pounds may yield these very additive compounds. For instance, iodoform is 17000 times more soluble in pyridine than in water; it is also known to form additive compounds with pyridine.[1] So also other substances possibly may form molecular compounds with pyridine and thus their solubilities in pyridine may be accounted for by Rules 1 and 2.

(3) Certain dyes (31, 47, 84), alkaloids (13, 19, 73), and allied substances (2, 11, 58, 76) are most soluble in $C_5H_5N.H_2O$. If these substances can be shown to form hydrates, such solutes and the solvent are observed to fall under Rules 1 and 2.

(4) Sugars are invariably most soluble in water, hence probably do not unite with the pyridine molecules. Maltose, lactose, and raffinose, however, are least soluble in $C_5H_5N.H_2O$. Being di- and tri-saccharides these three possibly absorb the molecule of water and the new solutes bear to the pyridine or to the $C_5H_5N.H_2O$ a relation of lowered solubility.

(5) Cholesterol is 262 times more soluble in pyridine than in water. As is well known, cholesterol is an antidote for saponins, toxalbumins, etc., substances of a basic nature. If it can be shown that cholesterol unites with pyridine and other bases, the detoxifying influence of it can be accounted for. This property of cholesterol, accurate studies of solubility in pyridine and its tendency to form additive compounds will be pursued.

The views expressed above are in accord with the views of many authors. For example, Hertz and Knoch[2] arrive at the conclusion that the solute combines with one of the mixed solvents. Holleman aud Antsch[2] postulate that: (1) The two solutes form a molecular compound; (2) the solute combines with one of the solvents, or (3) the solute combines with molecular compound of the two solvents. The work of Hudson,[3] Abegg[4] and others assume attraction between the solute and the solvents to account for certain properties of solubility.

More extensive and accurate studies of pyridine, quinoline and other solubilities are to be made, also efforts will be made to prepare the molecular compounds indicated.

SEATTLE, WASH.

[CONTRIBUTION FROM THE CHEMICAL LABORATORY OF HARVARD UNIVERSITY.]

STUDIES IN THE CYCLOPROPANE SERIES.

BY E. P. KOHLER AND J. B. CONANT.

Received April 20, 1917.

Owing to the influence of Baeyer's "Strain Theory," most recent investigators of cyclopropane derivatives have been interested mainly

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[1] THIS JOURNAL, **34,** 1413 (1913).

[2] *Loc. cit.*

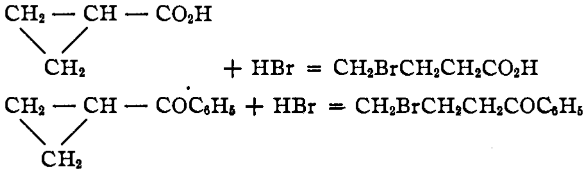
[3] *Z. physik. Chem.*, **17,** 114 (1904); *Phys. Rev.*, **23,** 370 (1906); THIS JOURNAL, **31,** 63 (1909).

[4] *Z. Electrochem.*, **7,** 677 (1901).

in the "stability" of the cyclopropane ring and the way in which this is affected by substituents. Their conclusions have almost invariably been based on the relative ease with which cyclopropane derivatives combine with hydrobromic acid or some similar reagent. All attempts to account for the many interesting facts that these investigators have discovered about the influence of substituents upon the *ease of addition* to cyclopropane derivatives seem, as yet, hopeless. For the present an investigation of the influence of substituents upon the *mode of addition* appears much more promising.

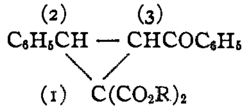
The many cyclopropane derivatives that are known belong, unfortunately, to a small number of classes, and in most of these only one or two representatives have been made. The hydrocarbons and acids, however, are known in great number and variety, and some of their addition reactions have been studied. The results indicate that substituents have exactly the same effect upon the mode of addition to a cyclopropane ring as to an ethylene linkage, even though the saturated open-chained compounds formed in the two cases are quite different in structure.

Thus the mode of addition of hydrobromic acid to cyclopropane hydrocarbons is determined by the number and arrangement of the alkyl groups. The ring invariably opens between the carbon atoms that hold the largest and the smallest number of these groups and the principal product is always an alkyl halide in which the halogen is in combination with the carbon that holds the largest number of alkyl groups. The mode of addition to the cyclopropane acids, on the other hand, is not influenced by alkyl groups. In the acids these groups may affect the ease with which addition takes place, but the product is always either a γ-bromo acid or the corresponding lactone. The few ketones that have been studied behave like the acids. In the case of cyclopropane derivatives that have carbonyl groups in direct union with the ring, therefore, the halogen always goes to the β-position in the ring:



The similarity in the behavior of these simple cyclopropane derivatives and the corresponding α,β-unsaturated compounds is evident. We have begun an investigation of a series of more complex cyclopropane derivatives in the expectation that the results will be of assistance in explaining the peculiarities of α,β-unsaturated compounds as well as those of cyclopropane derivatives.

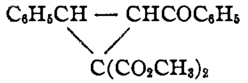
The substances that we have studied are represented by the formula

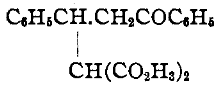


As these substances have both carbonyl and carboxyl groups in direct union with the ring, the question of special interest, was the extent to which they exhibit the peculiarities of α,β-unsaturated ketones and esters. We have therefore treated them with a number of reagents that give characteristic results with unsaturated compounds of this type—oxidizing agents, reducing agents, bases, halogen acids, halogens—and have studied both the mode of addition and the ease with which it takes place.

