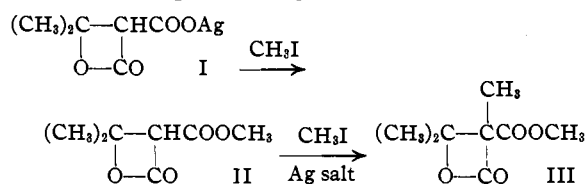[CONTRIBUTION FROM THE CHEMICAL LABORATORY OF HARVARD UNIVERSITY]
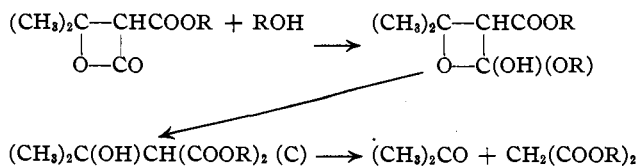
The Formation of Enolates from Lactonic Esters

BY ARTHUR MICHAEL AND NATHAN WEINER

Ott[1] attempted to prepare the methyl ester of β,β-dimethyl-β-propiolactonic acid (II) by treating the silver salt (I) with methyl iodide, but with esterification, C-methylation occurred and only α,β,β-trimethyl-β-propiolactonic methyl ester (III) was obtained. This anomalous, unexplained reaction undoubtedly proceeded through the primary formation of the expected methyl ester, which was alkylated by methyl iodide, the unchanged silver salt functioning as does silver oxide in analogous C-alkylations[2]

$$\text{(CH}_3)_2\text{C—CHCOOAg} \quad \text{(I)} \quad \xrightarrow{\text{CH}_3\text{I}}$$
$$\text{O—CO}$$

$$\text{(CH}_3)_2\text{C—CHCOOCH}_3 \quad \text{(II)} \quad \xrightarrow[\text{Ag salt}]{\text{CH}_3\text{I}} \quad \text{(CH}_3)_2\text{C—CCOOCH}_3 \quad \text{(III)}$$
$$\text{O—CO} \qquad\qquad\qquad \text{O—CO}$$

This reaction indicates the capacity of α-unsubstituted β-lactonic esters to form corresponding enolates, and to react with C-alkylation. We attempted to prepare ester (II) by condensing cyanoacetic acid and acid malonic ester, with acetone, by the Meldrum[3] and Ott[1] methods, but in agreement with Ott,[1] without result. Further a methanol solution of the lactonic sodium salt was heated with dimethyl sulfate, but only malonic methyl ester was obtained, and the sodium salt in a hot benzene solution of dimethyl sulfate remained unchanged. Treatment of the free acid at room temperature in an absolute ethanol solution with a trace of sulfuric acid also gave malonic ester. Probably the lactonic acid was esterified but addition of alcohol at the lactone carbonyl ocurred facilely, followed by catalytic fission at the α,β-carbon linkage

$$\text{(CH}_3)_2\text{C—CHCOOR} + \text{ROH} \longrightarrow \text{(CH}_3)_2\text{C—CHCOOR}$$
$$\text{O—CO} \qquad\qquad\qquad\qquad \text{O—C(OH)(OR)}$$

$$\text{(CH}_3)_2\text{C(OH)CH(COOR)}_2 \text{ (C)} \longrightarrow \text{(CH}_3)_2\text{CO} + \text{CH}_2\text{(COOR)}_2$$
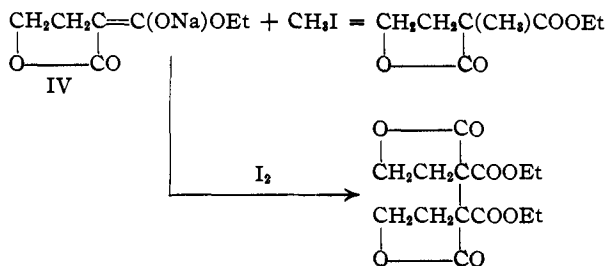
This course of decomposition is not abnormal, unless one so considers the assumed decomposition of the ortho ester group in (B) in not reversing

the mode of its formation. The passage to the straight chained, substituted hydroxymalonic ester (C) from the 4-membered ring derivative (B) undoubtedly represents a decrease in free chemical energy. Similarly, acids of the type $RCH(OH)$-CR_2COOH decompose upon distillation into $RCHO$ and $R_2CHCOOH$. This, comparatively facile, rupture between two saturated carbon atoms is due to the loosening influence of the directly attached negative hydroxyl and carboxyl radicals, which is evidently well developed in (B) and (C).

