extension" corresponding to the original figure. If this is correct, there appears no need to postulate an internal sub-microscopic but super-molecular structure of the gelatin. Any "structure" is not inherent in the gelatin, but is an environment impress, a strain structure in the original mass.[8] We are continuing the investigation of this with controlled humidity, to adjust the rate of evaporation.

The influence of hydrogen-ion concentration on swelling of gelatin masses with different drying histories is also under investigation, in relation to the Procter-Wilson-Loeb theory of gelatin swelling.[9]
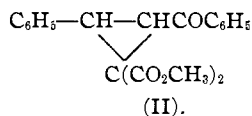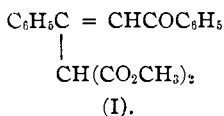
ROCHESTER, NEW YORK.

[CONTRIBUTION FROM THE CHEMICAL LABORATORY OF HARVARD UNIVERSITY.]

THE ADDITION OF MALONIC ESTERS TO BENZOYL-PHENYL-ACETYLENE.

BY E. P. KOHLER.

Received October 28, 1921.

The following investigation was originally undertaken for the purpose of making the unsaturated δ-ketonic acid (I) for comparison with an iso-meric cyclopropane derivative (II).
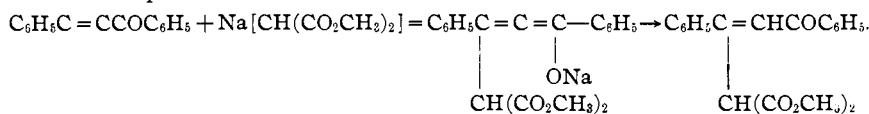
$$C_6H_5C = CHCOC_6H_5 \qquad\qquad C_6H_5-CH-CHCOC_6H_5$$
$$\underset{\displaystyle CH(CO_2CH_3)_2}{|} \qquad\qquad\qquad \underset{\displaystyle C(CO_2CH_3)_2}{\diagdown\diagup}$$
$$\text{(I).} \qquad\qquad\qquad\qquad\qquad \text{(II).}$$

It was abandoned for a time because the addition reaction gave sub-stances of a different type, and then taken up again in the hope of finding

---

[8] This view may be compatible with a development of the 2-phase theory for gelatin gels, with the proviso, however, that the structure elements are resultants of the physico-chemical changes of environment, not native to gelatin. Thus Miss J. Lloyd (*Biochem. J.*, **14**, 166 (1920)) pictures gelation as follows: "gelation will only occur on the cooling of a sol which contains in solution iso-electric gelatin and gelatin salts in equilibrium with free electrolytes. As the sol is cooled the insoluble iso-electric gelatin is precipitated in a state of suspended crystallization and forms a solid frame-work throughout the system. The more soluble gelatin salts remain in solution and by their osmotic pressure keep the framework extended. Gels, therefore, are 2-phase systems, the solid phase consisting of iso-electric gelatin, the liquid of gelatin in salt form." With regard to this conception, if the insoluble iso-electric gelatin forms a rigid "solid framework," one does not quite see how the osmotic pressure is necessary to keep it extended. It appears, however, that this precipitation theory can be extended to drying, the solid framework growing by accretion as the concentration changes in the liquid phase, and building up the skin extension to which we have referred.
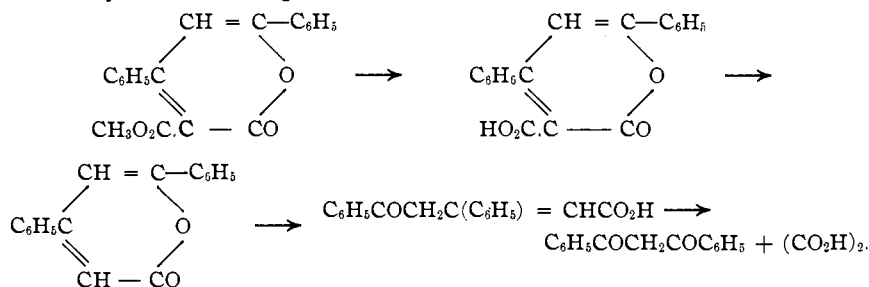
[9] H. R. Procter, Ref. 3. Also Procter and J. A. Wilson, *J. Chem. Soc.*, **109**, 307 (1916). J. A. Wilson and W. Wilson, THIS JOURNAL, **40**, 886 (1918). J. Loeb, *J. Gen. Physiol.*, 1918–1921; *Science*, **52**, 449 (1920).

