of 6° per minute. The x-ray diffraction pattern was: [10] 8.79; [8] 10.20; [6] 3.81; [5] 6.15, 4.30; [4] 5.24; [3] 3.52, 3.25; [2] 5.62, 3.18, 3.06. The identical compound was obtained by similar treatment of XXII.

Anal. Calc'd for $C_{10}H_{10}HgO_4$: C, 30.4. Found: C, 30.0.

The compound may be regenerated unchanged by solution in dilute alkali followed by reprecipitation by acidification with acetic acid to *p*H 6. Upon acidification with hydrochloric acid the solution is converted to XXVII. XXIV is insoluble in camphor and all common organic solvents but is sufficiently soluble in molten diphenylmercury for cryoscopic determination of its molecular weight. It may be recovered from solution in diphenylmercury by dissolving away the solvent with chloroform. Solution of the residue in alkali followed by acidification to *p*H 6 with acetic acid regenerated XXIV, identified by x-ray powder pattern.

5-↓-Hydroxy-6-↓-chloromercuri-2-↑-carboxy-1,4-↑↑-ethylenecyclohexane-3-↓-carboxylic acid, γ-lactone (XXV). A solution of 1.98 g. (0.0042 mole) of 2-↓-carbomethoxy-5-↓-hydroxy-6-↓-acetoxymercuri-1,4-↑↑-ethylenecyclohexane-3-↓-carboxylic acid γ-lactone (XXI) in 5 ml. of 10% aqueous sodium hydroxide (0.0125 mole) was allowed to stand for one day. The solution then was acidified at 0° to *p*H 3 with 10% hydrochloric acid, 0.80 g. (45%), m.p. 180–200° (decomp.). Crystallization from methanol (6 ml. per g.) raised the melting point to 209° (inserted at 200°, rate of heating 6° per minute). The compound could also be prepared from XXII or XXIV in higher (70%) yield. Hydrolysis of its lactone linkage could be effected by heating for four hours at 100° with four equivalents of 0.0813 *N* sodium hydroxide in a Corning #79900 alkali-resistant sealed tube.

Anal. Calc'd for $C_{10}H_{11}ClHgO_4$: C, 27.8; H, 2.57.
Found: C, 27.6; H, 2.82.

When 0.041 g. (0.0001 mole) of the substance was heated at 100° for five minutes with 0.5 ml. of concentrated hydrochloric acid the cooled system precipitated 0.012 g. (76%), m.p. 203–205°. Crystallization from 1 ml. of water raised this melting point to 209–210°. A mixture melting point with authentic 1,4-↑↑-ethylene-Δ^5-cyclohexene-2,3-↑↓-dicarboxylic acid was not depressed. The aqueous filtrates precipitated 70% of the expected mercuric oxide when made basic.

5-↓-Hydroxy-6-↓-chloromercuri-2-↓-carboxy-1,4-↑↑-ethylenecyclohexane-3-↓-carboxylic acid, γ-lactone (XXVII). A chilled solution of 1.00 g. (0.0025 mole) of XXIV in 2 ml. (0.005 mole) of 10% aqueous sodium hydroxide when acidified within five minutes to *p*H 3 with hydrochloric acid precipitated 0.98 g. (91%), m.p. 193–197°. Crystallization from methanol (4 ml. per g.) raised this melting point to 205° (decomp.), After one day in four equivalents of 5% alkali it was converted to XXV, identified by mixture melting point which was not depressed by admixture with the product described in the former procedure but was depressed by admixture with XXVII.

Anal. Calc'd for $C_{10}H_{11}ClHgO_4$: C, 27.9; H, 2.57.

Found: C, 28.0; H, 2.81.

When 0.14 g. was heated five minutes at 100° with 0.5 ml. of concentrated hydrochloric acid cooling of the solution precipitated 0.54 g. (80%), m.p. 130–140°. Crystallization from 10 ml. of petroleum ether (b.p. 60–70°) raised the melting point to 146–148°. A mixture melt-point with 1,4-↑↑-ethylene-Δ^5-cyclohexene-2,3-↓↓-dicarboxylic acid anhydride (XVII) was not depressed. The aqueous filtrate yielded 0.062 g. (88%) of mercuric oxide when it was made basic.

SUMMARY

1. The oxymercuration of 1,4-↑↑-methylene-Δ^5-cyclohexene-2,3-↓↓-dicarboxylic acid and its ester has been shown to occur directly rather than with the inversion expected on the basis of x-ray diffraction studies with the methoxymercurials of cyclohexene.

2. The configuration of the substituents allows them to form with the two carboxyl groups, both a γ-lactone and an *anhydro*-hydroxymercuri group. Since this 5-↓-hydroxy-*anhydro*-[6-hydroxymercuri-2-↓-carboxy]-1,4-↑↑-methylenecyclohexane-3-↓-carboxylic acid, γ-lactone is monomeric the hydroxy and anionomercuri groups must be disposed in the same configurational direction as that of the carboxyl groups.

3. A similar reaction series has been carried out with dimethyl 1,4-↑↑-ethylene-Δ^5-cyclohexene-2,3-↓↓-dicarboxylate with similar results.

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