alcohol made by the action of sulfuric acid on cracked petroleum hexene fraction is mainly hexanol-2, the fraction distilling at 138–139° giving an α-naphthyl urethan melting, not sharply, at 58–62°. Levene and Haller[11] have recorded 61–65° as the melting point of the α-naphthyl urethan of *d*-hexanol-2.

Reaction of Pentene-1 with Sulfuric Acid

Pentene-1 was prepared by the action of allyl bromide on ethylmagnesium bromide, ether being removed from the pentene by treating with 70% sulfuric acid below 20°. The pentene, 80 g., b. p. 30–30.5°, was treated with 130 g. of sulfuric acid 84%, containing 3 ml. of Merck "Perhydrol" and 1 g. of finely powdered dibenzoyl peroxide. Hydrolysis and steam distillation gave 58 ml. of alcohol (dried by potassium carbonate), which distilled completely at 118–119°, with no evidence whatever of *n*-pentanol-1 (boiling point 137.8°).

Reaction of Pentene-2 with Sulfuric Acid.—Pentene-2, prepared as noted above, was treated with a slight excess of 80% sulfuric acid at about 20°, the acid product hydrolyzed and distilled with steam. The dried alcohol, and also a sample of *s*-amyl alcohol made in a similar manner from the amylene fraction of cracked naphtha, were distilled eight times through a small packed column and the following fractions obtained:

Fraction	B. p., %	From pentene-2, ml.	Amylene fraction, ml.
(1)	113–114	6	5
(2)	114–115	32	22
(3)	115–116	98	59
(4)	116–117	63	25
(5)	117–117.5	42	22
(6)	117.5–118	54	50
(7)	118–119	238	340

Fraction (3) of each series gave an α-naphthyl urethan which, after several recrystallizations from petroleum ether, melted sharply at 95°, which melting point was unchanged when mixed with the same derivative of synthetic pentanol-3. Fraction (7) gave an α-naphthyl urethan melting at 72° and unchanged when mixed with the derivative made from pentanol-2. This melting point of the naphthyl urethan of pentanol-2 confirms the value given by Gordon and Kremers.[12] However, these authors give the melting point of the α-naphthyl urethan of pentanol-3 as 61–62°. Neuberg and Kramsky[13] give 76–79° as the melting point of this product. Pentanol-3 was prepared by the action of propionic aldehyde on ethylmagnesium bromide, the boiling point of the alcohol being 114.5–115°, as described in the literature. The α-naphthyl urethan was prepared by allowing the mixture of the alcohol and α-naphthyl isocyanate to stand at room temperature for about twenty-four hours.

Summary

In the reaction of propylene with sulfuric acid, no primary ester is formed. Peroxides do not cause the formation of primary normal amyl hydrogen sulfate from pentene-1. The addition of sulfuric acid, using 85–90% acid to propylene and pentene-1, differs from the addition of hydrogen bromide in forming no primary derivatives. The addition of sulfuric acid to pentene-2 gives sulfuric esters of both pentanol-2 and pentanol-3.

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[11] Levene and Haller, *J. Biol. Chem.*, **79**, 485 (1928).

[12] Gordon and Kremers, *J. Am. Pharm. Assn.*, **16**, 313 (1927).

[13] Neuberg and Kramsky, *Biochem. Z.*, **20**, 445 (1909).

New York City Received June 20, 1934

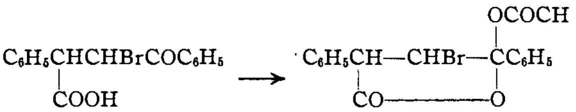
[Contribution from the Converse Memorial Laboratory of Harvard University]

The Reactions of Certain Gamma Ketonic Acids. III. Ketonic Beta Lactones

By E. P. Kohler, W. D. Peterson and C. L. Bickel

In continuation of the investigation described in the first paper of this series[1] we have studied the second β-bromo acid that is obtained by brominating α-phenyl β-benzoyl propionic acid. Since we are interested primarily in the manner in which ring formation is affected by configuration, we have devoted special attention to a comparison of the conditions under which the two stereoisomeric β-bromo acids are converted into lactones.

In acid solutions these bromo acids, like the unsubstituted ketonic acid itself, form γ-lactones. As nearly as can be determined in reactions which are accompanied by polymerization, there is no conspicuous difference in the ease with which the three acids are converted into these cyclic compounds. The unsubstituted acid forms only an unsaturated crotolactone,[2] but the bromo acids, doubtless because bromine depresses the activity of hydrogen atoms attached to the same carbon atom, form saturated lactones which can be isolated as acyl derivatives



$$\begin{array}{l} C_6H_5CHCHBrCOC_6H_5 \\ \quad | \\ \quad COOH \end{array} \longrightarrow \begin{array}{lcl} & & OCOCH \\ & & | \\ C_6H_5CH & -CHBr- & CC_6H_5 \\ | & & | \\ CO & \text{———} & O \end{array}$$

I II

Although the formation of these lactones involves the generation of a third center of asym-

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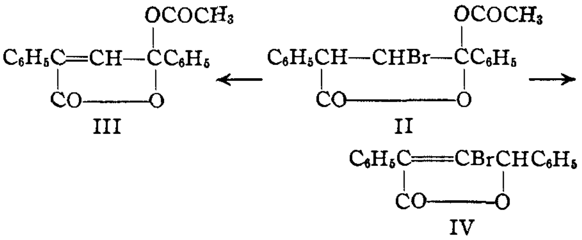
[1] Kohler and Kimball, This Journal, **56**, 729 (1934).