Towards oxidizing agents these cyclopropane derivatives are peculiarly insensitive; they do not reduce a cold solution of permanganate and they are not attacked by ozone. The behavior towards permanganate has been examined with fourteen different substances, that towards ozone with four—all with the same result. The indifference to oxidizing agents represents the most pronounced difference between these cyclopropane derivatives and those ethylenic compounds which have hydrogen in combination with the unsaturated carbon atoms.

The cyclopropane derivatives under consideration are readily reduced by nascent hydrogen. The primary product in all cases is a saturated open-chained compound, formed by breaking the ring between the 1 and 3 carbon atoms

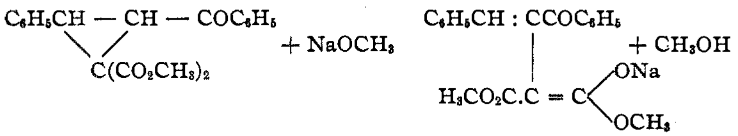




$$\underset{CH(CO_2H_3)_2}{C_6H_5CH}.CH_2COC_6H_5$$

In no case could cyclopropane derivatives be detected in the product; it seems just as impossible to reduce these substances to cyclopropane alcohols as it is to reduce the corresponding unsaturated ketones to unsaturated alcohols.

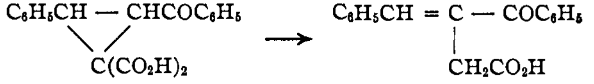
One of the most striking properties of these substances is their extreme sensitiveness to basic reagents. In the presence of water they are hydrolyzed to ester acids with unusual rapidity. In the absence of water alcoholates, ammonia and amines rapidly and smoothly transform them into derivatives of isomeric unsaturated compounds.



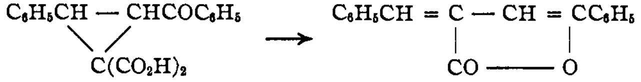
Whatever may be the mechanism of the reaction, it is clear that the ring in this case is opened between the carbon atoms 1 and 2.

To the action of halogen acids the substances seem less sensitive than might be expected from the behavior of cyclopropane hydrocarbons. In alcoholic solutions both the ester acids and the dibasic acids are esterified, and the esters undergo no change, even when boiled in alcoholic solutions that are saturated with halogen acids. In glacial acetic acid both the acids and the esters are changed by halogen acids but the results are complicated by secondary reactions that lead to loss of carbon dioxide and lactone formation. The relation between the substances used and the products isolated is represented by the following equations:

(I).



(II).



The second of these reactions represents a third way of opening the cyclopropane ring because a lactone of this kind could be formed only as a result of a process in which the ring is broken between carbon atoms 2 and 3.

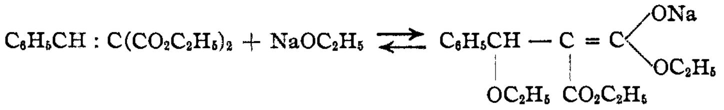
Towards the halogens our substances are almost as unreactive as towards oxidizing agents. No combination takes place under any conditions, and even substitution is surprisingly difficult in view of the fact that these compounds have hydrogen in the α-position to carbonyl. At high temperatures and in the presence of catalytic agents, a slow replacement of hydrogen by bromine takes place, but up to the present it has not been possible to establish the structure of the product.

As will be seen from this brief summary of results, it has been possible to open our cyclopropane rings at three different points—the most rigorous proof possible that any substance really contains such a ring. Since no cyclopropane derivatives that have been studied heretofore have entered into such a variety of reactions, these must be due to the particular arrangement of ketonic and carboxyl groups in our substances.

The results show also that the behavior of these cyclic esters is in some respects totally different from that of unsaturated compounds, while in others it is exactly like that of the most closely related ethylenic compounds. Such typical reagents for unsaturated compounds as permanganate, bromine, and ozone have no effect on the cyclopropane derivatives. These are the reagents that attack ethylenic compounds only at the double linkage between carbon atoms; the reagents with which, consequently, all classes of ethylenic compounds—those which contain conjugated systems as well as those which do not—give the same type of reaction.

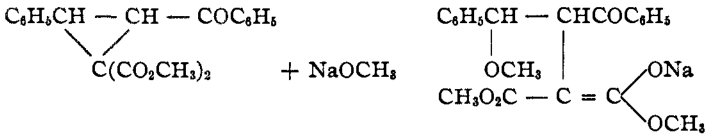
With nascent hydrogen, halogen acids, bases, and metallic derivatives, however—the reagents to which α,β-unsaturated ketones and acids are peculiarly sensitive—our cyclopropane derivatives react as readily and in the same manner as the most closely related ethylenic compounds.

The reaction between the cyclic esters and alcoholates, for example, appears to be exactly like that between benzalmalonic ester and the same reagents.

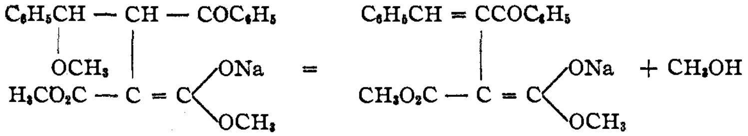


In dry ether this reaction is complete, in absolute alcohol it is partial, as indicated by the equation; and when, by addition of water or acids, the sodium is replaced with hydrogen, the product rapidly loses alcohol and reverts to the ethylenic compound.

