

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, UNIVERSITY OF CALIFORNIA AT LOS ANGELES]

Polyenes. I. The Synthesis and Absorption Spectra of the Ionylideneacetones and Related Compounds^{1,2}

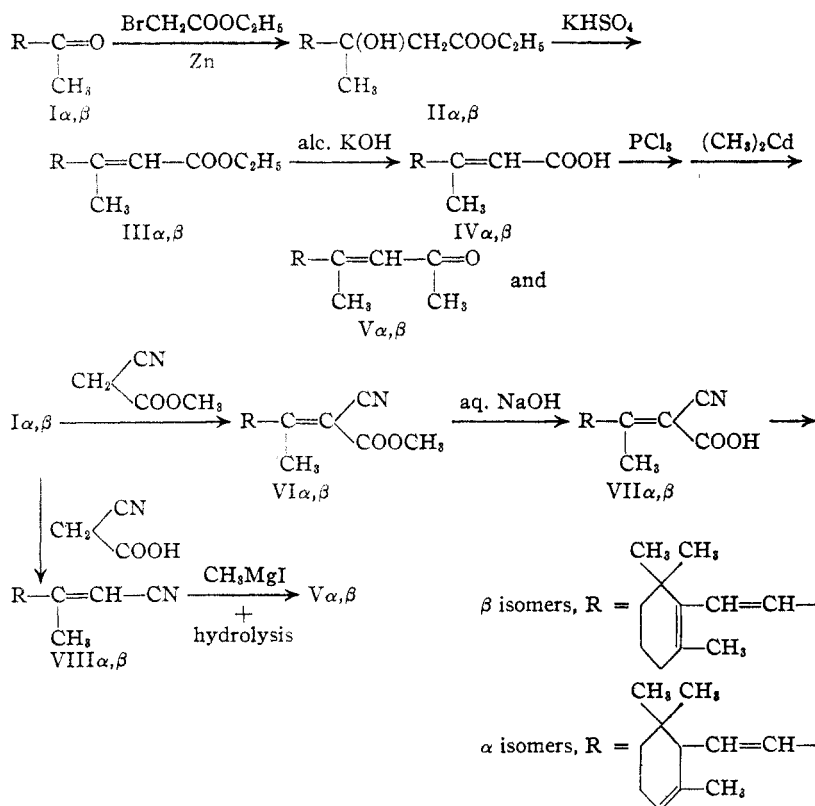
BY WILLIAM G. YOUNG, LAWRENCE J. ANDREWS AND STANLEY J. CRISTOL

In a study of synthetic methods for increasing the polyene chain of β -ionone, β -ionylideneacetone has been prepared by two different procedures.

Because the absorption maximum of this ketone was found to lie at 285 m μ instead of in the expected range of 300–320 m μ , it seemed possible that during some stage in the preparation of the sixteen carbon ketone the double bond in the β -ionone ring had rearranged to the position which it occupies in α -ionone. Consequently, the preparation of α -ionylideneacetone from α -ionone by the same methods used to prepare the β isomer was undertaken. A comparison of the absorption spectra of α - and β -ionylideneacetone and of the intermediates involved in their syntheses coupled with a critical investigation of the structure of these ketones by hydrogenation, ozonization and hypochlorite oxidation seems to indicate that no isomerization of the ring structure occurred during the synthesis of either sixteen-carbon ketone.

The Preparation of the Ionylideneacetones.—The β -ionone used in these syntheses had absorption maxima at 296 m μ , ϵ 8600 and 222 m μ , ϵ 7640;

the α -ionone had maxima at 227 m μ , ϵ 12850 and 296 m μ , ϵ 1950.³ The reaction paths involved are as follows



Contrary to the report of Karrer and co-workers,⁴ the crude product of the Reformatsky

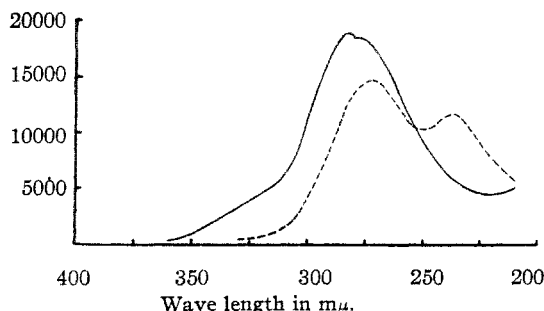


Fig. 1.—Spectra of the ethyl ionylideneacetates: —, β ; ---, α .