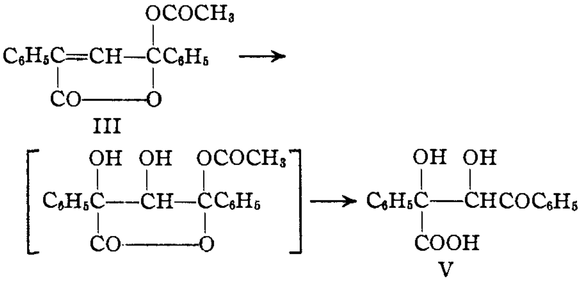
[2] Anschütz and Montfort, *Ann.*, **284**, 4 (1895); Ref. 1.

metry, each bromo acid yields but one cyclic acetate. Both acetates are stable in acid media—even in boiling acetic acid and acetic anhydride—but in the presence of a feeble base like sodium acetate in glacial acetic acid, the acetate of the lower melting bromo acid is rapidly transformed into that of its isomer and this substance then slowly loses either hydrogen bromide or acetic acid, forming a mixture of an unsaturated bromo lactone and the cyclic acetate of an unsaturated acid



$$\underset{\mathrm{III}}{\begin{array}{l}\qquad\qquad\quad\mathrm{OCOCH_3}\\ \mathrm{C_6H_5C{=}CH{-}CC_6H_5}\\ \quad\mathrm{CO{-}{-}{-}O}\end{array}} \longleftarrow \underset{\mathrm{II}}{\begin{array}{l}\qquad\qquad\qquad\quad\mathrm{OCOCH_3}\\ \mathrm{C_6H_5CH{-}CHBr{-}CC_6H_5}\\ \quad\mathrm{CO{-}{-}{-}{-}{-}O}\end{array}} \longrightarrow \underset{\mathrm{IV}}{\begin{array}{l}\mathrm{C_6H_5C{=}{=}CBrCHC_6H_5}\\ \quad\mathrm{CO{-}{-}{-}O}\end{array}}$$

Barring an improbable allylic shift of the acetyl group, the unsaturated acetate can have only the structure represented by III. In accordance with this formula it is readily formed from *cis* phenyl benzoyl acrylic acid and it equally readily regenerates this acid on hydrolysis. Moreover, in accordance with Thiele's rule[3] it can be oxidized to a dihydroxy ketonic acid.



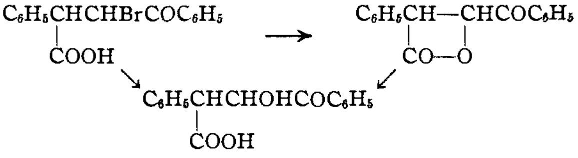
$$\underset{\mathrm{III}}{\begin{array}{l}\qquad\qquad\quad\mathrm{OCOCH_3}\\ \mathrm{C_6H_5C{=}CH{-}CC_6H_5}\\ \quad\mathrm{CO{-}{-}{-}O}\end{array}} \longrightarrow$$

$$\left[\begin{array}{l}\quad\mathrm{OH}\;\;\mathrm{OH}\;\;\mathrm{OCOCH_3}\\ \mathrm{C_6H_5C{-}{-}CH{-}{-}CC_6H_5}\\ \quad\mathrm{CO{-}{-}{-}{-}O}\end{array}\right] \longrightarrow \underset{\mathrm{V}}{\begin{array}{l}\qquad\;\;\mathrm{OH}\;\;\mathrm{OH}\\ \mathrm{C_6H_5C{-}{-}CHCOC_6H_5}\\ \qquad\;\;\mathrm{COOH}\end{array}}$$

Elimination of acetic acid from the bromo acetate II would be expected to result in a crotolactone with the double linkage in the β,γ position. It is well known, however, that the unsaturated system in crotolactones is exceedingly mobile, and since the bromo lactone on oxidation likewise gives a dihydroxy ketonic acid, it is much more probable that the double linkage is in the α,β position as represented in IV.