The cyclic ester likewise readily combines with sodium alcoholate.

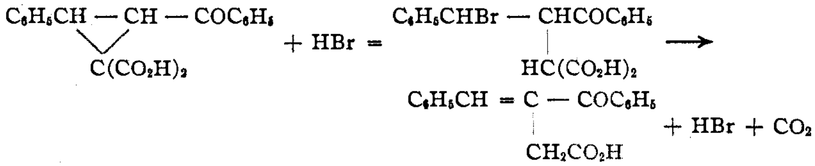


The product in this case, however, has methoxyl and active hydrogen in combination with adjoining carbon atoms. It, therefore, immediately loses alcohol and passes into the unsaturated sodium compound that was isolated.



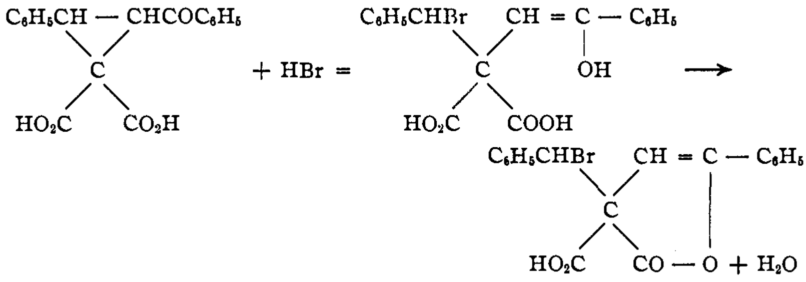
The two products resulting from the action of hydrobromic acid are not so closely related to the cyclopropane derivatives as are those obtained from the alcoholates, but the mechanism by which they are formed seems equally clear. Both are due primarily to addition of hydrobromic acid, and two are formed while alcoholates give but one for the same reason that hydrobromic acid, unlike alcoholates, combines as readily with α,β-unsaturated ketones as with unsaturated ethers. In one case the addition is like that of sodium alcoholate to the esters; but, because the free acids are used here, the product readily loses carbon dioxide as well as hydrobromic acid.

(I).

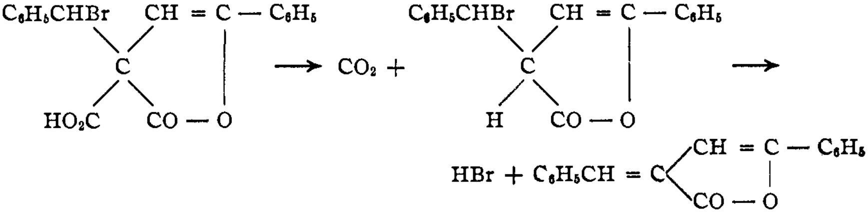


In the second case, the addition of hydrobromic acid is like that to α,β-unsaturated ketones. The result is an unsaturated γ-hydroxy acid, which as usual passes into the corresponding lactone.

(II).



The subsequent changes in this lactonic acid are such as would be expected from the well-known behavior of this type of substances.



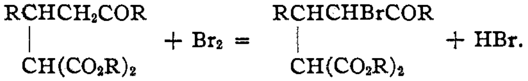
Nascent hydrogen alone, of all reagents tried, opens the ring between the 1 and 3 carbon atoms, and the ease with which both the esters and the acids are reduced is conspicuous.

Parallel experiments showed that the esters of benzoyl methylene-malonic acid are reduced with the same remarkable speed. This must be due to the relation between the carbonyl groups, which is the same in both substances, and it is probable that the reduction in both cases starts at the oxygen in these groups.

All the reactions of our cyclopropane derivatives belong to one or more of the three types that we have discussed in detail. They show that a cyclopropane ring, in which all of the carbon atoms are nominally saturated, and a carbonyl group in the proper position can form a "conjugated system," which is identical in properties with that found in many ethylenic compounds.

Experimental Part.

The substances that we have studied were made by general reactions that can be used for making a considerable variety of cyclopropane derivatives. In the presence of suitable condensing agents, most unsaturated ketones combine with malonic ester. The resulting ketonic esters readily react with bromine, giving, mainly, monobromo derivatives in which the bromine is α to the carbonyl group.

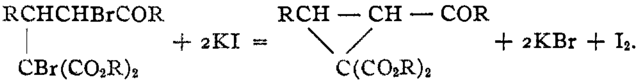


$$\begin{matrix}\mathrm{RCHCH_2COR} \\ | \\ \mathrm{CH(CO_2R)_2}\end{matrix} + \mathrm{Br_2} = \begin{matrix}\mathrm{RCHCHBrCOR} \\ | \\ \mathrm{CH(CO_2R)_2}\end{matrix} + \mathrm{HBr}.$$

From these bromine compounds it is usually easy to eliminate hydrobromic acid, the result being, always, a cyclopropane derivative. The product of this reaction sometimes contains variable quantities of unsaturated esters. These are not formed by elimination of hydrobromic acid from the bromo compound; they are due to the action of alkaline reagents upon the cyclopropane derivative. When they interfere with the crystallization of the cyclopropane, it is best to remove them by cautious treatment with permanganate in dilute acetone solution.

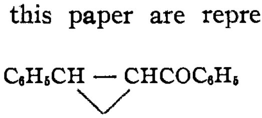
The elimination of hydrobromic acid from the bromo ester frequently results in a mixture of stereoisomeric trimethylenes from which it is difficult to get solids. In such cases it is usually possible to get one of the substances in solid form by dissolving the mixture in methyl alcohol, saturating the solution with hydrochloric acid and recovering the ester in the usual manner. By this process the unstable modifications are changed to the most stable form.