a means of detecting acetylenic ketones in alkaline media in which they are rapidly transformed into other substances.
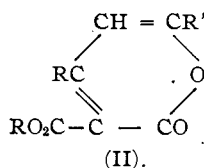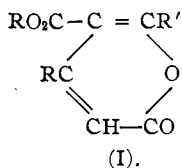
The addition of metallic derivatives to acetylenic ketones does not seem to have been tried heretofore; but Michael[1] found that sodium malonic ester combines with esters of acetylenic acids, and the extensive researches of Moureu[2] have shown that acetylenic ketones combine with other substances even more readily than do the corresponding ethylenic compounds. It was to be expected, therefore, that in the presence of sodium alcoholate, malonic ester would combine with benzoyl-phenylacetylene in accordance with the equation,

$$C_6H_5C = CCOC_6H_5 + Na[CH(CO_2CH_3)_2] = C_6H_5C = C = C—C_6H_5 \rightarrow C_6H_5C = CHCOC_6H_5.$$
$$\underset{CH(CO_2CH_3)_2}{\overset{ONa}{|}} \qquad \underset{CH(CO_2CH_3)_2}{|}$$

The experiment showed that addition takes place rapidly in the direction expected, but that the product immediately loses alcohol and passes into a pyrone derivative. The structure of the resulting product was established by the following series of transformations:
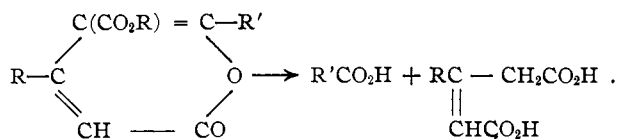
$$\begin{array}{c} CH = C—C_6H_5 \\ C_6H_5C \qquad\qquad O \\ CH_3O_2C.C — CO \end{array} \longrightarrow \begin{array}{c} CH = C—C_6H_5 \\ C_6H_5C \qquad\qquad O \\ HO_2C.C —— CO \end{array} \longrightarrow$$

$$\begin{array}{c} CH = C—C_6H_5 \\ C_6H_5C \qquad\qquad O \\ CH — CO \end{array} \longrightarrow \begin{array}{l} C_6H_5COCH_2C(C_6H_5) = CHCO_2H \longrightarrow \\ \qquad C_6H_5COCH_2COC_6H_5 + (CO_2H)_2. \end{array}$$

These transformations show that the product is an α-pyrone derivative and that the course of the reaction is similar to that observed by Ruhemann when he added ketonic esters or diketones to esters of phenyl-propiolic acid. The products of the two reactions, however, never have the same structure. Thus the addition of a ketonic ester to an acetylenic ester gives a pyrone derivative which has the ester group in the 5 position (Type I) while the same group occupies the 3 position in the products obtained by adding an ester to an acetylenic ketone (Type II).
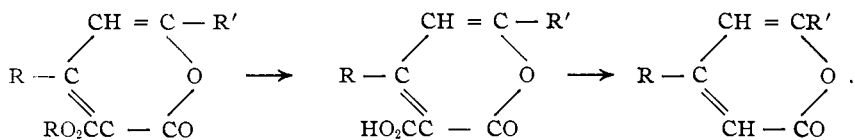
$$\begin{array}{c} RO_2C—C = CR' \\ RC \qquad\qquad O \\ CH—CO \end{array} \qquad\qquad \begin{array}{c} CH = CR' \\ RC \qquad\qquad .O \\ RO_2C—C — CO \end{array}$$
$$\qquad (I). \qquad\qquad\qquad\qquad\qquad (II).$$

[1] Michael, *J. prakt. Chem.*, [2] **49**, 22 (1894).
[2] Moureu, *Bull. soc. chim.*, [3] **33**, 131 (1905).