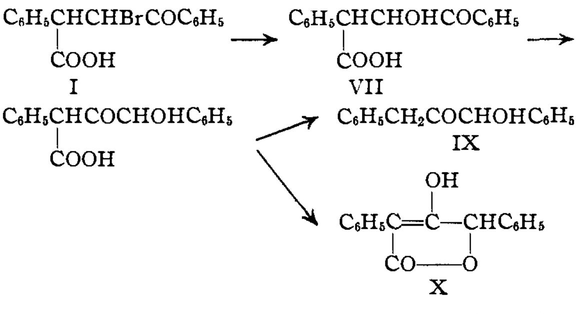
Evidently configuration plays but a very minor role in the formation and properties of these γ-lactones. The reverse is true with respect to the β-lactones; here the configuration of the bromo acids determines the speed with which the lactones are formed and prescribes the conditions under which they can be obtained. At the ordinary temperature and in dilute aqueous solution the neutral salt of the higher melting acid passes completely into a lactone in less than three hours. Under the same conditions the isomeric acid requires five days for its complete disappearance and the product is a mixture of lactone and hydroxy acid. In the case of the higher melting acid the lactone is formed so much faster than the hydroxy acid that slight alkalinity does not affect the result while the lower melting acid under similar conditions yields only hydroxy acid.

The origin of the hydroxy acids is still uncertain. Direct experiments show that in slightly alkaline solutions they are formed far more rapidly from the bromo acids than from the lactones, but this evidence is inconclusive because other experiments show that in alkaline solutions of the bromo acids the concentration of the lactones is considerably greater than any which can be obtained by dissolving the lactones. For the present, therefore, it is necessary to assume that the hydroxy acids may be either primary or secondary products



$$\begin{tikzcd}[column sep=small] \begin{array}{l}\mathrm{C_6H_5CHCHBrCOC_6H_5}\\ \quad\mathrm{COOH}\end{array} \arrow[rr] \arrow[dr] & & \begin{array}{l}\mathrm{C_6H_5CH{-}CHCOC_6H_5}\\ \qquad\;\mathrm{CO{-}O}\end{array} \arrow[dl] \\ & \begin{array}{l}\mathrm{C_6H_5CHCHOHCOC_6H_5}\\ \quad\mathrm{COOH}\end{array} & \end{tikzcd}$$

Under very special conditions caustic alkalies convert both bromo acids into a substance which was formerly regarded as trans phenyl benzoyl crotonic acid,[4] but which in reality represents an interesting and an apparently new type of γ-lactone. The successive steps in the formation of this lactone have not been clearly established but the most plausible mechanism is represented by the following chart



$$\begin{tikzcd}[column sep=small] \underset{\mathrm{I}}{\begin{array}{l}\mathrm{C_6H_5CHCHBrCOC_6H_5}\\ \quad\mathrm{COOH}\end{array}} \arrow[r] & \underset{\mathrm{VII}}{\begin{array}{l}\mathrm{C_6H_5CHCHOHCOC_6H_5}\\ \quad\mathrm{COOH}\end{array}} \arrow[r] & {} \\ \begin{array}{l}\mathrm{C_6H_5CHCOCHOHC_6H_5}\\ \quad\mathrm{COOH}\end{array} \arrow[r] \arrow[dr] & \underset{\mathrm{IX}}{\mathrm{C_6H_5CH_2COCHOHC_6H_5}} & \\ & \underset{\mathrm{X}}{\begin{array}{l}\qquad\quad\;\mathrm{OH}\\ \mathrm{C_6H_5C{=}C{-}CHC_6H_5}\\ \quad\mathrm{CO{-}{-}O}\end{array}} & \end{tikzcd}$$

All the reactions described in the foregoing account occur in cold dilute aqueous solutions. Increase in concentration leads to secondary

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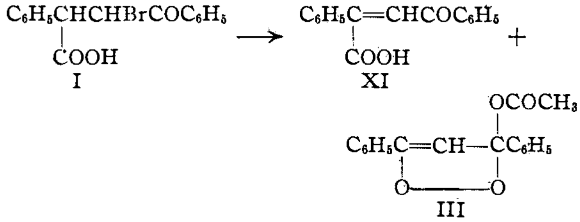
[3] Thiele, *Ann.*, **319**, 144 (1901).

[4] Kohler, THIS JOURNAL, **30**, 221 (1928).

products which are due to polymerization, and increase in temperature promotes the formation of secondary products which are due to cleavage, but these variations in the conditions do not materially affect the relative rates at which the bromo acids disappear and both bromo acids invariably form similar products. In these aqueous solutions, therefore, the only difference in the behavior of the two acids which can be attributed to dissimilarity in configuration is that of the speed with which they form β-lactones.

In non-aqueous solutions more extensive differences make their appearance. In glacial acetic acid and acetic anhydride, for example, sodium acetate converts the lower melting bromo acid cleanly into a mixture composed of trans phenyl benzoyl crotonic acid and the cyclic acetate of the corresponding *cis* acid



$$C_6H_5\underset{COOH}{CH}CHBrCOC_6H_5 \longrightarrow C_6H_5\underset{COOH}{C}{=}CHCOC_6H_5 + C_6H_5\underset{O}{C}{=}CH{-}\overset{OCOCH_3}{\underset{O}{C}}C_6H_5$$

I XI III

In the case of this bromo acid, changes in temperature and procedure affect the composition of the mixture but the product invariably contains only these two substances. In the case of the higher melting bromo acid, however, the product always contains, in addition to these two substances, some benzalacetophenone. At the ordinary temperature the amount of the unsaturated ketone is small—less than 10%—but it increases rapidly with increase in temperature and at the boiling point it is the principal product—more than 80%.