A more interesting method of meeting the same difficulty consists in first transforming the bromo ester into the dibromo compound and then eliminating bromine. Further bromination of the monobromo compound is most easily accomplished in direct sunlight; it yields an α,γ-dibromo compound from which the bromine can be removed by treatment with zinc dust or with an alcoholic solution of potassium iodide.



The reaction with potassium iodide, which takes place in the cold, shows how easily the cyclopropane ring is sometimes closed.

The two stereoisomeric cyclopropane derivatives that were used in the experiments described in this paper are represented by the following formula:



I. Preparation of Materials.

Methyl β-phenyl-γ-benzoyl-ethylmalonate.—The preparation of this substance was described in an earlier paper[1] but we have found since that it is much better to use a small quantity of sodium methylate instead of piperidine as condensing agent. The procedure is illustrated by the following experiment: A solution of sodium methylate was added, drop by drop, to a hot solution of 208 g. of benzalacetophenone and 140 g. of methyl malonate in 300 cc. dry methyl alcohol until the mixture was

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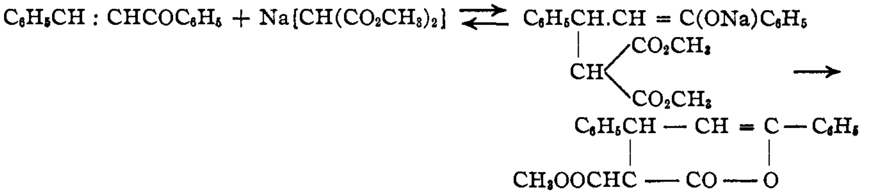
[1] *Am. Chem. J.*, 46, 481 (1911).

distinctly alkaline. The temperature of the mixture rapidly rose to the boiling point but began to fall in a few minutes. The mixture was allowed to stand without further heating for five hours, then cooled in a freezing mixture and filtered. One recrystallization from methyl alcohol gave 320 g. of pure product—a yield of 94%. The alcohol used had been distilled from calcium; it must be dry to avoid hydrolysis and loss of condensing agent. The amount of alcoholate should be kept at a minimum, both because the reaction is reversible, and because increase in the concentration of the alcoholate favors the formation of unsaturated lactones which contaminate the ester.



Methyl β-phenyl-γ-bromo-γ-benzoyl-ethylmalonate.—The preparation of two monobromo derivatives melting at 113° and 98° was also described in the earlier paper. The method used gives a mixture of the two in about equal amounts. Working with larger quantities, we have found the separation of this mixture so exceedingly troublesome that we have tried to find a more satisfactory procedure. The best that we have found is as follows:

For getting the higher melting compound a small quantity of bromine is added to a suspension of the ester in chloroform. As soon as the reaction has started—after warming, if necessary—the mixture is cooled in a freezing mixture and kept below —10° while the remainder of the bromine is added. Most of the solvent is then evaporated in a current of dry air. The solid that separates is composed mainly of higher melting compound which is easily purified by crystallization from methyl alcohol. The yield was 118 g. from 170 g. of ester. The filtrate deposited a mixture which was used in experiments in which separate substances were unnecessary.

For making the lower melting compound, it is best to brominate in methyl alcohol. Slightly more than the calculated quantity of bromine is added to a suspension of the ester in dry methyl alcohol, and the mixture exposed to sunlight. The reaction proceeds very slowly and is seldom quite complete but it gives only the lower melting compound and as that is easily freed from unchanged ester by crystallization from methyl alcohol, this is much the easiest method for getting the substance. The yield is quantitative.

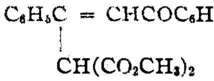
Methyl 2-phenyl-3-benzoyl-cyclopropane Dicarboxylate.—A number of substances may be used for closing the cyclopropane ring; potassium acetate, sodium methylate, sodium amide, ammonia, amines, and magnesium methylate were tried. All but the last gave either two stereoisomeric cyclopropane derivatives, or a mixture of these with unsaturated esters that are formed by the action of bases on the cyclic compounds. Magnesium methylate alone gave a single substance from each of the isomeric bromine compounds. The methylate was prepared by adding magnesium to carefully dried methyl alcohol which contained a small quantity of mercuric chloride. It is necessary to warm in order to start and complete the reaction, but unless the temperature is kept low, a large part of the methylate separates in an insoluble and unreactive form. The methylate prepared in this way was added, in small portions, to boiling solutions of the bromo esters until the appearance of a faint yellow color showed a slight excess of methylate. Most of the solvent was then distilled off, the residue poured into iced acid, the organic product extracted with ether, and the ether allowed to evaporate.

The product from the lower melting bromine compound crystallized in large tables melting at 72°; that from the higher melting bromide in plates which melt at 92°. These products are isomeric.

Calc. for $C_{20}H_{18}O_5$: C, 71.0; H, 5.4. Found (72°): C, 70.7; H, 5.4; (92°): C, 71.1; H, 5.3.

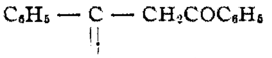
The substance melting at 72° gave all the reactions discussed in the introduction; in particular, it gave, with various reagents, three different types of compounds which could only be formed as a result of opening a carbon ring. It is therefore a cyclopropane derivative.

