tallized to a tan solid (4.5 g.) melting at 100–121°. Repeated crystallization from benzene–petroleum ether (b. p. 90–100°) gave white needles (2.58 g.) which melted at 126.5–128°.

Anal. Calcd. for $C_{13}H_{14}O_4$: C, 66.64; H, 6.03. Found: C, 66.48, 67.00; H, 5.88, 6.19.

The substance is relatively stable toward heat and inert solvents, but is unstable toward polar solvents. It is insoluble in sodium carbonate and in sodium bicarbonate solutions. No ether was formed using either methyl sulfate or diazomethane, nor could an oxime be obtained.

When the acetylisocoumaranone (0.4 g.) was steam distilled, coumaron II (0.07 g.), m. p. and mixed m. p. 137–138°, was isolated from the distillate and the isocoumaranone I (0.26 g.), m. p. 200.5–202.5°,[13] remained in the flask.

Summary

1. The sodium enolates of acetylacetone and isobutyrylacetylmethane react with trimethylquinone to give (3,6-dihydroxy-2,4,5-trimethylphenyl)-acetylacetone (VIII) and -acetylisobutyrylmethane (XII), respectively. No pure substances could be isolated from the product of the reaction between the quinone and the enolates of *n*-butyrylacetylmethane or benzoylacetone, and only unchanged diketone was isolated when the enolate of dibenzoylmethane was used.

2. Acylation of the diketones VIII and XII involves a rearrangement of one of the side chain acyl groups from carbon to the *ortho*-oxygen atom; simultaneously, the other hydroxyl group is acylated by the reagent used. A mechanism is suggested for this rearrangement.

3. An intermediate has been isolated from the reaction between trimethylquinone and sodium acetoacetic ester. This intermediate, when steam distilled, gives the final products obtained previously in a study of this reaction.

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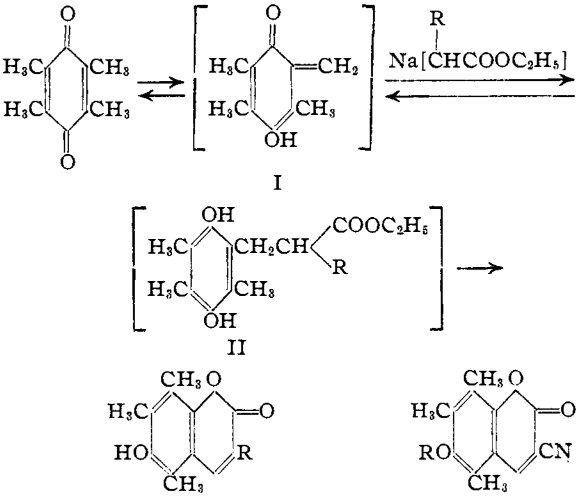
[13] The m. p. previously reported was 197–198°.

[CONTRIBUTION FROM THE SCHOOL OF CHEMISTRY OF THE UNIVERSITY OF MINNESOTA]

The Reaction between Quinones and Metallic Enolates. XI. Duroquinone and the Enolates of Cyanoacetic Ester and of β-Diketones[1]

BY LEE IRVIN SMITH AND E. W. KAISER[2]



III, R = $COOC_2H_5$
IV, R = $COCH_3$
V, R = H
VI, R = Ac

VII, R = $CONH_2$
VIII, R = COOH
IX, Diacetate of VII

The reaction between duroquinone and sodium malonic ester,[3] was extended to other tetrasubstituted quinones by Webster,[4] who used 2,3-dimethyl-1,4-naphthoquinone, and by Johnson,[5] who used trimethylbromoquinone. Tenenbaum[6] varied the enolate by using sodium acetoacetic ester, but in all these cases the reaction led to a substituted coumarin (III, IV), and evidence was supplied by Horner[7] that the quinone was first converted into a "pentad-enolate" (I) which then underwent a Michael reaction with the other enolate. The first product (II) was cyclized and oxidized, leading to the coumarin as the final product. In every case so far studied, the enolate used contained an ester group so that the ring closure, by elimination of an alcohol, took place easily, and it has been thought that this easy ring closure was in large part responsible for driving the series of reactions to completion, since the first step presumably, and the second step certainly, are reversible. In order to explore still further the limits of this reaction, the enolates of cyanoacetic ester and of two β-diketones (acetylacetone

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[1] Paper X, THIS JOURNAL, **62**, 133 (1940).