The unsaturated ketone cannot be formed by loss of carbon dioxide from the lactones because the same reagents convert both of the lactones quantitatively into the mixture of trans acid and cyclic acetate. It also does not arise from either of the unsaturated acids because both are ultimately converted completely into the cyclic acetate. And no benzalacetophenone could be obtained either from the cyclic bromo acetates or from the hydroxy acids. The unsaturated ketone, therefore, cannot come from any of these possible intermediates; it must be formed directly from the bromo acid by a process that is concurrent with lactone formation and which is dependent upon the configuration of the acid.

Similar relations prevail in pyridine. And here the difference in the behavior of the two bromo acids is even more impressive because the reactions are simpler. In water pyridine combines with both bromo acids to form salts which are so sparingly soluble that further action is negligible, but solution—either of these salts or of the bromo acids themselves—in dry pyridine is followed by prompt reaction. The lower melting acid is slowly but completely converted into the *cis* unsaturated acid. The higher melting acid dissolves with perceptible effervescence and always yields a mixture of *cis* acid and benzalacetophenone, the amount of unsaturated ketone ranging from about 15% at the ordinary temperature to more than 90% at the boiling point. Here also the unsaturated ketone must come directly from the bromo acid because pyridine has no action on either the *cis* or *trans* unsaturated acids and it transforms both lactones completely into *cis* acid.

As will be seen from the foregoing account we do not yet have sufficient data for a general discussion of the reaction between β-bromo acids and bases. We have established experimentally that two of the three compounds which are generally formed when a β-bromo acid is neutralized with a base, namely, the β-lactone and the ethylenic compound, are due to competing reactions, but we are still in doubt with respect to the origin of the hydroxy acid. We have also succeeded in establishing a connection between the configuration of the bromo acid, the speed of lactone formation, and the tendency to form an ethylenic compound. And we have found that in the case of diamers the bromo acid which forms a β-lactone most rapidly is the only one that gives rise to an ethylenic compound.

Experimental Part

I. The Bromo Acids and their γ-Lactones

In order to secure pure bromo acids it is essential to use only perfectly pure phenyl benzoyl propionic acid. The acid obtained by hydrolyzing its nitrile in the manner described heretofore, invariably contains nitrogenous impurities which are removed only with great difficulty. It is better, therefore, and also much easier, to convert the nitrile into the methyl ester and then to hydrolyze the ester with a base.

When the pure acid is brominated in chloroform it forms variable quantities of neutral, indeterminate polymerization products and three bromo acids, namely, the two β-bromo substitution products melting, respectively, at 208 and 185°, and the *cis* form of α-phenyl-β-bromo-β-benzoylacrylic acid which melts at 195°. The relative amounts in which the three bromo acids are formed vary little if any with the conditions but the loss from polymerization decreases with dilution and with increase in temperature. In boiling chloroform one mole of acid yields about 0.66 mole of the bromo acid melting at 208°, 0.24 mole of the acid melting at 185° and 0.03 mole of the unsaturated bromo acid.

From the mixture of bromination products it is easy to isolate much of the sparingly soluble higher melting bromo acid, but the separation of the remaining material by systematic fractional crystallization is exceedingly troublesome. It is much better to simplify the separation of this material by taking advantage of the great difference in the speed with which the two bromo acids are converted into β-lactones. In this manner both the rest of the higher melting bromo acid and the polymers can be removed completely in the form of non-acidic compounds. The separation of the two remaining acids then presents no great difficulty.

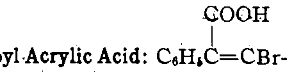
Preparation of Pure Ketonic Acid.—To a suspension of 100 g. of the nitrile in 600 cc. of methyl alcohol, 160 g. of concd. sulfuric acid is added as rapidly as possible without causing too violent boiling. The mixture is boiled for two and one-half hours, then cooled in a freezing mixture. The solid ester is collected on a sintered glass funnel, washed with iced methyl alcohol and recrystallized from methyl alcohol. The weight of pure ester melting at 103–104° equals that of the nitrile.

The ester is hydrolyzed in the usual manner with methyl alcoholic sodium hydroxide. In order to get rid of a small quantity of polymeric material, the resulting acid is dissolved in ether, extracted from the ethereal solution with sodium bicarbonate, reprecipitated and dried on a steam-bath.