The product melting at 92° is identical with a substance previously obtained by Kohler[1] as a result of condensing α-bromobenzalacetophenone with the sodium derivative of methyl malonate and described as methyl γ-benzoyl-β-phenyl-vinyl malonate. At the time, it was supposed to be the ester of an unsaturated γ-ketonic acid represented either by Formula I or II, but later results show that it really is a stereoisomer of the cyclopropane derivative melting at 72° and must be represented by III.



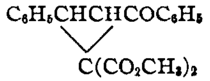
$$C_6H_5C{=}CHCOC_6H_5,\ \ |\ \ CH(CO_2CH_3)_2$$

(I).



$$C_6H_5-C(=C(CO_2CH_3)_2)-CH_2COC_6H_5$$

(II).



(III).

The facts in support of this conclusion are as follows: When perfectly pure, the substance does not reduce a cold solution of permanganate in acetone. Under the influence of both acids and bases the substance passes very easily and quantitatively into the isomer melting at 72°; it therefore gives, with all reagents, the same products that are obtained from the latter. Finally, it is the sole product of the reaction between

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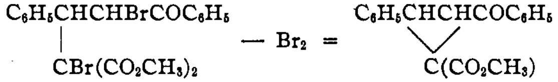
[1] *Am. Chem. J.*, 46, 485 (1911).

methyl γ-benzoyl-α,γ-dibromo-β-phenylmalonate and potassium iodide—a reaction that could give only a cyclopropane derivative.



The sensitiveness of the substance towards acids is shown by the results obtained with this reaction. The best procedure is to dissolve the dibromide in pure, dry acetone, add excess of potassium iodide and mercury, and shake until the color of the solution—yellow, owing to dissolved mercuric iodide; does not change on standing. By cautious addition of water, it is possible to precipitate nearly the whole of the organic material in crystalline form and leave the double iodide of mercury and potassium in solution. The crystals melt sharply and the yield is quantitative. If the mercury is omitted, iodine is liberated; this slowly attacks the acetone and forms a small quantity of acid. As a result a part of the product is isomerized and water precipitates, along with the solid, an oil containing the same substance mixed with variable quantities of its isomer. A complete and quantitative isomerization is easily accomplished by dissolving the substance in methyl alcohol, saturating the solution with hydrochloric acid and recovering the ester in the usual manner.

Since the two isomeric cyclopropane derivatives always give the same products with reagents, most experiments involving the use of considerable quantities of material were carried out with the substance melting at 72°. The easiest way to get this is as follows: An excess of potassium acetate is added to a solution of either of the bromine compounds, or of a mixture of the two, in the minimum quantity of boiling methyl alcohol. The solution is boiled for an hour, after which most of the alcohol is removed by distillation and the residue poured into water. This usually precipitates a pale yellow oil, which is extracted with ether. The ethereal solution is washed thoroughly with dilute sodium carbonate and water, dried and evaporated. In the absence of solid, the product generally separates as an oil that may take weeks to solidify, while most of it separates as a colorless solid if the concentrated solution is inoculated with some of the substance melting at 72°. The remainder can be converted into solid by treatment with hydrochloric acid in methyl alcoholic solution. The yield is 90–93%.

II. Action of Bases on the Cyclopropane Derivatives.

Both of the cyclopropane derivatives are very easily hydrolyzed to the same ester acid. The most convenient method is to add slightly more than the calculated quantity of sodium methylate, slowly, to a solution of the substances in ordinary ether, allow the mixture to stand for five minutes, and then extract the sodium salts with water. The ether retains a small quantity of yellow by-product. From the water solution acids precipitate an oil which soon solidifies. The solid was recrystallized from aqueous methyl alcohol or chloroform.

Calc. for $C_{19}H_{16}O_5$: C, 70.4; H, 4.9. Found: C, 70.2; H, 5.1.

The acid is very soluble in alcohol and ether, moderately in chloroform and benzene, very sparingly in ligroin. It separates from aqueous methyl alcohol in needles, from chloroform in large prisms. It melts, without decomposition, at 155°. The acid must have the same configuration as the ester that melts at 72°, because this is formed when it is esterified by allowing its silver salt to react with methyl iodide in the cold, as well as by saturating its solution in methyl alcohol with hydrochloric acid.

2-Phenyl-3-benzoylcyclopropane Diacid may be obtained, as described in an earlier paper,[1] by hydrolyzing either of the esters with excess of alcoholic potassium hydroxide; but a better yield and a purer product are obtained by first making the ester acid and heating this with excess of potassium hydroxide. In the earlier paper this acid was formulated as a ketolactonic acid because titrations with standard base, using methyl orange as indicator, indicated a monobasic acid. This is erroneous. Titrations with standard base using phenolphthalein as indicator, as well as titrations by the method of Hildebrand[2] have convinced us that the acid is dibasic. When esterified, either with methyl alcohol and hydrochloric acid or by treating the silver salt with methyl iodide, it gives as sole product the ester melting at 72°.

III. Action of Anhydrous Alkaline Reagents on the Cyclopropane Derivatives.

In the presence of water alkaline reagents rapidly hydrolyze the cyclopropane esters to the ester acids. Parallel experiments under approximately similar conditions showed that the change is much more rapid than with the open-chained substitution products of malonic ester. The ester acid is then more slowly hydrolyzed to the dibasic acid. The salts of this are not affected by boiling with the most concentrated bases.