Pyrone derivatives of the first type have long been known.   It is impossible to hydrolyze them without opening the ring.   On treatment with alkalies they lose a molecule of acid and give substituted glutaconic acids.

$$\begin{array}{c} C(CO_2R) = C-R' \\ \diagup \qquad\qquad \diagdown \\ R-C \qquad\qquad\qquad O \longrightarrow R'CO_2H + RC-CH_2CO_2H \ . \\ \diagdown \qquad\qquad \diagup \qquad\qquad\qquad\qquad \| \\ CH \longrightarrow CO \qquad\qquad\qquad CHCO_2H \end{array}$$

Derivatives of the second type have not been described heretofore.   They can be hydrolyzed without breaking the pyrone ring.   On treatment with alkalies they give either the pyrone acid or the corresponding pyrone.

$$\begin{array}{ccc} CH = C-R' & CH = C-R' & CH = CR' \\ \diagup \quad\ \diagdown & \diagup \quad\ \diagdown & \diagup \quad\ \diagdown \\ R-C \qquad O \longrightarrow & R-C \qquad O \longrightarrow & R-C \qquad O \ . \\ \diagdown \quad\ \diagup & \diagdown \quad\ \diagup & \diagdown \quad\ \diagup \\ RO_2CC-CO & HO_2CC-CO & CH-CO \end{array}$$

This characteristic behavior towards alkalies, which is analogous to that of the corresponding open-chained compounds, serves as an easy means of identifying substances belonging to either of these types of pyrone derivatives.

The α-pyrone esters are moderately soluble in organic solvents, crystallize extremely well, and separate readily even from solutions that hold large quantities of oily products.   As their structure is easily determined, they are admirably adapted for detecting and identifying acetylenic ketones.
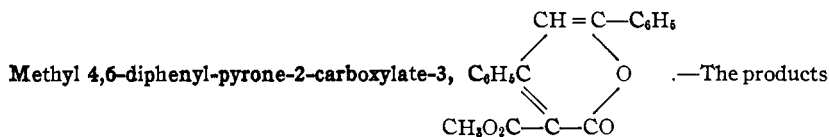
Experimental Part.

Condensation.—The simplest way to carry out the condensation is to add a small quantity of sodium alcoholate to a warm, concentrated, alcoholic solution containing equivalent quantities of ester and unsaturated ketone.   The liquid immediately becomes blood-red in color, the temperature rises to the boiling point of the liquid, and the reaction is complete by the time the liquid has cooled to the ordinary temperature.   Most of the pyrone separates in an almost pure state when the solution is acidified with acetic acid.   The balance is obtained by pouring the filtrate into water, extracting with ether, removing a small quantity of acid by shaking with sodium carbonate, and allowing the ether to evaporate.

The procedure was varied in a number of ways in an effort to prevent the pyrone formation and thus get the unsaturated dibasic ester which is, doubtless, the primary product of the reaction.   Thus, ether and benzene were substituted for the alcohols as solvents, suspensions of sodium malonate were used in place of malonic ester and sodium alcoholate, and the temperature was reduced to the lowest point at which the reaction would proceed; but the results were essentially the same in all cases: 70 to 95%

of the product was pyrone ester, the balance consisting of variable quantities of pyrone acid due to hydrolysis, and of dibenzoyl-methane formed by the action of alkali on benzoyl-phenylacetylene.

When the sodium derivative of malonic ester was used in ether or in benzene, a brilliant red sodium compound separated as the reaction proceeded. Since the same compound was obtained by adding conc. sodium alcoholate to solutions of the pyrone ester in the same solvents, it is evident that the pyrone is formed under the influence of the alkali and not during acidification. It is not necessary to use pure benzoyl-phenylacetylene for the preparation of the pyrone ester. The crude washed and dried product of the reaction between sodium phenylacetylene and benzoyl bromide, which usually contains less than 60% of unsaturated ketone, serves equally well, and it is thus possible to avoid the serious losses involved in the vacuum distillations of this product.

$$CH = C—C_6H_5$$

Methyl 4,6-diphenyl-pyrone-2-carboxylate-3, C_6H_5C $\qquad$ O .—The products

$$CH_3O_2C—C—CO$$

obtained by condensing dimethyl malonate with benzoyl-phenylacetylene crystallize in long, pale yellow, fluorescent needles which melt at 129°.

Analysis. Calc. for $C_{19}H_{14}O_4$: C, 74.5; H, 4.6. Found: C, 74.6; H, 4.7.