Preparation of the Bromo Acids

Bromination.—A solution of 100 g. of the ketonic acid in 250 cc. of chloroform is shaken with calcium chloride because the solution contains enough water and alcohol to affect the bromination. The dried solution is heated to boiling and treated with bromine until the color persists, then rapidly cooled to the ordinary temperature and immediately filtered. After thorough washing with chloroform the solid is almost pure high melting bromo acid; one recrystallization from ether or glacial acetic acid gives the pure acid.

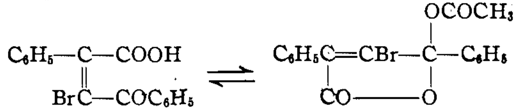
The filtrate is shaken with successive lots of 5% sodium bicarbonate until it is free from acid, leaving nothing except polymer in the chloroform. The bicarbonate extracts are set aside for three hours—ample time for converting all of the higher melting bromo acid into the insoluble β-lactone. The solutions, which now contain only the two remaining bromo acids and a small quantity of hydroxy acids, on acidification deposit only the bromo acids and these acids are separated by crystallization from ether.



α-Phenyl β-Bromo β-Benzoyl Acrylic Acid: $C_6H_5\overset{\overset{\text{COOH}}{|}}{C}{=}CBr\text{-}COC_6H_5$.—Since the unsaturated acid is formed only in small quantities and is insensitive to dilute alkalies, it is most easily purified by destroying the acids which accompany it with 2% sodium hydroxide. It crystallizes well from all solvents in plates or large prisms and it melts at 195°.

Anal. Calcd. for $C_{16}H_{11}O_3Br$: C, 58.4; H, 3.7. Found: C, 58.3; H, 3.7.

A solution of the acid in sodium bicarbonate slowly reduced permanganate which oxidized the acid to phenyl glyoxylic acid and a small quantity of benzoic acid—sufficient proof of its structure. The configuration of the acid was established by transforming it into a cyclic acetate from which it is regenerated both by acids and by bases. The carboxyl and benzoyl groups are therefore in the *cis* positions



The Cyclic Acetate.—The bromo acid forms a cyclic acetate less readily than the corresponding bromine-free compound but practically complete conversion was obtained by boiling a solution of 1 g. of the acid in 10 g. of acetic acid and an equal weight of acetic anhydride for two and one-half hours. The acetate crystallizes from ether and petroleum ether in small tables and it melts at 98°. Warm hydrochloric acid regenerates the bromo acid.

Anal. Calcd. for $C_{18}H_{13}O_4Br$: C, 57.7; H, 3.5. Found: C, 57.8; H, 3.6.

The Methyl Ester.—A solution of the acid in methyl alcohol saturated with hydrogen chloride deposited an ester which crystallizes in small prisms and melts at 98°. Since the ester has not been prepared from the acid with diazomethane it may be either open chained or cyclic.

Anal. Calcd. for $C_{17}H_{13}O_3Br$: C, 59.1; H, 3.8. Found: C, 59.0; H, 3.8.

α-Phenyl-β-bromo-β-benzoylpropionic Acid. I.—The higher melting acid was described in an earlier paper. The lower melting acid crystallizes well only from ether. It is readily distinguished from all other bromo acids that are formed along with it because it crystallizes with a molecule of ether, in large transparent prisms which lose ether on exposure to the air.

Anal. Calcd. for $C_{17}H_{15}O_3Br(C_2H_5)_2O$: $(C_2H_5)_2O$, 18.2. Found: $(C_2H_5)_2O$, 18.1. Calcd. for $C_{17}H_{15}O_3Br$: C, 57.7; H, 3.9. Found: C, 57.5; H, 4.0.

The Cyclic Acetates, II.—Both of the bromo acids are converted into cyclic acetates with surprising rapidity. Thus when 6 g. of the higher melting acid was shaken with 50 g. of acetic anhydride, most of it remained undissolved but upon the addition of 10 drops of concd. sulfuric acid the suspended material disappeared almost immediately and ten minutes later all but a trace of the acid had reacted. The solution was then stirred with cracked ice until all of the anhydride was decomposed. It left a crystalline solid composed of the acetate and a small quantity of a polymeric product which was readily removed by recrystallization from glacial acetic acid containing a few drops of anhydride. It crystallized in flat needles melting at 145°. The yield was 4.6 g.

The lower melting bromo acid on similar treatment formed an acetate which crystallized from ether and petroleum ether in thick needles or tables melting at 110°. The yield was 6.0 g. from 7.0 g. of acid.

Anal. Calcd. for $C_{18}H_{15}O_4$: C, 57.6; H, 4.0. Found: (145°) C, 57.6; H, 4.3; (110°) C, 57.6; H, 4.1.

Interconversion of the Acetates.—Neither of the acetates was changed when its solution in acetic acid containing a little anhydride was heated on a steam-bath for an hour, but when sodium acetate was added to the mixture, the lower melting acetate was rapidly transformed into its higher melting isomer. Thus 0.5 g. of the compound melting at 110° heated for an hour with a mixture obtained by dissolving 0.5 g. of sodium bicarbonate in 10 g. of acetic acid and 10 g. of acetic anhydride gave 0.43 g. of the isomer melting at 145°.