We next studied the behavior of γ-butyrolactone toward sodium and sodium amalgam. Bredt[4] stated that γ,γ-dimethyl-γ-butyrolactone reacted vigorously with these reagents, forming a sodium derivative, which gave the lactone on acidification. This behavior indicated the capacity of γ-lactones to form enolates. However, it was found that γ-butyrolactone does not react with sodamide in ether suspension and with pulverized sodium, or 40% sodium amalgam, only slightly, upon long standing. It is probable, therefore, that Bredt's sodium compound was analogous to the intermolecular condensation product, dibutylactone, obtained by Fittig and Ström[5] on warming butyrolactone in sodium ethylate solution.

On the other hand, Traube and Lehmann[6] prepared a sodium derivative of α-carbethoxybutyro-γ-lactone from ethylene oxide and sodium enol malonic ester, but drew no conclusion concerning its structure. This derivative is an enolate (IV). It can be formed from the lactone and sodium ethoxide and gives other reactions characteristic of enolates, e. g., C-alkylation with methyl iodide to form (V) and with iodine a mixture of two isomeric dilactonic esters, (VI). The dilactones are probably stereomeric, since they gave the same dibasic dilactonic acid (VII) on saponification. The dilactonic esters are, thermally, very stable substances, distilling unchanged from a bath at 250°. The corresponding acids lost carbon dioxide on heating

(1) Ott, Ann., 401, 151 (1913).
(2) Lander, J. Chem. Soc., 77, 743 (1900).
(3) Meldrum, ibid., 93, 605 (1908).
(4) Bredt, Ann., 208, 58 (1881).
(5) Fittig and Ström, ibid., 267, 192 (1891).
(6) Traube and Lehmann, Ber., 34, 1977 (1901).

CH₂CH₂C=C(ONa)OEt + CH₃I = CH₂CH₂C(CH₃)COOEt

(structures)

IV

I₂

$$CH_2CH_2C=C(ONa)OEt + CH_3I = CH_2CH_2C(CH_3)COOEt$$

above their melting points, with a good yield of α,α'-dibutyro-γ-dilactone, (VIII); a high melting compound, also very stable toward heat. The excellent yields of (VII) and (VIII) are in marked

VII $\xrightarrow{\text{heat}}$ (VIII)
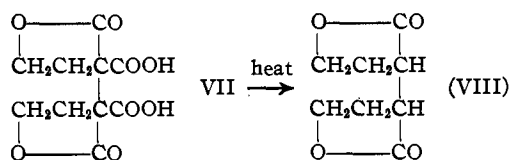
contrast to the result with α-carboxybutyrolactone, which gave γ-butyrolactone in yield of only 50%.[7] However, the main difficulty lies in the complete miscibility of those compounds with water, which may be overcome by the use of a continuous ether extractor for a long period, when a nearly quantitative yield of γ-butyrolactone was obtained.

By the action of epichlorohydrin on sodium enol malonic ester, Traube and Lehmann[6] isolated a sodium derivative of α-carbethoxy-δ-chlorovalero-γ-lactone, (IX). On heating this compound in alcohol and the formed, viscous product with concentrated hydrochloric acid, Leuchs[8] obtained the dilactone of γ,δ-dihydroxypropylmalonic acid, (X). The sodium compound obtained by Traube and Lehmann is also an enolate. The first step in Leuchs' synthesis is an intramolecular C-alkylation, forming an intraannular γ-lactone, 1-carbethoxy-1-carboxy-3-hydroxy-cyclobutane-γ-lactone, (XI). This lactonic ester, (XI) on treatment with boiling hydrochloric acid, is converted into Leuchs' γ,δ-dilactone, (X). The two negative carbalkoxy radicals of (XI) exert the same loosening in-