The ester is readily soluble in acetone and in chloroform, moderately in ether and in methyl alcohol, sparingly in ligroin. Under diminished pressure it distils without decomposition. The pyrone ring is not opened by acids; a suspension of 2 g. of the ester in methyl alcohol was saturated with hydrogen chloride, sealed in a tube, and kept for over a year; but the only change was a small amount of hydrolysis to the corresponding acid. The ester dissolves readily in conc. sulfuric acid, and is precipitated unchanged when the orange colored solution is diluted with water or alcohol.

The ETHYL ESTER was obtained in the same way as the methyl compound which it closely resembles in color, in crystal form, and in solubility. It melts at 119°. Neither this nor the methyl ester reduces a solution of permanganate in acetone, or combines with bromine.

Analysis. Calc. for $C_{20}H_{16}O_4$: C, 75.0; H, 5.0. Found: C, 74.8; H, 5.1.

The ACID. The pyrone esters are exceedingly sensitive to alkalies. They dissolve in cold aqueous and alcoholic potash forming blood-red solutions which rapidly turn yellow. These yellow solutions contain small quantities of the corresponding acid, with relatively much malonic acid, dibenzoyl-methane, benalzdehyde and other decomposition products. Under these conditions, evidently, the addition reaction is reversed and the products noted result from the action of alkalies on malonic ester and benzoyl-phenylacetylene. Cold alcoholic sodium alcoholate causes less extensive decomposition, but gives only a minimal quantity of acid products. A fairly satisfactory hydrolysis to the pyrone acid was finally accomplished as follows. A solution of either ester in excess of cold conc. sodium methylate was diluted with 8 to 10 times its volume of benzene and the mixture boiled on a steam-bath. It rapidly lost its red color and deposited an impure yellow sodium salt. This was recrystallized from a strong solution of sodium carbonate in which it is sparingly soluble and from which it separates in

colorless plates. The yield of pure salt was 70%. The corresponding acid was purified by crystallization from benzene which deposits it in stout needles that contain benzene of crystallization.

Analysis. Calc. for $C_{18}H_{12}O_4.C_6H_6$: C, 77.7; H, 4.8. Found: C, 76.8; H, 4.7.

In the air these crystals lose benzene and crumble to a yellow powder which melts at 168°.

Analysis. Calc. for $C_{18}H_{12}O_4$: C, 74.0; H, 4.1. Found: C, 73.6; H, 4.1.

The yield of pure acid was about 70%. Neither the pyrone acid nor its salts reduce permanganate at the ordinary temperature. The acid begins to decompose at about 200°; it gives off carbon dioxide freely above 210°.

$$CH — C—C_6H_5$$

4,6-Diphenyl-pyrone-2, C_6H_5C O . — Ten g. of the pyrone acid,

$$CH — C = O$$
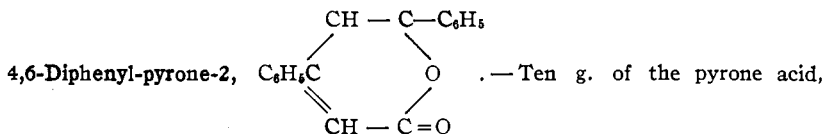
when heated for 2 hours at 210–212° gave 8.39 g. of a pale yellow melt which crystallized when rubbed with a little methyl alcohol, and 7.69 g. of pure pyrone melting at 142°.

Analysis. Calc. for $C_{17}H_{12}O_2$: C, 82.3; H, 4.8. Found: C, 82.0; H, 5.1.

The same substance can be obtained more easily directly from the pyrone esters. Thus 5 g. of the methyl ester was suspended in a solution of 1.2 g. of sodium in 20 cc. of dry methyl alcohol and the mixture set aside until the red color had completely disappeared. Meanwhile, the liquid had deposited 1.5 g. of pure pyrone and, when the filtrate from this was diluted with water, it yielded 1.6 g. more of slightly less pure material. The pyrone crystallizes in pale yellow plates which are moderately soluble in alcohol, sparingly in ether. Its solution in acetone does not reduce permanganate.