In the absence of water, the results are quite different. When sodium methylate in perfectly dry methyl alcohol is added to a solution of either of the esters in the same solvent, the liquid at once becomes yellow and later, if the solutions are sufficiently concentrated, deposits a bright yellow sodium compound. This on treatment with acids gives an ester that is isomeric with the cyclopropane derivative. The same change takes place when the cyclic compound is treated with sodium amide, ammonia, amines, and, to a slight extent, even with potassium acetate, but all of these hydrolyze a part of the ester. The most satisfactory reagent for bringing about the change is magnesium methylate. Our procedure was

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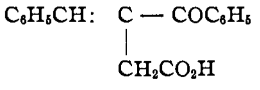
[1] *Am. Chem. J.*, **46**, 487 (1911).

[2] THIS JOURNAL, **35**, 847 (1913).

as follows: 75 g. of cyclopropane ester were added to a solution of magnesium methylate obtained by dissolving 7.5 g. magnesium in 150 cc. of dry methyl alcohol containing a little mercuric chloride. The mixture was boiled as long as the amount of yellow magnesium compound seemed to increase—usually a few hours. Most of the alcohol was then distilled, and the residue poured slowly into dilute hydrochloric acid. The colorless solid obtained in this way crystallized from methyl alcohol in plates melting at 119°. The transformation is almost quantitative.

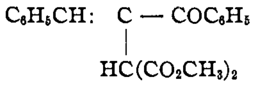
Calc. for $C_{20}H_{18}O_5$: C, 71.0; H, 5.4. Found: C, 70.8; H, 5.6.

The substance readily reduces permanganate, gives a green color reaction with ferric chloride and a brilliant canary-yellow sodium compound with metallic sodium or sodium alcoholate. The nature of the carbon chain was established by hydrolyzing the ester and heating the resulting dibasic acid. This gave a benzoyl-phenylisocrotonic acid of known structure (I). The substance is, therefore, *methyl-β-benzoyl-γ-phenylvinylmalonate* (II).



$$\begin{array}{l} C_6H_5CH{:}\ C-COC_6H_5 \\ \qquad\qquad\ \ | \\ \qquad\qquad\ \ CH_2CO_2H \end{array}$$

(I).



$$\begin{array}{l} C_6H_5CH{:}\ C-COC_6H_5 \\ \qquad\qquad\ \ | \\ \qquad\qquad\ \ HC(CO_2CH_3)_2 \end{array}$$

(II).

The behavior of the substances towards permanganate is peculiar. In acetone that contains enough water or acetic acid to prevent the formation of a metallic derivative, it is, as would be expected, rapidly oxidized to 2 molecules of benzoic acid, carbon dioxide and water. In perfectly dry acetone, on the other hand, it takes up only one atom of oxygen per molecule of substance and forms a high melting, sparingly soluble, complex product. Analyses of a product that had been repeatedly recrystallized from chloroform gave the following results.

I: C, 70.5, H, 5.2. II: C, 70.8, H, 5.2. III: C, 70.6; H, 5.4.

The substance is very sparingly soluble in all solvents, and melts with decomposition at about 220°. Its structure has not as yet been determined.

Isomeric Methyl-β-benzoyl-γ-phenylvinylmalonate. — When either of the cyclopropane esters is boiled with methylate for a longer time—six to eight hours—and then acidified, the principal product is a fourth isomer, which melts at 147°.

Calc. for $C_{20}H_{18}O_5$: C, 71.1; H, 5.4. Found: C, 70.8; H, 5.6.

This substance is far more sparingly soluble in all solvents than the ester melting at 119°. It crystallizes from acetone in characteristically striated plates. When treated with sodium or sodium methylate it formed a lemon-colored sodium compound that is almost insoluble in ether, and from which it is regenerated by acids. This proves that it is not formed by a shift of the double linkage in the ester melting at 119°.

The two esters give the same products when oxidized with potassium permanganate as well as when they are hydrolyzed with alkalies. They are, therefore, geometrical isomers. The higher melting ester is formed in calculated quantity when a solution of the lower melting isomer in methyl alcohol is saturated with hydrochloric acid; it reverts in part to that substance when its solution in benzene is exposed to direct sunlight. Neither of the esters combines with bromine, and attempts to introduce alkyl groups by means of the sodium derivatives were unsuccessful.

β-Benzoyl-phenyl-hydroxy-ethylmalonic Acid, $C_6H_5CH(OH)CH(COC_6H_5)CH(CO_2H)_2$.—The hydrolysis of the unsaturated esters is difficult and no satisfactory method for doing it was found. The best results were obtained as follows: Very finely ground ester, in 2 g. quantities, was added to excess of hot 20% aqueous sodium hydroxide. This immediately transformed the ester into a solid yellow sodium derivative. The suspension was then boiled for about 5 minutes, in the course of which the solid dissolved and the orange-colored solution became colorless or faintly yellow. The solution was cooled and poured into iced hydrochloric acid. This precipitated a pale yellow oil, which was dissolved in ether. The acids were extracted from the ethereal solution and the ether allowed to evaporate; it left variable quantities of benzaldehyde which results from cleavage at the double linkage. From the carbonate solution, acids precipitated a colorless solid which was purified by recrystallization from ether.

Calc. for $C_8H_{16}O_6$: C, 65.9; H, 4.8. Found: C, 66.1; H, 4.8.

Both esters gave the same acid. At low temperatures this crystallizes from ether, in thin, long needles containing ether of crystallization, which is lost at the ordinary temperature. When heated rapidly in a capillary tube, the acid melts with decomposition at about 125°. On esterification with methyl alcohol and hydrochloric acid, it loses water and gives, as the sole product, the unsaturated ester melting at 147°.