ClCH₂CHCH₂C=C(ONa)Et

IX

X

XI
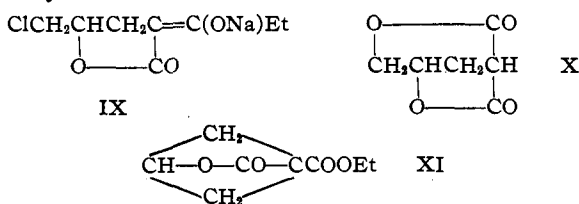
fluence[9] upon the saturated α- and β-carbon atoms that the two carbethoxy groups do upon those of trimethylene α,α-dicarboxylic esters, although to a less degree, but, under the influence of the strong mineral acid, not only saponification but ring fission takes place at the α- and β-carbon atoms with formation of the δ-hydroxy carboxylic acid and then (X) by lactonization. The tetramethylene lactonic ester (XI) is structurally related to α-carbethoxybutyrolactone and should exhibit lactonic properties similar to those of that compound toward alkali and heat. The behavior of (XI) is also theoretically interesting because it contains a heterogeneous bi-annular system and therefore should indicate the relative stability of rings of different sizes and chemical nature in a single molecule toward heat and reagents and also these relations to three-membered rings in structurally comparable compounds. According to the "Strain Theory," a four-membered ring system should show only slightly greater stability toward heat and chemical reagents than the corresponding three-membered ring in structurally comparable compounds. However, it has long been known that theory and experiment differ widely in this respect. This is also clearly manifest in the very facile ring fission of trimethylene-α,α-dicarboxylic acid and the great stability of the tetramethylene ring in the structurally comparable γ-lactone-tetramethylene-α-carboxylic acid. The latter was recovered in large part after prolonged heating at 200°, followed by vacuum distillation,[10] and it required prolonged heating with concentrated hydrochloric acid to rupture the hydrocarbon ring. The far greater stability and facility of formation of the five over the six-membered lactone ring is evident in the behavior of the γ,δ-dilactone, (X), and the lactonic acid corresponding to the ester (XI). The tetramethylene C-ring of (XI) shows less stability toward mineral acid than the γ-lactone ring and C-fission not only occurs but a stable δ-lactone ring appears in its place in the formed dilactone, (X). On the other hand, toward alkaline treat-

(7) Johansonn and Sebelius, Ber., **51**, 480 (1918).

(8) Leuchs and Splettstösser, ibid., **40**, 307 (1907).

(9) However, this is only one of the influences determining the stability of rings; see Michael and Ross [THIS JOURNAL, **55**, 3690 (1933)].
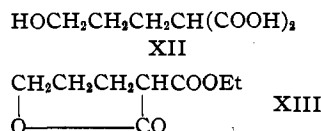
(10) Stability is also shown in analogous compounds of the malonic acid type; acid malonic ester distils at 147° (21 mm.) without decomposition [Marguery, Bull. soc. chim. [3] **33**, 544 (1905)], and we have found cyanoacetic acid boils at 145–150° (2 mm.) without decomposition.

ment the tetramethylene ring of (XI) is far more stable than the lactone ring; mild treatment splits the δ-ring of (X) and the δ-hydroxy-γ-lactonic acid obtained from the salt is a stable substance, but the salt of the γ,δ-dihydroxypropylmalonic acid, formed by more vigorous treatment, is labile and the δ-hydroxy-γ-lactonic acid is formed spontaneously. Obviously these relations are not in harmony with the "Strain Theory."[11]

It became of interest to determine whether the δ-lactone group manifests the property of enolate formation in analogously constituted δ-lactonic esters. A possible method to prepare these derivatives appeared to be through γ-hydroxypropylmalonic acid, (XII), which might be inter- and intramolecularly esterified to α-carbethoxy-δ-valerolactone, (XIII).

$$HOCH_2CH_2CH_2CH(COOH)_2$$
XII

$$\underset{\underset{O\text{———}CO}{|\qquad\qquad|}}{CH_2CH_2CH_2CHCOOEt} \qquad XIII$$

An alcoholic solution of sodium malonic ester was treated with trimethylene bromohydrin, but the product could not be distilled, even in high *vacuo*, and polymerized to a plastic, rubber-like mass and decomposed. Trimethylene bromohydrin acetate, in alcoholic solution, gave a similar product, but with dry sodium enol malonic ester, in boiling benzene or dioxane, $CH_2(OCOCH_3)CH_2CH_2CH(COOEt)_2$ (XIV) was obtained. Attempts to lactonize this compound resulted in recovery of the ester; or in an amorphous product, which could not be distilled. The γ,δ-dilactone (X) appeared a suitable compound, and the sodium enolate of α-carbethoxy-δ-hydroxy-valero-γ-lactone (XV) which could lead to (X) was prepared in good yield from glycidol and sodium malonic ester

$$HOCH_2CH\overset{\diagdown O\diagup}{-\!\!-\!\!-}CH_2 + CH(COOEt)=C(ONa)OEt \longrightarrow$$

$$\underset{\underset{O\text{———}CO}{|\qquad\quad|}}{HOCH_2CHCH_2C=C(ONa)OEt} \qquad XV$$