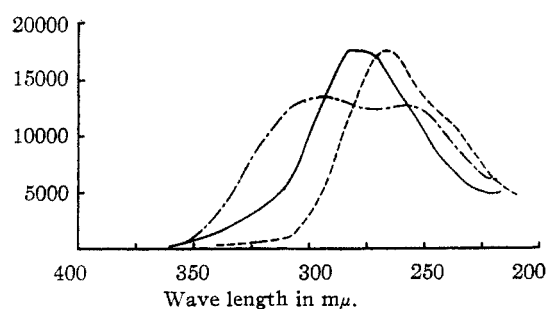


Fig. 2.—Spectra of the ionylideneacetic acids: —, β (solid); —, β (liquid); - - -, α .

(1) This paper was presented before the Division of Organic Chemistry of the American Chemical Society, Pittsburgh, Pa., September, 1943.

(2) This work was made possible by a research grant from Sharp and Dohme, Inc.

(3) The purities of these ionones were estimated at 80–85% based on a highly purified sample prepared by a method the details of which are in the process of publication.

(4) Karrer, Salomon, Morf and Walker, *Helv. Chim. Acta*, **15**, 878 (1932).

reaction on β -ionone did not dehydrate on distillation. It was always found necessary to heat the hydroxy esters ($\text{II}\alpha, \beta$) with potassium bisulfate to obtain the ethyl ionylideneacetates ($\text{III}\alpha, \beta$). The esters were saponified to the corresponding acids ($\text{IV}\alpha, \beta$). Figure 1 gives the spectra of these esters ($\text{III}\alpha, \beta$). The β compound showed a maximum farther toward the visible than that of the α isomer.⁵ Figure 2 gives the spectra of α -ionylideneacetic acid and of liquid and crystalline β -ionylideneacetic acid. The crystalline β acid shows two maxima at 294 $m\mu$, ϵ 13700 and at 260 $m\mu$, ϵ 12900 (Karrer⁴ reports a flat maximum from 270–310 $m\mu$, ϵ ca. 11200). The cyclocitrylideneacetic acids, prepared for comparison purposes by hypochlorite oxidation of the ionones, show a much larger difference in the positions of their maxima (α isomer, <212.5 $m\mu$, β isomer, 277 $m\mu$) than do the corresponding ionylideneacetic acids.

The ionylideneacetones ($\text{V}\alpha, \beta$) were prepared by the action of dimethylcadmium⁶ on the acid chlorides of $\text{IV}\alpha, \beta$.⁷ They were also prepared by the reaction of the ionylideneacetonitriles ($\text{VIII}\alpha, \beta$) with methylmagnesium iodide.

The transformations of the ionones to the ionylideneacetonitriles were carried out by condensation with cyanoacetic acid⁸ using a mixture of ammonium acetate and acetamide as catalysts and removing water formed, by co-distillation with the solvent as the reaction proceeded.⁹ The structure of the β -nitrile was proved by conversion of the nitrile to β -ionylideneacetic acid.^{4,8} The nitriles

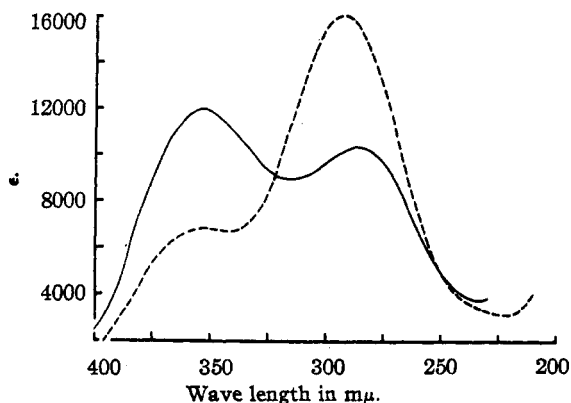


Fig. 3.—Spectra of the methyl ionylidenecyanoacetates: ---, α ; —, β .