γ-**Benzoyl-β-phenyl crotonic acid,** $C_6H_5COCH_2C(C_6H_5)$: $CHCO_2H$.—The pyrone is not attacked by conc. aqueous potassium hydroxide. It dissolves readily, however, both in alcoholic potash and in a solution of sodium methylate. From the resulting yellow solutions, acids precipitate a mixture of 2 colorless acids extremely difficult to separate. By repeated recrystallization from ether-ligroin mixtures, one of these was obtained in a pure condition. It crystallized in slender needles which melted, with effervescence, at about 130°.

Analysis. Calc. for $C_{17}H_{14}O_3$: C, 76.7; H, 5.2. Found: C, 76.4; H, 5.2.

The METHYL ESTER. The purity of the acid was established by esterification through the silver salt. With methyl iodide this gave, in calculated amount, a solid methyl ester which crystallized in needles and melted at 36°.

Analysis. Calc. for $C_{18}H_{16}O_3$: C, 77.1; H, 5.7. Found: C, 76.7; H, 5.8.

Oxidation.—Both the acid and its methyl ester are readily oxidized by permanganate. When the oxidation is carried out in acetone, the entire carbon chain is destroyed and the only products are benzoic and oxalic acids. By cautious oxidation of the sodium salt in aqueous solution, however, it is possible to confine the action of the oxidizer largely to the double linkage. Thus 2.5 g. of the acid was dissolved in excess of sodium hydrogen carbonate, the solution saturated with carbon dioxide at 0°, and treated, gradually, with a solution of 3 g. of permanganate, a current of carbon dioxide being maintained throughout the operation. The oxides of manganese were then dissolved with sulfur dioxide and the organic products extracted from the water solution with ether. The ethereal solution was shaken, first with sodium carbonate to remove acids, and then with a solution of copper acetate. This precipitated a green copper compound which melted, with decomposition, at about 300°.

The copper compound was suspended in ether and decomposed with dil. hydrochloric acid. The ethereal layer, on evaporation, deposited 0.9 g. of colorless needles that melted at 81°. A mixture of the substance with dibenzoyl-methane likewise melted at 81°.

The second acid that is formed when the pyrone ring is opened with alkalies was not obtained in a perfectly pure condition. An analysis of the mixture of the two acids gave: C, 76.8%, and H, 5.9%. The 2 acids are, therefore, certainly isomeric, and there are some indications that one readily passes into the other; but whether the isomerism is spatial or structural remains in doubt. These acids are still under investigation. They are the only known unsaturated δ-ketonic acids—a type that is of especial interest in connection with the peculiar isomerism of the glutaconic acids.

Action of Ammonia on the Pyrone Esters.—It is well known that ammonia transforms many pyrones into the corresponding hydroxy pyridines; but Ruhemann found that when α-pyrones which have hydrocarbon residues in the α′ position are heated with conc. aqueous ammonia they generally give ammonium salts of amino compounds. The structure of these salts is uncertain, and they can be turned into pyridine derivatives only by roundabout methods. The α-pyrone esters described in this paper give a similar result when they are heated with aqueous ammonia, but when they are shaken at the ordinary temperature with conc. alcoholic ammonia they pass slowly but completely into a mixture of hydroxy-pyridine esters and the corresponding hydroxy-pyridine. At the ordinary temperature, conc. aqueous ammonia acts very slowly, but in the course of several months it transforms these α-pyrone esters quantitatively into the hydroxy-pyridine derivative.

2-Hydroxy-4,6-diphenyl-pyridine,

$$CH—C—C_6H_5$$
$$C_6H_5C \qquad N$$
$$CH = COH$$

.—A suspension of 5
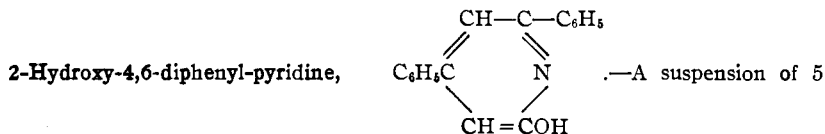
g. of the ethyl ester in 20 cc. of saturated alcoholic ammonia was shaken for 48 hours. By this time the dark yellow color which developed on the addition of the alcoholic ammonia had largely disappeared and the liquid had deposited a fine white powder. This was filtered off and the filtrate evaporated in a draught. The solid consisted mainly of the hydroxy-pyridine. It was purified by recrystallization from alcohol from which it separated in colorless or very pale yellow plates that melted at 210°.