However, the corresponding ester was a viscous liquid, which polymerized quickly and decom-

posed on heating. A feasible method seemed through the enolate of malonic γ-chloropropyl ethyl ester, $CH_2(COOEt)COOCH_2CH_2CH_2Cl$, (XVI), which might be prepared from malonic ester acid chloride and trimethylene chlorohydrin. These reagents yielded, however, equimolecular amounts of malonic diethyl ester, and $CH_2(COOCH_2CH_2CH_2Cl)_2$, as well as the desired unsymmetrical ester, (XVI). This result suggested that interchange of ester radicals took place catalytically through the liberated hydrogen chloride, and suggested the preparation of ester (XVI) from malonic ester and trimethylene chlorohydrin with the aid of hydrogen chloride, which was obtained in good yield. Similarly, $CH_2(COOEt)COOCH_2CH_2Cl$ and also the corresponding symmetrical dichloro ester were prepared from ethylene chlorohydrin. It was not found possible to lactonize chloro ester (XVI) in alcoholic sodium ethylate solution; the alcoholate caused an interchange of ester groups and the same product was obtained as from sodium malonic ester and trimethylene bromohydrin. When the enolate was formed by the action of pulverized sodium on ester (XVI) in benzene solution, a product of unworkable nature was obtained. The usefulness of this method was shown for the preparation of γ-lactonic esters, as $CH_2(COOEt)COOCH_2CH_2Cl$ gave α-carbethoxybutyrolactone. It appears that α-carbethoxyvalero-δ-lactone (XIII), cannot be isolated on account of the extreme facility of polymerization. Similarly, Fichter and Beisswenger[12] found that δ-valerolactone polymerized spontaneously.

Experimental

α - Methyl - α - carbethoxybutyro - γ - lactone, (V).— Twenty-seven grams of sodium enol α-carbethoxybutyro-γ-lactone, (IV), was suspended in 200 cc. of dry benzene containing two equivalents of methyl iodide and the mixture was boiled for three hours. The finely suspended sodium iodide was separated from the solution by centrifuging and the solution and ether washings of the salt were concentrated *in vacuo*. The residue, distilled at reduced pressure, gave: (I) 2.9 g., b. p. up to 100° (2 mm.) 120–125°; (II) 19.1 g., b. p. 108–109° (2 mm.) 135–140°. Fraction II was redistilled. b. p. 104.5–105° (2 mm.), and analyzed.

Anal. Calcd. for $C_9H_{12}O_4$: C, 55.82; H, 6.98. Found: C, 55.48; H, 7.05. The γ-lactonic ester boiled at 264–265° (765.5 mm.). Upon saponification it yielded α-carboxy-α-methylbutyro-γ-lactone melting at 98°, identical with the substance obtained by Marburg[13] in a different manner.

(11) A theory should be capable of explaining experimental results and predicting their outcome. From this viewpoint, Baeyer's "Strain Theory" has led to many conclusions, contradictory to the results of experiment. Baeyer's attempt [*Ber.*, **18**, 2277 (1885)] to interpret its underlying assumptions from an energy standpoint has been shown to be fallacious [Michael, THIS JOURNAL, **55**, 3690, footnote 16 (1933)]. It is doubtful whether this "theory" serves a useful purpose in organic theory.—A. M.

(12) Fichter and Beisswenger, *Ber.*, **36**, 1200 (1903).

(13) Marburg, *Ann.*, **294**, 102 (1897).