(5) After this paper was submitted for publication the article of Sobotka, Bloch and Glick, *THIS JOURNAL*, **65**, 1981 (1943), appeared. These authors found that the barium salt of β -ionylideneacetic acid cleaves to give α -ionone on dry distillation. Their suggestion that the ring double bond isomerization takes place during the Reformatsky reaction on β -ionone does not seem in accord with our findings. There is a much larger difference in the refractive indices of the α - and β -ionylideneacetates prepared in the present work than in those found by Sobotka and co-workers.

(6) Gilman and Nelson, *Rec. trav. chim.*, **55**, 518 (1936).

(7) Karrer and Morf, *Helv. Chim. Acta*, **17**, 3 (1934), have prepared β -ionylideneacetone by treatment of β -ionylideneacetyl chloride with methylzinc iodide.

(8) Wittig and Hartmann, *Ber.*, **72B**, 1387 (1939).

(9) Cope, *THIS JOURNAL*, **59**, 2327 (1937).

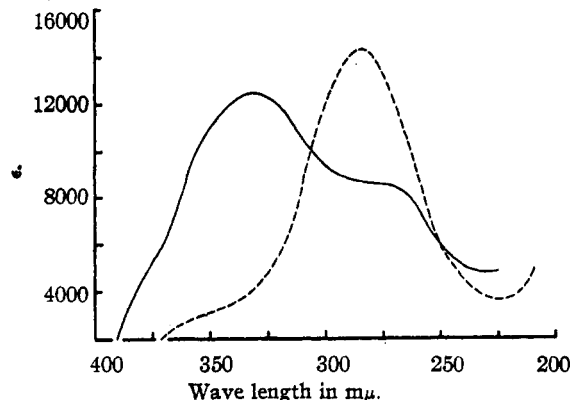


Fig. 4.—Spectra of the ionylidenecyanoacetic acids: ---, α ; —, β .

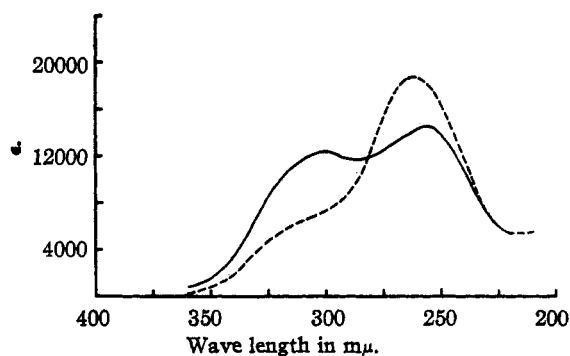


Fig. 5.—Spectra of the ionylideneacetonitriles: ---, α ; —, β .

were also prepared by decarboxylation of the ionylidenecyanoacetic acids ($\text{VII}\alpha, \beta$) which were obtained by saponification of the methyl esters ($\text{VI}\alpha, \beta$) produced by condensation of the ionones with methyl cyanoacetate. The spectra of VI, VII, VIII α and β are given in Figs. 3–5. These spectra do not suggest that any of the compounds prepared from β -ionone had isomerized to the α form.

The absorption maxima and extinction coefficients of the polyenes derived from the ionones are given in Table I.

TABLE I

THE ABSORPTION MAXIMA AND EXTINCTION COEFFICIENTS OF THE POLYENES DERIVED FROM THE IONONES

Compound ^a	$\lambda_{\text{max.}}$, $m\mu$	$\epsilon_{\text{max.}}$ ^b
Ethyl β -ionylideneacetate	283	18950
Ethyl α -ionylideneacetate	272, 236	14700, 11800
β -Ionylideneacetic acid (solid) ^c	283 ¹	17700
(liquid)	294, 260	13700, 12900
α -Ionylideneacetic acid	267	17650
β -Ionylideneacetone	285	11600
α -Ionylideneacetone	285	14500
Methyl β -ionylidenecyanoacetate	353, 286	12000, 10300
Methyl α -ionylidenecyanoacetate	292.5	16100
β -Ionylidenecyanoacetic acid	332, 275	12500, 8700
α -Ionylidenecyanoacetic acid	286	14300
β -Ionylideneacetonitrile	300, 256	12500, 14500
α -Ionylideneacetonitrile	262.5	18900
β -Cyclocitrylideneacetic acid	277	9240
α -Cyclocitrylideneacetic acid	<212.5	>10100