The hydroxy acid is rapidly decomposed by bases, the principal products being benzaldehyde and β-benzoylpropionic acid, which was identified by a mixed melting point determination with a specimen on hand.

$$C_6H_5CHOHCH(COC_6H_5)CH(CO_2H)_2 \longrightarrow C_6H_5CHO + C_6H_5COCH_2CH_2CO_2H + CO_2.$$

This accounts for the poor and variable yields—50 to 70%—obtained in the hydrolysis of the ester. The acid also decomposes when it is boiled with water or heated on a steam-bath. The odor of benzaldehyde is perceptible when the acid is heated in this way but most of it simply loses water and carbon dioxide, and forms an unsaturated acid. Thus, when 10 g. of the acid were heated on the steam-bath for three hours, it left 7.5 g. of a pale yellow melt that solidified to an amorphous mass on cooling.

This was dissolved in ether. From the ethereal solution, sodium carbonate extracted 6.6 g. of an acid that crystallized from aqueous methyl alcohol in fine needles and melted at 131°.

Calc. for $C_{17}H_{14}O_3$: C, 76.5; H, 5.2. Found: C, 76.7; H, 5.4.

This substance is β-benzoyl-phenyl isocrotonic acid, $C_6H_5CH : C(COC_6H_5)CH_2CO_2H$. It was identified by comparison with a specimen made by condensing benzaldehyde with β-benzoylpropionic acid according to the directions given by Borsche.[1]

IV. Action of Hydrobromic Acid on the Cyclopropane Derivatives.

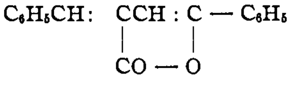
No definite substances could be obtained by treating the esters with hydrobromic acid. In alcohol and in benzene the ester melting at 85° was converted into its lower melting isomer and this was not changed either on standing for a long time at the ordinary temperature or on boiling with saturated solutions of the acid. The esters combine with hydrobromic acid in glacial acetic acid but the process is accompanied by hydrolysis and no solid products could be isolated from the mixture of substances formed.

Better results were obtained by using the dibasic acid in place of the esters. This combined readily with hydrobromic acid in glacial acetic acid. The product was precipitated as a colorless oil when ice was added after the solution had stood for several hours. The oil partially solidified in a freezing mixture, but the solid lost hydrobromic acid so readily that every attempt to recrystallize it failed. When the solution in glacial acetic acid was allowed to remain in an ice chest it gradually assumed a yellow color, which increased for several weeks. From this solution ice precipitated a yellow oil which solidified completely. By repeated recrystallization from ether and methyl alcohol, it was possible to separate this into a colorless acid and a neutral yellow compound. The acid was found to be identical with the benzoylphenyl isocrotonic acid already described.

The yellow compound separated from methyl alcohol in thin needles melting at 150°.

Calc. for $C_{17}H_{12}O_2$: C, 82.3; H, 4.8. Found: C, 82.0; H, 4.9.

This substance was found to be α-benzal-γ-phenylcrotolactone



It was identified by comparison with a specimen made synthetically by the method of Borsche. Both of these products are secondary but the character of the carbon chain shows that they must be formed by opening a cyclopropane ring in two different ways. The most probable mechanism is given in the introduction.

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[1] *Ber.*, 47, 1108 (1914).

V. Effect of Heat on the Cyclopropane Derivatives.

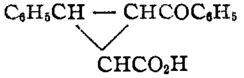
The cyclopropane esters are stable to very high temperatures, but the dibasic acid begins to decompose freely at about 150°, and gives a great variety of products. Four of these—two acids and two lactones—were described in the earlier paper but misinterpreted because they were supposed to come from a keto-lactonic acid. Two more have been isolated since and the structure of all six has been established by synthesis. The procedure was essentially the same as that previously described: The acid was kept at a temperature of 175° until no further evolution of carbon dioxide could be detected. The melt, while still hot, was poured into a large quantity of ether contained in a separating funnel and the solution extracted with sodium carbonate until free from acid.

From the carbonate solution acids precipitated an oil that solidified. The solid was washed, dried over phosphorus pentoxide in a vacuum desiccator and crystallized from ether-carbontetrachloride mixtures. It was thus separated into three acids melting at 135°, 150° and 180°. The unsaturated acid melting at 135°—previously called benzoyl-phenylvinyl acetic acid—has been identified as benzoyl phenyl isocrotonic acid by comparison with a specimen of this acid made synthetically. The acid melting at 180° was obtained in very small quantity in the earlier work and no attempt was made to determine its structure. We have found since then that it is an α-phenacylcinnamic acid, isomeric with the acid made synthetically by Thiele. This is established by the fact that, like Thiele's acid, it gives α-benzoyl-γ-phenyl-crotolactone when acetic anhydride is added to its solution in glacial acetic acid.

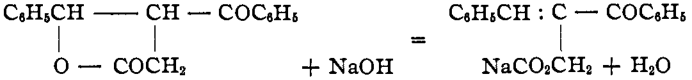
The acid melting at 150° is new. It is very soluble in ether, alcohol and chloroform, moderately in carbon tetrachloride and benzene, very sparingly in petroleum ether. It crystallizes in long, silky needles.

Calc. for $C_{17}H_{14}O_3$: C, 76.7; H, 5.3. Found: C, 76.4; H, 5.4.

This acid does not reduce permanganate. It will be shown in a subsequent paper that it is a monobasic cyclopropane acid.