[2] Abstracted from a Thesis by E. W. Kaiser, presented to the Graduate Faculty of the University of Minnesota, in partial fulfilment of the requirements for the Ph.D. degree, August, 1939.

[3] Smith and Dobrovolny, THIS JOURNAL, **48**, 1693 (1926).

[4] Smith and Webster, *ibid.*, **59**, 662 (1937).

[5] Smith and Johnson, *ibid.*, **59**, 673 (1937).

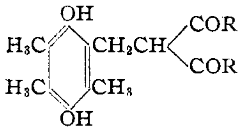
[6] Smith and Tenenbaum, *ibid.*, **59**, 667 (1937).

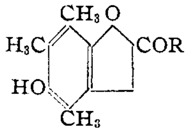
[7] Smith and Horner, *ibid.*, **60**, 676 (1938).

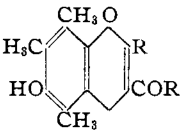
and dibenzoylmethane) have been studied with regard to their behavior toward duroquinone.

Sodium methyl cyanoacetate and duroquinone reacted in benzene to give the yellow cyanocoumarin V. In common with coumarins of the type of III and IV, this yellow coumarin V gave a colorless monoacetate, VI. The presence of the cyano group in the coumarin was shown by hydrolysis to the amide (VII). Although the cyano compound survived the action of hydrogen peroxide,[8] it was hydrolyzed to the amide in fair yield by warming with 80% sulfuric acid. This amide was resistant to further hydrolysis by sulfuric acid or phosphoric acid, consequently it was not possible to convert it to the acid VIII, a known substance. However, the acid VIII was readily converted into the amide VII via the acid chloride, and the two specimens of VII thus prepared were identical. Both specimens also gave the same acetate IX. Although this acetate IX was not a simple acetate and was probably a diacetate, the identity of the amides prepared by the two methods and the identity of the acetates prepared from these amides, serve amply to fix the structure of the coumarin V. This coumarin is therefore 3-cyano-5,7,8-trimethyl-6-hydroxycoumarin, and its formation from duroquinone and sodium cyanoacetic ester shows that this enolate, in common with all of the enolates containing a carbalkoxyl group, enters into a reaction with the quinone which involves the loss of the elements of alcohol as one of the steps.

Turning to the β-diketones, it is obvious that the reaction between the enolates of these substances and duroquinone, involving as an intermediate an analog X of II, cannot be completed by elimination of the elements of an alcohol. Elimination of the elements of an aldehyde RCHO to give the 2-acylcoumaran XI would not be very probable, but elimination of water from the enolate of X to give the 2-alkyl-3-acyl-Δ^2-chromene XII would be a possibility. Attempts were made to add the enolates of acetylacetone and dibenzoylmethane to duroquinone, under varying conditions, without success. No products were obtained under any of the experimental conditions tried and in most cases considerable unchanged duroquinone was recovered. The failure of the β-diketones to add to duroquinone is of significance in connection with the mechanism of the addition of enolates to this quinone, and lends support to the hypothesis that an easy ring closure is necessary in order that the sequence from I to III may be completed. This sequence involves a Michael reaction which is reversible[9]; if, therefore, in the intermediate X ring closure is difficult, reversal of the Michael reaction will result in the recovery of the starting materials, or products resulting from the action of alkali upon them. It therefore may be concluded from these results that elimination of the elements of water (or NaOH) from the enol of the diketone X is inherently more difficult than the elimination of the elements of alcohol (or RONa) from such a substance as II. Definite statements, however, must await the synthesis of substances such as X and a study of the action of alkali upon them; such experiments are under way.