α,α' - Di - [α - carbethoxybutyro - γ - lactone], (VI).—
Fifty-four grams of sodium enol α-carbethoxybutyro-γ-lactone (IV) was suspended in 200 cc. of dry benzene in a three-necked flask. An equivalent weight of iodine was placed in a dropping funnel arranged in an apparatus which returned the refluxed benzene through the funnel. In this manner a benzene solution of iodine was added slowly to the boiling, stirred suspension of the enolate. The iodine was decolorized immediately, until only a small amount remained, when it disappeared slowly. The mixture was boiled for an hour after the addition of iodine, and the salt, which contained some of the enolate (52.6 g., calcd. 45 g.), was filtered, and washed with ether. The filtrate, colored slightly by iodine, was washed with a sodium thiosulfate solution. dried and the benzene removed under reduced pressure. Dilution of the residue with ether caused crystallization of 9.6 g. of a solid. After filtration the solvent was removed and the residue fractionated *in vacuo:* (I) 4.3 g., b. p. 115–120° (2 mm.) 155–185°; (II) 17 g., b. p. 185–200° (2 mm.) 215–250°. Fraction I was colored slightly with iodine and was not further examined. Fraction II was a viscous liquid. which did not solidify, even on cooling to −80°. It was redistilled and boiled at 189° (2 mm.) 215–220°.

The solid, recrystallized from benzene–petroleum ether, was obtained as plates, melting at 145°.

Anal. Calcd. for $C_{14}H_{18}O_8$: C, 53.52; H, 5.73. Found (solid): C, 53.67, 53.52; H, 6.14, 5.95. (Liquid): C, 52.81, 52.78; H, 6.50, 6.39.

Although the liquid was distilled repeatedly, the above analysis could not be improved.

α,α' - Di - [α - carboxybutyro - γ - lactone], (VII).—The above lactonic esters and the other lactonic esters examined were saponified by a method which yielded 80–100% of the corresponding acids. The lactonic ester was treated with a 70–80° solution of one and one-half equivalents of Ba-$(OH)_2 \cdot 8H_2O$ in twice the weight of water. The insoluble barium salt was suspended in ether and an equivalent of concentrated hydrochloric acid added gradually with cooling and stirring. The aqueous solution was then extracted in a continuous extractor until the acid was completely removed from the aqueous solution.

In this way the isomeric dilactonic esters yielded the same acid, which, after recrystallization from ether–petroleum ether, melted at 154–156° with decomposition.

Anal. Calcd. for $C_{10}H_{10}O_8$: C, 46.51; H, 3.88; neut. equiv., 129. Found: C, 46.32; H, 4.00; neut. equiv. 130.

α,α'-Dibutyrolactone, (VIII).—Twenty-one and two-tenths g. of mixed isomeric dilactonic esters was saponified and after drying and removing the ether a sirupy residue was obtained. This residue was heated in a distilling flask, in a metal bath maintained at 170°, until evolution of carbon dioxide ceased. The residue was distilled under reduced pressure and yielded first a small quantity of liquid, boiling at 140–142° (4 mm.), 180–200° and then the greater part of the residue, which boiled at 200° (4 mm.), 250–270° and solidified in the receiver. The total distillate weighed 8.3 g., a yield of 72%. The solid was washed free of liquid with ether, and crystallized from acetone as cubes that melted at 176°.

Anal. Calcd. for $C_8H_{10}O_4$: C, 56.47; H, 5.88. Found: C, 56.33; H, 5.84.

Butyrolactone.—One hundred and forty grams of α-carbethoxybutyrolactone (IV) prepared according to Traube and Lehmann,[6] was saponified·with hot barium hydroxide. The barium salt did not separate from the hot solution but crystallized partially on cooling. The solution and suspension of barium salts was treated with an equivalent of concentrated hydrochloric acid and the solution extracted for forty-eight hours with a continuous ether extractor. The ether solution was concentrated without drying and the residue was transferred to a distilling flask and heated at 140° until the evolution of carbon dioxide and water had ceased. The residue boiled completely at 200–205° and weighed 68 g. (87%).

1 - Carbethoxy - 1 - carboxy - 3 - hydroxycyclobutane Lactone, (XI).—Twenty-five grams of α-carbethoxy-δ-chlorovalero-γ-lactone (IX) (b. p. 153° at 2 mm.) was diluted with absolute alcohol to 100 cc. and added dropwise over a period of four hours to a well-stirred, boiling solution of 2.8 g. of sodium in 100 cc. of absolute ethanol. When the reaction was completed, the greater part of the solvent was removed at atmospheric pressure and the remainder at reduced pressure. The residue was diluted with 200 cc. of ether and the separated sodium chloride removed by centrifuging (weight 6.1 g., calcd. 7.1 g.). The ether solution was shaken with a small quantity of dilute acid to decompose the small quantity of unchanged sodium compound, when it changed color from deep orange to pale yellow. The residue (20.6 g.) gave on fractionation 14.2 g., boiling at 132–140° (2 mm.), 165–200°, which on redistillation boiled mainly at 132° (2 mm.).