^a These compounds were prepared from the commercial ionones. ^b The solvent was 95% ethanol. ^c M. p. 124°.

The Structure of β -Ionylideneacetone.—The spectra of α - and β -ionylideneacetone are given in Fig. 6. The results obtained for the β isomer were rather surprising in that the position of maximum absorption was at the same wave length as that of the α isomer (though the shapes of the curves were quite different), whereas the increased conjugation of the β isomer would lead to a prediction for the maximum at a higher wave length.¹⁰

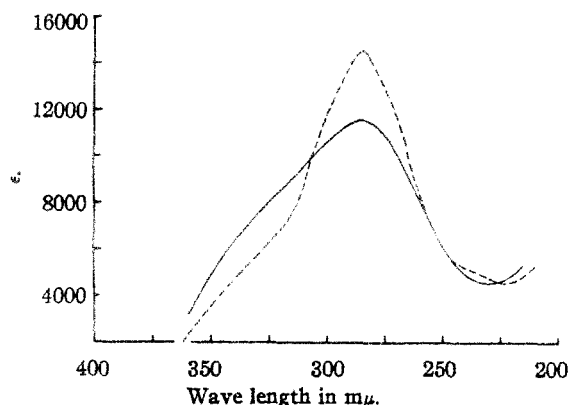


Fig. 6.—Spectra of the ionylideneacetones: - - - α ; —, β .

The semicarbazone and oxime of the β ketone could not be obtained in crystalline form, although the α isomer formed a crystalline semicarbazone. The presence of the ketone group in the β isomer was shown by reaction with Girard's reagent T¹¹ and subsequent recovery of the ketone by acid hydrolysis.

On hydrogenation over a platinum oxide catalyst the β ketone, which should have three carbon—carbon double bonds, absorbed 3.06 moles of hydrogen. Under the same conditions, β -ionone absorbed 2.05 moles of hydrogen. Ozonolysis of the ketone according to the method of Karrer and co-workers¹² gave geronic acid (isolated as the semicarbazone) in the same yield as that obtained from β -ionone, indicating that the compound had the β ring structure. No isogeronic acid semicarbazone (arising from an α ring) was isolated, although specific attempts were made to isolate this substance by virtue of its limited solubility in hot ethyl acetate.^{12,13} Under the same conditions, ozonolysis of α -ionone or of α -ionylideneacetone gave similar yields of isogeronic acid. Hypochlorite oxidation¹⁴ of β -ionylideneacetone

(10) This anomalous spectral behavior in a β -ionone derivative has been noted in one other case by Burawoy, *J. Chem. Soc.*, 20 (1941). He compared the spectra of a large number of semicarbazones of unsaturated aldehydes and ketones with those of the parent carbonyl compounds. In general the semicarbazones have absorption maxima farther toward the visible than those of the parent compounds. β -Ionone furnished the sole exception to this rule; it (λ_{\max} at 293 mμ) gave a semicarbazone with λ_{\max} at 277 mμ.

(11) Girard and Sandulesco, *Helv. Chim. Acta*, 19, 1095 (1936).

(12) Karrer, Helfenstein, Wehrli and Wettstein, *ibid.*, 18, 1096 (1930).

(13) Karrer, Morf and Walker, *ibid.*, 16, 975 (1932).

(14) Bogert and Davidson, *This Journal*, 54, 334 (1932).

produced a liquid acid which solidified after molecular distillation. This proved to be β -ionylideneacetic acid. These data serve to establish the structure of the β -ionylideneacetone.