X


XI


XII

Experimental Part[10]

3-Cyano-5,7,8-trimethyl-6-hydroxycoumarin, V.—Methyl cyanoacetate (5.0 g., 0.05 mole) was converted into the enolate by refluxing it for an hour with powdered sodium (1.1 g., 0.05 mole) in dry benzene (50 cc., thiophene-free). A solution of duroquinone (6 g., 0.037 mole) in benzene (40 cc.) was added and the mixture was refluxed for seven days. The deep red solid was filtered off and washed thoroughly with benzene until the washings showed no yellow color. The solid was suspended in alcohol and iced hydrochloric acid (15 cc. acid, 15 g. ice) was added. The product weighed 2.38 g. and melted at 210–225°. After several crystallizations from acetic acid (with Norit the first time) the substance was obtained as a yellow solid which melted at 261.5–263°.

Anal. Calcd. for $C_{13}H_{11}O_3N$: C, 68.13; H, 4.80. Found: C, 68.17; H, 4.79.

3-Cyano-5,7,8-trimethyl-6-acetoxycoumarin, VI.—The coumarin (0.102 g.) was suspended in acetic anhydride (2 cc.) and a drop of sulfuric acid was added. The solid gradually dissolved and after standing for ten minutes at room temperature, the product began to crystallize out. More acetic anhydride (1 cc.) was added and the mixture was allowed to stand at room temperature for two hours. The suspension was poured onto a mixture of ice and am-

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(8) (a) Murray and Cloke, THIS JOURNAL, **56**, 2749 (1934); (b) McMaster and Noller, *J. Indian Chem. Soc.*, **12**, 652 (1935).

(9) (a) Connor and Andrews, THIS JOURNAL, **56**, 2713 (1934); (b) Kroeker and McElvain, *ibid.*, **56**, 1171 (1934).

(10) Microanalyses by J. W. Opie, C. O. Guss and H. H. Hoehn.

monium hydroxide (8 cc.) and the solid was removed. It weighed 0.11 g. and melted at 213–219°. After successive recrystallization from dry ethanol, acetic acid and dilute acetic acid, it was white and melted at 227–228°.

Anal. Calcd. for $C_{15}H_{13}O_4N$: C, 66.40; H, 4.84. Found: C, 66.46; H, 5.15.

3-Carbamido-5,7,8-trimethyl-6-hydroxycoumarin, VII. The cyanocoumarin V (0.2 g.) was heated on the steam-bath with sulfuric acid (13 cc., 81%) for three and one-half hours. The reddish-yellow solution was poured over cracked ice (75 g.) and the solid was removed and crystallized from acetic acid. The product weighed 0.129 g. (60%) and melted at 290–293° (metal block) with decomposition. Repeated crystallization from acetic acid gave a product which melted at 302° (block) with decomposition; the melting point of this sample, determined in a capillary in the usual manner, was 288–290° with decomposition.

Anal. Calcd. for $C_{13}H_{13}O_4N$: C, 63.15; H, 5.55. Found: C, 62.74; H, 5.50.

Acetyl Derivative, IX.—The amide VII (0.14 g.) was refluxed for forty-five minutes in acetic anhydride (4.5 cc.) containing a drop of sulfuric acid. The cooled solution was poured over cracked ice (50 cc.) and concd. ammonium hydroxide was added until the mixture was basic to litmus. The solid (0.15 g.) was removed and crystallized from acetic acid; it then melted at 243–244.5°.

Anal. Calcd. for $C_{15}H_{15}O_5N$ (monoacetyl): C, 62.28; H, 5.19. Calcd. for $C_{17}H_{17}O_6N$ (diacetyl): C, 61.63; H, 5.13. Found: C, 60.84, 61.17; H, 5.07, 5.53.

3-Carboxy-5,7,8-trimethyl-6-hydroxycoumarin, VIII.—The acid was prepared by hydrolysis of the ester III (0.36 g.)[3] with hydrochloric acid (6 *N*, 40 cc.) in acetone (20 cc.).[11] The crude product (0.29 g.), which melted at 255–256°, was used directly for conversion to the acid chloride.