Anal. Calcd. for $C_8H_{10}O_4$: C, 56.47; H, 5.88. Found: C, 56.21, 56.14; H, 6.22, 6.08.

The residue solidified to a glassy mass, probably polymer formed by intermolecular alkylation.

Five and five-tenths grams of the cyclic lactonic ester was placed in a distilling flask and heated in a metal bath. There was no apparent action until the bath reached 280° when the liquid turned pale yellow. At a bath temperature of 340°, the liquid began to boil at about 285°. It was heated for thirty minutes and was then distilled, giving the ester boiling at 135° (2 mm.) (4.7 g., residue 0.4 g.).

1,1 - Dicarboxy - 3 - hydroxycyclobutane Lactone.—
Three grams of the tetramethylene lactonic ester (XI) was saponified as described above. The barium salt, soluble in the hot solution, crystallized out upon cooling. It was crystallized twice from boiling water and dried in the air.

Anal. Calcd. for $C_6H_6O_5Ba \cdot 2H_2O$: H_2O, 10.88. Found: H_2O, 11.81.

The salt was dehydrated on heating *in vacuo* at 100° over phosphorus pentoxide.

Anal. Calcd. for $C_6H_6O_5Ba$: Ba, 46.51. Found: Ba, 46.22.

The barium salt was decomposed by acid, and the organic acid separated by continuous extraction of the aqueous solution. In this manner the acid is obtained as a viscous sirup, which slowly deposited the solid acid when dissolved in ether–petroleum ether mixture and the solution cooled in a freezing mixture. On recrystallization from ether–petroleum ether it melted at 80–81°.

Anal. Calcd. for $C_6H_6O_4$: C, 50.70; H, 4.23; neut. equiv., 142. Found: C, 50.57; H, 4.48; neut. equiv.,

141.2, 144. After heating with excess of 0.1 N NaOH, 72.2.

A distilling flask, containing 6.8 g. of the above acid, was heated in a bath for an hour at 200° with only slight evolution of gas and darkening. On distillation it gave 4.4 g. of a viscous, colorless oil, b. p. 155–160° (2 mm.), 200–220°, which solidified on rubbing with a little ether and was identified as the original acid by mixed melting point.

γ,δ-Dihydroxypropylmalonic Acid Dilactone, (X).— Eleven and seven-tenths grams of the tetramethylene lactonic ester was dissolved in 50 cc. of cold concentrated hydrochloric acid. This solution was boiled for one and a half hours, 45 cc. of liquid distilled off and the residue diluted with 10 cc. of alcohol. A precipitate of 1.5 g. of a crystalline solid was obtained, which, after crystallization from alcohol. melted at 178–179°. This substance is identical with γ,δ-dihydroxypropylmalonic acid dilactone obtained by Leuchs.[8]

δ - Hydroxy - α - carbethoxyvalero - γ - lactone, (XV).— Twenty grams of glycidol in 100 cc. of absolute ethanol was added dropwise to a stirred solution of 5.7 g. of sodium in 200 cc. of absolute alcohol and 40 g. of malonic ester, the temperature of the solution being kept at about 40°. After the mixture no longer warmed spontaneously, the solution was cooled, finally with an ice-bath, when 20 g. of sodium compound separated. This was filtered, washed thoroughly with ether and dried *in vacuo*.

Anal. Calcd. for $C_8H_{11}O_5Na$: Na, 10.95. Found: Na, 10.82.

The alcoholic filtrate was concentrated under reduced pressure, and the residue diluted with ether, when a voluminous sodium compound separated. The two amounts of the sodium compound were decomposed together with iced acid and ether. The aqueous solution of the very soluble organic compound was extracted in a continuous extractor for twenty-four hours. The yield of dry, ether-free oil was 42.2 g. or 90%. In agreement with Traube,[6] this lactonic ester could not be distilled in a vacuum, but decomposed on heating to 200°.