Elimination of Hydrogen Bromide and Acetic Acid.—Five grams of the higher melting acetate was heated on a steam-bath for an hour with a solution of sodium acetate that was made by dissolving 5.0 g. of sodium bicarbonate in 50 g. of glacial acetic acid. The resulting liquid, on evaporation in a draught, left a mixture of solids that was separated by crystallization from ether and petroleum ether. The principal product was a bromine-free compound which was identified as the unsaturated cyclic acetate III.

Anal. Calcd. for $C_{18}H_{14}O_4$: C, 73.4; H, 4.8. Found: C, 73.1; H, 4.7.

The unsaturated acetate crystallizes in large prisms and melts at 95°. It is formed quantitatively when *cis* phenyl benzoyl acrylic acid is heated with acetic acid and acetic anhydride, and it is hydrolyzed to this same acid when it is digested with hydrochloric acid.

Oxidation: α,β-Dihydroxy-α-phenyl-β-benzoylpropionic Acid, V.—The unsaturated acetate very readily reduced permanganate in aqueous acetone at 0°. Among the products was a sparingly soluble acid which crystallized from ether–petroleum ether in thin plates and which melted at 165°. The yield was only about 10%, most of the material being oxidized to phenyl glyoxylic and benzoic acids.

Anal. Calcd. for $C_{16}H_{14}O_5$: C, 67.2; H, 4.9. Found: C, 67.3; H, 4.8.

α,γ-Diphenyl-β-bromocrotolactone, IV.—The second product formed by the action of sodium acetate on the saturated bromo acetate is much more sparingly soluble in ether. It crystallizes in small prisms and melts at 149°.

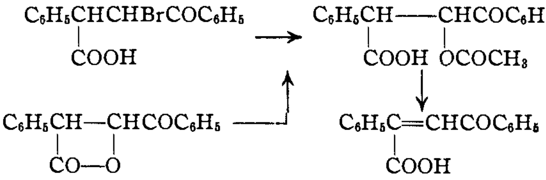
Anal. Calcd. for $C_{16}H_{11}O_2Br$: C, 60.9; H, 3.5. Found: C, 60.8; H, 3.6.

Oxidation α,β-Dihydroxy-α-phenyl-β-benzoylpropionic Acid, VI.—For the purpose of locating the double linkage, the bromo lactone was treated with permanganate in the usual manner. Much of it was oxidized to benzoic and phenyl glyoxylic acids but a part of the product was a less soluble acid which crystallized from ether–petroleum ether in small prisms and melted at 154–155°. The same acid was obtained in small quantity by oxidizing the cyclic acetate of the unsaturated bromo acid. It is isomeric with the dihydroxy acid obtained from the unsubstituted acetate III. Both of these dihydroxy acids are readily oxidized to phenyl glyoxylic and benzoic acids.

Anal. Calcd. for $C_{16}H_{14}O_6$: C, 67.2; H, 4.9. Found: C, 67.3; H, 4.8.

II. The β-Lactones and the Unsaturated Acids

The two β-lactones and the *cis* acid can be made with ease but the *trans* acid is secured with difficulty because strong bases isomerize it rapidly and completely to the *cis* acid. Thus far it has been obtained only in a maximum yield of 20% by the action of sodium acetate in glacial acetic acid on the bromo acids and the β-lactones. The manner in which it is formed in these reactions is not certain but all the available evidence indicates that the bromo acids and the lactones are first converted into the corresponding acetoxy acids and that these subsequently lose acetic acid—the one to form the *cis* and the other the *trans* acid



In accordance with this interpretation the yield of *trans* acid from the higher melting bromo acid and its lactone is at least five times as great as that from their isomers. That the reaction in all cases should give rise to both *cis* and *trans* acids is to be expected because sodium acetate in acetic acid is known to isomerize the bromo acids, their lactones and the *trans* acid, and it doubtless would have also the same action on the intermediate acetoxy compound.

In order to avoid the necessity of separating the *cis* and *trans* acids, which differ little in solubility, it is expedient to add acetic anhydride to the reacting mixture. The two lactones and the lower melting bromo acid then yield only the trans acid and the cyclic acetate III while the higher melting bromo acid yields, in addition, benzalacetophenone. These products can be separated quantitatively because the *trans* acid can be removed with sodium bicarbonate, the cyclic acetate hydrolyzed to the *cis* acid and removed in the same manner, leaving only the unsaturated ketone.

The β-Lactone.—For reasons given in the introduction good yields of the β-lactone corresponding to the lower melting bromo acid can be obtained only in dilute and nearly neutral solutions. Such solutions are most conveniently obtained by shaking a one per cent. solution of sodium hydroxide with excess of finely powdered acid until it is neutral to litmus and removing the excess by filtration. Solutions prepared in this manner remain colorless, but they become cloudy almost immediately and all the bromo acid disappears in the course of six or seven days; the precipitate is almost pure lactone. The lactone can also be obtained by shaking the bromo acid for five or six days with excess of aqueous sodium acetate and removing the unreacted bromo acid with sodium bicarbonate.