Acid Chloride of VIII, and Amide, VII.—The acid VIII (0.15 g.) was refluxed for fifteen minutes with thionyl chloride (2 cc.). Excess thionyl chloride was removed under reduced pressure and the acid chloride (not purified) was converted to the amide by addition of ammonium hydroxide (2 cc.). The amide (0.14 g.) was removed and crystallized from acetic acid, when it melted at 288–290° with decomposition (capillary tube and liquid bath) alone or when mixed with a specimen prepared from duroquinone and cyanoacetic ester.

Acetyl Derivative, IX.—The above amide VII was acetylated as already described. The product weighed 0.14 g., and after crystallization first from acetic acid and then from dilute acetic acid, it melted at 241–242.5°, alone or when mixed with the acetyl amide derived from duroquinone and cyanoacetic ester.

Anal. Calcd. given above. Found: C, 60.87; H, 5.57.

Duroquinone and Acetylacetone.—Several attempts, using different conditions, were made to carry out this condensation, but all failed.

A. In Dry Benzene with Metallic Sodium.—Acetylacetone (7 g., 0.07 mole) was added to a suspension of powdered sodium (1.60 g., 0.07 mole) in dry benzene (50 cc., thiophene free). Duroquinone (5 g., 0.031 mole) dissolved in a few cc. of benzene was then added and the mixture was refluxed for four days. The initial very dark color changed to deep blue-green during this time. The solid (8.4 g.) was filtered off and thoroughly washed with benzene. Decomposition of this material with hydrochloric acid (2 *N*, 15 cc.) gave 2.7 g. of a reddish solid, which after crystallization from alcohol melted at 112–113° alone or when mixed with duroquinone. Extraction of the acid filtrate with benzene gave 1.6 g. of acetylacetone boiling at 135–140°. No other products could be isolated.

B. In Ethanol with Magnesium Ethoxide.[5]—Acetylacetone (2.0 g.) was added to a suspension of magnesium ethoxide (1.17 g.) in dry ethanol (15 cc.). Duroquinone (1 g.) was then added and the mixture was refluxed for forty-eight hours. Most of the alcohol was removed by distillation, and replaced by ether. The light tan solid which separated was removed and decomposed with dilute hydrochloric acid. An oil resulted which soon resinified to a very dark brown mass. No definite products could be isolated from this resinous material.

C. In Ethanol with Ammonia.—A solution of duroquinone (1 g.) and acetylacetone (2 g.) in dry ethanol (40 cc.) was saturated with dry ammonia. After standing overnight at room temperature, the clear red solution was acidified with hydrochloric acid and diluted with water. The only product obtained was duroquinone, m. p. and mixed m. p. 112–114°.

D. In Ethanol with Sodium Ethoxide.—To a solution of sodium ethoxide in dry ethanol (0.42 g. sodium, 15 cc. ethanol) acetylacetone (2.0 g.) was added. Duroquinone (1 g.) in dry ethanol (25 cc.) was added to the enolate solution and the mixture was refluxed for twenty-four hours. A deep red color developed as soon as the quinone was added, but decomposition of the reaction mixture with iced hydrochloric acid gave only a brick-red solid which melted at 115–150°. This solid was very soluble in alcohol, ether, acetic acid and other organic solvents and all attempts to obtain pure material from it failed. It was probably a mixture of duroquinone (m. p. 111–112°) and diduroquinone (m. p. 207°).

Summary

1. The enolate of methyl cyanoacetate condenses with duroquinone to give 3-cyano-5,7,8-trimethyl-6-hydroxycoumarin (V), the reaction taking the same course as that of other enolates containing a carbalkoxyl group.
2. The structure of the cyanocoumarin was proved by converting it to the amide and synthesizing the latter from the known 3-carboxy-5,7,8-trimethyl-6-hydroxycoumarin.
3. The cyanocoumarin could not be hydrolyzed to the acid; all attempts failed to carry the hydrolysis beyond the amide stage.
4. The enolates of acetylacetone could not be condensed with duroquinone. The possible bearing of this fact upon the mechanism of duroquinone–enolate reactions is discussed.

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[11] Smith and Denyes, THIS JOURNAL, **58**, 306 (1936).