γ-Acetoxypropylmalonic Ester, (XVI).—One hundred grams of dry sodium enol malonic ester was dissolved in 200 cc. of dry dioxane containing 100 g. of CH_3COOCH_2-CH_2CH_2Br, and the solution boiled for eight hours. The precipitated salt was removed by centrifuging and the solution was concentrated at reduced pressure. The residue was taken up in ether and shaken with dilute acid to decompose any unchanged enolate. The residue from the dried, concentrated ether solution was fractionated; after removal of the lower boiling malonic ester and the bromide, 100 g. of liquid, b. p. 143–145° (4 mm.), 175–185°, was obtained; yield 70%.

Anal. Calcd. for $C_{12}H_{20}O_6$: C, 55.38; H, 7.69. Found: C, 54.82, 54.82; H, 7.57, 7.49.

$ClCH_2CH_2CH_2OOCCH_2COOEt$ (XVI) and $CH_2(COO$-$CH_2CH_2CH_2Cl)_2$.—When 20 g. of $ClCH_2CH_2CH_2OH$ and 30.8 g. of $CH_2(COCl)COOEt$ were treated in the usual manner and the reaction product distilled, there was obtained 7.4 g. of malonic ester, b. p. 98–105° (18 mm.), 22.1 g. of unsymmetrical ester (XVI), b. p. 118° (3 mm.), and 11.9 g. of $CH_2(COOCH_2CH_2CH_2Cl)_2$ b. p. 164–165° (2 mm.).

Anal. of 118° (3 mm.). Calcd. for $C_8H_{13}O_4Cl$: Cl, 17.06. Found: Cl, 16.89.

Anal. of 165° (2 mm.). Calcd. for $C_9H_{14}O_4Cl_2$: Cl, 27.6. Found: Cl, 27.02.

These esters were also prepared by interchange of the ester radicals as follows: 1 g. of gaseous hydrogen chloride was dissolved in a mixture of 40 g. of malonic ester and 24 g. of trimethylene chlorohydrin. After twenty-four hours at room temperature the mixture was separated by fractionation into a mixture of 30.4 g. of malonic ester and the chlorohydrin, which passed over together, 20.2 g. of unsymmetrical ester (XVI), and 6.5 g. of symmetrical chloro ester. The proportions of products were not changed by allowing a similar mixture to stand for seventy-two hours.

$ClCH_2CH_2OOCCH_2COOEt$ and $CH_2(COOCH_2CH_2Cl)_2$. —An interchange was also effected in a mixture of 39 g. of ethylene chlorohydrin and 80 g. of malonic ester containing 1 g. of hydrogen chloride. After removal of the alcohol the residue was fractionated: (I) 18 g. of $ClCH_2$-CH_2OH, b. p. 70–80° (70 mm.); (II) 55.2 g. of malonic ester, b. p. 100–101° (21 mm.); (III) 34.8 g., b. p. 105–106° (3 mm.); and (IV) 6.6 g., b. p. 142–143° (3 mm.).

Anal. of fraction III. Calcd. for $C_7H_{11}O_4Cl$: Cl, 18.23. Found: Cl, 18.04.

Fraction IV was not further investigated, as it was identical with the compound $CH_2(COOCH_2CH_2Cl)_2$, described by Bennett.[14]

α-Carbethoxybutyrolactone from $ClCH_2CH_2OOCCH_2$-$COOEt$.—Nineteen and five-tenths grams of $ClCH_2CH_2$-$OOCCH_2COOEt$ was allowed to react in a benzene suspension of 2.3 g. of pulverized sodium, until enolate formation was complete. The solution was then boiled for twenty-four hours, shaken with dilute acid, and the dried solution concentrated *in vacuo*. The residue was fractionated into: (I) 0.4 g., b. p. 75–100° (2 mm.), and 5.3 g., b. p. 125–127° (2 mm.). Fraction II was identical with α-carbethoxybutyrolactone prepared by the method of Traube and Lehmann;[6] yield 35%.

Summary

1. Attempts to esterify β,β-dimethyl-β-propiolactonic acid resulted in a retrogressive decomposition, with formation of acetone and malonic ester. Evidence, however, has been advanced to show that such an ester would form an enolate.

2. Butyro-γ-lactone shows a very slight tendency, if any, toward enolate formation. A method for preparing the lactone from α-carbethoxybutyro-γ-lactone in 85% yield is described.

3. The sodium derivatives of α-carbethoxybutyro-γ-lactone and α-carbethoxy-δ-chlorovalero-γ-lactone are enolates and exhibit the characteristic properties of this class of compounds. The chlorolactone enolate, on heating in alcoholic solution, undergoes an intramolecular

(14) Bennett. *J. Chem. Soc.*, **127**, 1278 (1925).