The precipitated lactone is partially hydrated and contains enough of the alkaline salt to cause extensive polymerization on heating or on solution in a polar medium. It should therefore be purified immediately by dissolving it in ether, washing the solution thoroughly with water and drying it with calcium chloride. It crystallizes in prisms, is sparingly soluble in ether, readily soluble in alcohols and in acetone and it melts at 148°.

Anal. Calcd. for $C_{16}H_{12}O_3$: C, 76.2; H, 5.0; mol. wt., 252. Found: C, 75.9; H, 5.2; mol. wt., 248.

The chemical properties of the lactone are precisely the same as those of its isomer: concentrated hydrobromic acid regenerates the lower melting bromo acid; methyl alcoholic hydrobromic acid forms a bromo ester, m. p. 106°; aqueous sulfuric acid a hydroxy acid, m. p. 145°; methyl alcoholic sulfuric acid a hydroxy ester, m. p. 98°. All of these reactions occur readily and they are free from racemization. Since all the products have been obtained in other ways and described elsewhere, the experiments need not be described in detail.

Action of Bases on the Two Lactones.—Aqueous bases first convert the lactones into the corresponding hydroxy acids, then partly isomerize each of these acids into an equilibrium mixture and ultimately transform both of them into the hydroxy ketone IX. Dry pyridine has very little action on the lactones at the ordinary temperature but at 100° it rapidly rearranges both of them to the *cis* unsaturated acid. Here the *cis* acid must be formed directly from both lactones because at this temperature pyridine has no action whatsoever on the *trans* acid.

***Trans* Phenyl Benzoyl Crotonic Acid, XI.**—To a hot solution of 10 g. of sodium bicarbonate in 30 g. of glacial acetic acid were added in succession 20 g. of acetic anhydride and 10 g. of the lactone melting at 95°. The solution, which immediately assumed the deep yellow color common to all solutions of the *trans* acid, was boiled gently for an hour, then evaporated as completely as possible in a strong draught. The solid residue was dissolved in ether and water, the ethereal layer was thoroughly washed with water, then extracted with sodium bicarbonate. From the bicarbonate solution hydrochloric acid precipitated 1.8 g. of crude *trans* acid from which 1.65 g. of pure acid was obtained by recrystallization from ether and petroleum ether. The ethereal solution from which the acid had been removed was dried, concentrated and diluted with petroleum ether. It yielded 9.0 g. of the cyclic acetate and a trace of polymer. By exactly similar treatment, 10 g. of the higher melting bromo acid yielded 1.6 g. of *trans* acid, 1.9 g. of the acetate and 6.0 g. of benzalacetophenone, while 5.0 g. of the lower melting bromo acid yielded only 0.3 g. of *trans* acid, and 5.0 g. of the lactone melting at 148° yielded only 0.2 g. of *trans* acid. Neither of the lactones was affected in any way when boiled for an hour with acetic acid and acetic anhydride.

The *trans* acid crystallizes in colorless needles melting at 128°. It is readily soluble in all common solvents except petroleum ether. The color of the solutions like that of the melt is yellow.

Anal. Calcd. for $C_{16}H_{12}O_3$: C, 76.2; H, 4.8. Found: C, 76.2; H, 5.0.

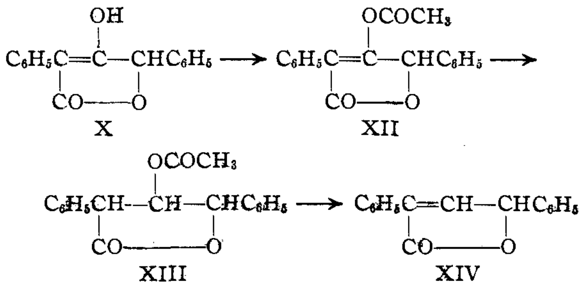
The acid is fairly stable in acid solutions but on prolonged heating with hydrochloric acid in glacial acetic acid it is completely changed into the *cis* acid and it is slowly converted into the cyclic acetate when it is boiled with sodium acetate and acetic anhydride in acetic acid (0.24 g. of acetate from 1.0 g. of acid after an hour's boiling). It is not affected by boiling pyridine and cold sodium hydroxide acts slowly but hot sodium hydroxide converts it rapidly and completely into the *cis* acid.

III. The Enolic Gamma Lactone X

Among the products of reactions between strong bases and the bromo acids, the β-lactones and the hydroxy acids there is frequently a very small quantity of a sparingly soluble acid which melts at about 212°. When this acid was first discovered it was regarded as the *trans* acid because it is isomeric with the *cis* acid and like the latter it is readily oxidized to phenylglyoxylic and benzoic acids. Moreover, it turns up, occasionally, in processes which would be expected to yield the more stable of the two unsaturated acids, as for example, in the pyrolysis of the hydroxy acids and in the rearrangement of the β-lactones at high temperatures.