Analysis. Calc. for $C_{17}H_{13}ON$: C, 82.6; H, 5.3. Found: C, 82.2; H, 5.5.

The substance is soluble in acids and in alkalies. It is doubtless identical with a substance previously obtained by Von Meyer.

Ethyl-2-hydroxy-4,6-diphenyl-pyridine carboxylate-3,

$$CH—C—C_6H_5$$
$$C_6H_5C \qquad N$$
$$C_2H_5O_2C—C = COH$$
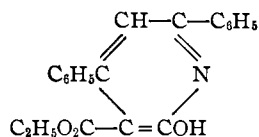
The residue left after evaporating the filtrate from the hydroxy-pyridine consists largely of this ester, which is more sparingly soluble in alcohol but much more readily soluble in alcoholic ammonia than the corresponding hydroxy-pyridine. The ester crystallizes from alcohol in colorless pyramids or prisms which show a faint blue fluorescence and melt at 197°. It dissolves in strong alkalies, but not in acids. Its solutions in conc. aqueous sodium hydroxide and in alcoholic ammonia are pale yellow in color.

Analysis. Calc. for $C_{20}H_{17}O_3N$: C, 75.1; H, 5.3.   Found: C, 74.9; H, 5.6.

When the ester is heated with conc. aqueous potassium hydroxide it is converted into a mixture of the corresponding acid and the hydroxy-pyridine.   The acid readily loses carbon dioxide at 250° and passes quantitatively into the same hydroxy-pyridine.

Summary.

1. Under the influence of sodium alcoholate, benzoyl-phenylacetylene rapidly condenses with malonic esters to form pyrone esters that have an ester group in the 3 position.

2. Pyrone esters which have the ester group in the 3 position are readily distinguished from those which have this group in the 5 position by their behavior towards alkalies.

3. By opening the ring of an α-pyrone which has phenyl groups in the 3 and 6 positions it is possible to get unsaturated δ-ketonic acids which have the carbon chain that is responsible for the peculiar isomerism of the glutaconic acids.
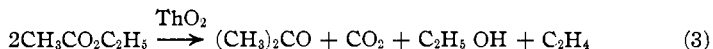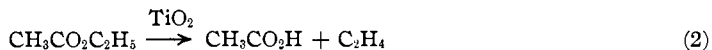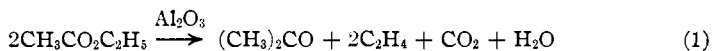
CAMBRIDGE 38, MASSACHUSETTS.

THE ACTION OF ALUMINA, TITANIA AND THORIA UPON ETHYL AND ISOPROPYL ACETATES.

BY HOMER ADKINS AND A. C. KRAUSE.

It has seemed that a more intensive, quantitative study of some of the gas-phase reactions of organic compounds induced by catalysts might shed some light upon the mechanism of catalysis.   In view of the widely different decompositions which, according to Sabatier, are induced in esters by alumina, titania and thoria, it was suggested by Dr. Wilder D. Bancroft that these reactions offered a fruitful field for study.   Sabatier[1] reports that alumina induces Reaction 1; titania, 2; and thoria, 3.

$$2CH_3CO_2C_2H_5 \xrightarrow{Al_2O_3} (CH_3)_2CO + 2C_2H_4 + CO_2 + H_2O \qquad (1)$$

$$CH_3CO_2C_2H_5 \xrightarrow{TiO_2} CH_3CO_2H + C_2H_4 \qquad (2)$$

$$2CH_3CO_2C_2H_5 \xrightarrow{ThO_2} (CH_3)_2CO + CO_2 + C_2H_5OH + C_2H_4 \qquad (3)$$

If these equations accurately represent the decompositions, we have a very specific reaction for each catalyst, and it was hoped that it would be possible to find some connection between the properties of the catalyst and the reaction induced.   Our results do not indicate that the catalysts are highly specific, but we have found that the decomposition of the esters offers the possibility of a comparative study of the same catalyst upon

[1] Sabatier "La Catalyse en Chemie Organique," Van Nostrand Co., 1920, p. 341.