Experimental Part

Ethyl α - and β -ionylideneacetates ($\text{III}_{\alpha,\beta}$).—These esters were prepared from 100 g. of ionones by a modification of the method of Karrer⁴ for the preparation of the β ester. The petroleum ether—benzene solution of the product from the Reformatsky reaction was distilled from a water-bath to remove the lower boiling solvent. To the residue was added 20 g. of fused and powdered potassium bisulfate after which the removal of the solvent was continued on an oil-bath. Dehydration began when the bath temperature was 150°. After two hours at this temperature the residue was cooled and taken up in ether. The ether solution was washed first with sodium bicarbonate solution then with water and dried over magnesium sulfate. After removal of the ether the ester was distilled under reduced pressure (yield approximately 50%). The properties of the esters were as follows: for ethyl β -ionylideneacetate, b. p. 162.5–164.5° (6 mm.); n_{D}^{20} 1.5310. *Anal.* Calcd. for $\text{C}_{17}\text{H}_{24}\text{O}_2$: C, 77.82; H, 9.99; sapon. eq., 262.4. Found: C, 77.42; H, 10.13; sapon. eq., 260.2. For ethyl α -ionylideneacetate, b. p. 162.5° (5–7 mm.), n_{D}^{20} 1.5140. *Anal.* Found: C, 77.65; H, 10.31; sapon. eq., 264.8.

In one preparation of ethyl β -ionylideneacetate the dehydration with potassium bisulfate was omitted. Distillation of the crude reaction product gave the hydrated ester (II_{β}), b. p. 153.5–155.5° (2–3 mm.); n_{D}^{20} 1.4880; sapon. eq. calcd., 280.4; found, 281.5. This material reacted vigorously with acetyl chloride. Dehydration with potassium bisulfate in a manner similar to that previously described gave ethyl β -ionylideneacetate.

α - and β -Ionylideneacetic Acids ($\text{IV}_{\alpha,\beta}$).—These were prepared from the ionylideneacetates according to the saponification procedure previously described.⁴ Forty-five g. of ester produced 37.4 g. of acid (95% yield). The crude acids were purified by low vacuum distillation at 3×10^{-2} mm. (bath temperature 110°). The distilled products were greenish-yellow oils. One small sample of distilled β -ionylideneacetic acid crystallized after standing several days. After the crystalline product was freed from the residual oil using a suction filter, it was recrystallized once from aqueous ethanol and twice from aqueous acetic acid. The white needle-like crystals melted from 122–124° (Karrer and co-workers,⁴ 125°). *Neut. eq.* of β -ionylideneacetic acid. Calcd. for $\text{C}_{15}\text{H}_{22}\text{O}_3$, 234; found, 241.

The Methyl Ionylideneacyanoacetates ($\text{VI}_{\alpha,\beta}$).—A mixture of 19.2 g. (0.10 mole) of ionone, 10.0 g. (0.10 mole) of methyl cyanoacetate, 40 ml. of glacial acetic acid, 1.0 g. of acetamide and 1.0 g. of ammonium acetate was heated on an oil-bath at such a rate that the acetic acid solvent and the water formed in the reaction were removed over a period of four hours. The residue was dissolved in ether and the resulting solution was washed with water and dilute aqueous sodium carbonate and dried over magnesium sulfate. The ether was removed and the products were distilled at reduced pressure. Methyl β -ionylideneacyanoacetate was a viscous orange oil boiling at 165–168° (2 mm.), n_{D}^{20} 1.5795 (Wittig and Hartmann⁸ give b. p. 171–172° (0.38 mm.)). *Anal.* Calcd. for $\text{C}_{17}\text{H}_{22}\text{N}_2\text{O}_3$: C, 74.69; H, 8.48. Found: C, 74.63; H, 8.64. The α isomer was a viscous yellow oil which boiled at 154.5–157.5° (1.5 mm.), n_{D}^{20} 1.5628. *Anal.* Found: C, 74.57; H, 8.71. The yield of ester was about 50%.