As more material became available for examination this interpretation, however, became more and more doubtful because the differences between the new and the *cis* acid appeared to be too fundamental to be due merely to geometrical isomerism. Thus in contrast with the *cis* acid it dissolves in concd. sulfuric acid without producing color and while it is sufficiently acidic to dissolve in sodium bicarbonate, it cannot be esterified under conditions which readily give the *cis* esters. Also, in contrast with the *cis* acid, it fails to respond to any of the common reagents for carbonyl groups—not even to excess of methylmagnesium iodide.

All of these peculiarities seemed incompatible with the structure of the *trans* acid and when the real *trans* acid was finally discovered a revision of the formula became imperative. In the end the structure of the acid was definitely established by a series of transformations ending with a known diphenylcrotolactone.



This series of transformations is conclusive because while the diphenylcrotolactone could also be formed from an α-hydroxyl derivative, such a substance would neither be acidic nor form, as does the acid, a methyl ether from which it is regenerated by bases. In solution the substance may be in part ketonized but there is no evidence of such a form; the high melting point and the slight solubility in ether show that the solid is the enolic modification.

Preparation.—To a hot solution of 6 g. of sodium in 400 cc. of dry methyl alcohol was added 30 g. of the higher melting bromo acid. The solution remained colorless until all the acid had dissolved, then became first yellow and finally bright orange in color as it reached the boiling point. It was boiled for fifteen minutes, then poured into excess of 10% hydrochloric acid. The resulting solution was evaporated in a draught until most of the methyl alcohol had disappeared, and finally extracted with ether. From the ethereal solution, which contained a number of other substances, sodium bicarbonate extracted only the enol. Small quantities of the enol easily recrystallized from ether, larger quantities from methyl alcohol and ether. It separates in small lustrous prisms and melts at 209°.

Anal. Calcd. for $C_{16}H_{12}O_3$: C, 76.2; H, 4.8; mol. wt., 252. Found: C, 76.2; H, 5.0; mol. wt., 262.

The substance immediately develops a dark green color in methyl alcoholic ferric chloride and it forms a brown copper compound in methyl alcoholic copper acetate. When added to excess of methylmagnesium iodide it consumes one mole of reagent, liberates one mole of gas and forms a crystalline magnesium derivative from which it is regenerated by acids; prolonged boiling does not alter this result. It does not react with bromine under the conditions of the Kurt Meyer test for enols and it is not destroyed either by concentrated hydrochloric acid or by strong potassium hydroxide.

The Methyl Ether.—All attempts to methylate the acid with methyl alcohol and acid, the sodium salt with dimethyl sulfate, the silver salt with methyl iodide, were unsuccessful but diazomethane in ether converted it into two products of which one was the methyl ether.

Anal. Calcd. for $C_{17}H_{14}O_3$: C, 76.6; H, 5.3. Found: C, 76.6; H, 5.2.

The methyl ether is moderately soluble in ether. It separates in flattened needles and melts at 105°. Its solution in cold methyl alcoholic sodium hydroxide remained colorless and when it was acidified after half an hour it deposited the enol in the calculated quantity.

The Acetate, XII.—A solution of 4 g. of the enol in 60 cc. of warm acetic anhydride containing a few drops of concd. sulfuric acid was set aside for two hours, then stirred into 200 cc. of ice water. The resulting solid was dissolved in ether and the ethereal solution was freed from acid by extraction with bicarbonate, dried and concentrated. The acetate separated in stout prisms melting at 85°. The yield was 4.1 g.

Anal. Calcd. for $C_{18}H_{14}O_4$: C, 73.5; H, 4.8. Found: C, 73.3; H, 4.8.

Reduction: The Saturated Acetate, XIII.—The unsaturated acetate was dissolved in five times its weight of glacial acetic acid and twice its weight of acetic anhydride and reduced with hydrogen and Adams' catalyst. Most of the reduction product separated during the reduction. It was recrystallized from acetone and petroleum ether, and thus obtained in flat needles melting at 165°.

Anal. Calcd. for $C_{18}H_{16}O_4$: C, 73.0; H, 5.4. Found: C, 73.0; H, 5.5.

Hydrolysis and Dehydration of the Reduction Product: Phenylcrotolactone, XIV.—A solution of 0.4 g. of the acetate in 10 cc. of glacial acetic acid was treated with 1 cc. of concd. hydrochloric acid, then boiled for ten minutes and diluted with water. It deposited a crystalline solid which was identified as diphenylcrotolactone by comparison with an authentic sample.

Summary

1. The ethylenic compounds which are generally formed along with β-lactones when β-bromo acids are neutralized with bases are not due to decomposition of the lactones; the lactones and the ethylenic compounds are formed in concurrent reactions.

2. Of two diastereomeric bromo acids the one from which the β-lactone is formed most rapidly is also the one which gives rise to the ethylenic compound.

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