C-alkylation, to form the intracyclic γ-lactone of the bi-annular, 3-hydroxy-1-carboxycyclobutane carboxylic ester. The four-membered hydrocarbon ring in this compound is very stable to heat and alkali, but is ruptured by boiling hydrochloric acid with saponification, to yield the dilactone of γ,δ-dihydroxypropylmalonic acid.

4. The relative stabilities of the rings in the lactone of 3-hydroxy-1-carboxycyclobutane carboxylic acid and the dilactone of γ,δ-dihydroxypropylmalonic acid toward heat, dilute and strong alkali, and mineral acid are opposed to the relations postulated from Baeyer's "Strain Theory."

5. It was not found possible to prepare an enolate of a δ-lactonic ester; the compounds examined polymerized spontaneously.

6. Malonic esters with different ester radicals have been prepared by effecting an interchange between one of the ester radicals and a chlorohydrin in the presence of hydrogen chloride. Experiments to prepare γ- and δ-lactonic esters from these compounds were successful only in the case of a γ-derivative.

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The Utilization of S-Benzyl Thiuronium Chloride for the Isolation and Identification of Organic Acids

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The reaction of benzyl chloride upon thiocarbamide was first investigated by Bernthsen and Klinger[1] in 1879. Some years later Werner[2] again studied this reaction and obtained the reaction product in a state of purity for the first time. Werner established its composition and recorded a melting point of 172–174° for the pure salt. He observed, however, upon three occasions the formation of a low melting product (m. p. 146–148°) and as a result suggested it to be a possible case of dimorphism.

Taylor[3] attempted to account for the existence of the two forms upon a structural basis but the original suggestion of Werner was shown to be the correct explanation by Lecher[4] and his co-workers as the result of an extensive investigation.

Lecher named the product S-benzyl thiuronium chloride and assigned to it the structure

$$\left[C_6H_5CH_2{-}S{-}C\begin{smallmatrix} \nearrow NH_2 \\ \searrow NH_2 \end{smallmatrix} \right]^+ Cl^-$$
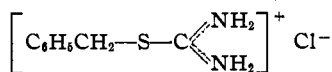
Following the work of Taylor and prior to the publications of Lecher, the writer was engaged in a study of the salts of benzyl pseudothiocarbamide with various carboxylic and sulfonic acids. The marked ease of formation and the well-defined crystalline nature of these salts suggested immediately their possible use in the isolation and identification of the acids. An investigation was undertaken and a preliminary report made.[5]

While the work was still in progress Chambers and Scherer[6] published a paper describing the benzyl pseudothiourea salts of some naphthalene sulfonic acids. In this paper, conspicuous for its lack of analytical data and reference to earlier workers in the field, they erroneously described the reaction of benzyl chloride upon thiourea with the evolution of hydrochloric acid. In order to correct this error and because of the current interest now manifested in this field the results of our investigation are here recorded.

S-benzyl thiuronium chloride is obtained in practically quantitative yields when benzyl chloride reacts upon thiourea. The following procedure is the best to employ.

Preparation of S-Benzyl Thiuronium Chloride. —A mixture of 126 g. of benzyl chloride, 76 g. of thiourea and 200 cc. of alcohol is gently heated upon a reflux condenser for one-half hour. A vigorous reaction ensues and a homogeneous solution soon results. Upon cooling the product solidifies to a crystalline magma. The crude salt may be purified by recrystallization from alcohol or a mixture of one part of concentrated hydrochloric acid and one part of water. The pure salt melts at 172–174°. At times the lower melting form (146–148°) is obtained. This form may be

(1) A. Bernthsen and H. Klinger, *Ber.*, **12**, 574 (1879).

(2) E. A. Werner, *J. Chem. Soc.*, **57**, 285 (1890).

(3) J. Taylor, *ibid.*, **111**, 650 (1917).

(4) H. Lecher and C. Heuck, *Ann.*, **438**, 169 (1924); H. Lecher, *et al., ibid.*, **445**, 35 (1925).

(5) Meeting of A. C. S., New Haven, April, 1923.

(6) R. F. Chambers and P. C. Scherer, *Ind. Eng. Chem.*, **16**, 1272 (1924).