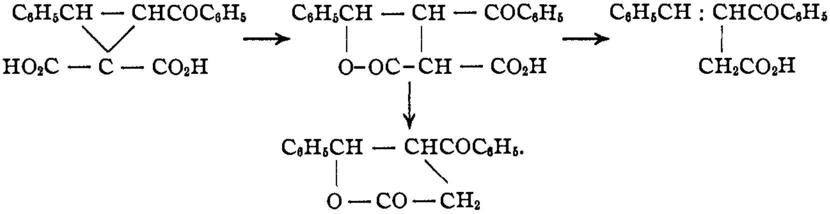
The ethereal solution from which the acids had been extracted contained three indifferent substances which were separated by recrystallization from ether-ligroin mixtures. They melted at 93°, 150° and 180°. The two yellow substances melting at 150° and 180° are isomeric α-benzal-γ-phenylcrotolactones. The first was identified by comparison with a specimen made synthetically. The structure of the second follows from the fact that it gives one of the isomeric α-phenacyl-cinnamic acids when treated with bases, and that it is formed along with the isomer melting at 150° when either of the phenacyl-cinnamic acids is treated with acetic anhydride and acetic acid. The third indifferent substance—previously described as a β-lactone—is β-benzoyl-γ-phenyl-butyro lactone. This is proved by the fact that it passes quantitatively into β-benzoyl-phenyl-isocrotonic acid when treated with alcoholic sodium hydroxide.



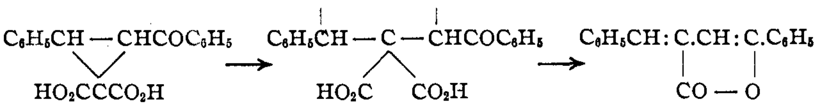
$$\begin{array}{l} C_6H_5CH — CH — COC_6H_5 \\ | \qquad\qquad | \\ O — COCH_2 \end{array} + NaOH = \begin{array}{l} C_6H_5CH : C — COC_6H_5 \\ \qquad\quad | \\ NaCO_2CH_2 \end{array} + H_2O$$

It is not possible to determine in what order this variety of products is formed when the cyclopropane derivative is heated; but it is easy to see that the substance results from three different processes. Most of the material is due to loss of carbon dioxide and a break in the ring between the 1 and 3 carbon atoms.

(I).



(II).



A very small part of the substance merely loses carbon dioxide.

(III).

VI. Reduction of the Cyclopropane Derivatives.

Both the esters and the acids are easily reduced by nascent hydrogen. With the esters the procedure was as follows: A solution of 5 g. in 50 cc. of methyl alcohol was diluted with water until a permanent precipitate began to form. The solution was cleared by addition of a small quantity of acetic acid, treated with 5 g. of zinc dust and boiled for an hour. The liquid was filtered and allowed to cool. It deposited practically pure methyl phenyl-benzoyl-ethyl malonate. The mother liquors from this gave a small additional quantity of this substance and an oil which was probably a reduction product of the saturated ester. The two cyclopropane esters seem to be reduced with equal ease. The yield of reduction product isolated slightly exceeded 90%.

The ester acid and the dibasic acid were reduced in the same way as the esters but the products were isolated in a different manner. The filtered solution was poured into water and the acids removed with ether. The ethereal solution, on evaporation, left a semi-solid residue. This was dissolved in methyl alcohol and the solution saturated with hydrochloric acid. The only solid ester obtained in each case was found to be the same as that obtained from the cyclopropane ester. The yield of pure product was 92.5%.

Summary.

1. We have described two general methods for making cyclopropane derivatives that contain both ketonic and carboxyl groups.
2. We have studied the behavior of one of these cyclopropane derivatives towards bases, hydrobromic acid, reducing agents and on heating.
3. The facts presented show that cyclopropane derivatives of this type can enter into a great variety of reactions owing to the peculiar combination of groups possible in a three-ring compound.
4. By using different reagents, it was possible to open the ring at three different points.
5. The facts justify the conclusion that there is no fundamental difference between corresponding derivatives of ethylene and cyclopropane, and that if the peculiarities of the former are due to the presence of a conjugated system, those of the latter prove that a cyclopropane ring and a carbonyl group in the proper position form a conjugated system.

CAMBRIDGE, MASS.

[CONTRIBUTION FROM THE CHEMICAL LABORATORY OF OHIO STATE UNIVERSITY.]

THE ACTION OF ANHYDROUS ALUMINIUM CHLORIDE UPON UNSATURATED ORGANIC COMPOUNDS. II.

BY WILMER C. GANGLOFF AND W. E. HENDERSON.

Received May 3, 1917.

In a preliminary article[1] the authors described the results of a study of the action of anhydrous aluminium chloride upon some simple unsaturated organic compounds, particularly hydrocarbons. The object of that investigation was to throw light upon the function of such catalysts as anhydrous aluminium chloride or ferric chloride in the process of cracking petroleums. The views suggested at that time appear to have been confirmed by further work which we now report.

Some of the compounds obtained are well crystallized. Others appear more or less granular to the naked eye, but when examined microscopically the crystalline structure is well shown. Without doubt all the compounds to be described are definitely crystalline. Clear cut melting points are not obtained from these compounds since dissociation or decomposition occurs before fusion. Consequently no melting points appear in the description of the products obtained. These compounds are in general unstable and decompose easily. Aluminium chloride itself volatilizes at about 180°, and this tends to promote decomposition.

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[1] THIS JOURNAL, 38, 1382 (1916).