The Ionylideneacyanoacetic Acids ($\text{VII}_{\alpha,\beta}$).—Two grams (0.0073 mole) of each ester ($\text{VI}_{\alpha,\beta}$) was heated on a steam-bath with 18 ml. of 1 *N* sodium hydroxide solution with intermittent shaking until the second phase disappeared. The alkaline solution was extracted with ether and acidified with dilute phosphoric acid. The liberated acid was extracted with ether. After removal of the ether, the β ,

acid crystallized slowly. It was recrystallized from ligroin and benzene giving a yellow solid, m. p. 160–163° with decomposition. *Anal.* Calcd. for $C_{16}H_{21}NO_2$: C, 74.10; H, 8.16. Found: C, 73.87; H, 8.24. Wittig and Hartmann⁸ report this acid as an oil. The α acid did not crystallize even after long standing. The recovery of the acids from the esters was about 90%.

The Ionylideneacetonitriles (VIII α,β).—The nitriles were prepared by the condensation of the ionones with cyanoacetic acid as described above for the reaction of the ionones with methyl cyanoacetate. β -Ionylideneacetonitrile was a yellow oil, b. p. 138–140° (3 mm.), n_D^{20} 1.5566. *Anal.* Calcd. for $C_{15}H_{21}N$: C, 83.67; H, 9.83; N, 6.50. Found: C, 82.88; H, 9.97; N, 6.30. The α isomer was a yellow oil, b. p. 147.5–150° (3 mm.), n_D^{20} 1.5486. *Anal.* Found: C, 83.14; H, 9.91. The yield of crude nitrile was 69%.

β -Ionylideneacetonitrile was prepared by the decarboxylation of β -ionylidenecyanoacetic acid,⁸ and the product was comparable to that prepared directly from cyanoacetic acid and β -ionone.

β -Ionylideneacetic Acid from β -Ionylideneacetonitrile.— β -Ionylideneacetic acid was obtained by hydrolysis of the β nitrile with alcoholic potassium hydroxide according to the directions of Wittig and Hartmann.⁸ After three recrystallizations from dilute acetic acid the white solid, m. p. 122–125°, gave no melting point depression with the acid prepared from ethyl β -ionylidenecetate.

The Ionylideneacetones (V α,β).—The preparation of α -ionylidenecetone was carried out as follows: dimethylcadmium was prepared by the method of Gilman and Nelson⁶ by treatment of a solution of 0.20 mole of methylmagnesium iodide in 100 ml. of ether with 18.4 g. (0.10 mole) of anhydrous cadmium chloride. To the well-stirred mixture was added over a one-hour period a solution of 32.3 g. (0.128 mole) of α -ionylidenecetyl chloride⁷ in 130 ml. of ether. The reaction mixture was refluxed and stirred on a water-bath for three hours and poured onto a mixture of cracked ice and aqueous ammonium chloride. The ether layer was washed with two 50-ml. portions of water and dried over magnesium sulfate. After removal of the ether the product was distilled under reduced pressure. The main portion (7.0 g.) distilled from 135.5–138° (2.5 mm.), n_D^{20} 1.5298. *Anal.* Calcd. for $C_{16}H_{24}O$: C, 82.70; H, 10.41. Found: C, 81.05; H, 10.35.

Similarly 1.0 g. of β -ionylidenecetone was prepared from 6.4 g. of β -ionylidenecetyl chloride. This ketone distilled from 131–132° (2.5 mm.), n_D^{20} 1.5412. *Anal.* Found: C, 81.86; H, 10.33. Karrer and Morf⁷ reported that β -ionylidenecetone prepared by the reaction of β -ionylidenecetyl chloride and methylzinc iodide distills from 105–106° (0.1 mm.), n_D^{17} 1.5430.

The ionylidenecetones were also prepared as follows: a solution of 35.0 g. (0.16 mole) of β -ionylidenecetonitrile in 40 ml. of ether was added dropwise with stirring to 0.5 mole of methylmagnesium iodide in 200 ml. of ether. Then the solution was heated at gentle reflux for three days and decomposed in the usual manner with aqueous ammonium chloride. The ether layer was washed repeatedly with water, filtered and shaken for several days with 360 ml. of 2 *N* sulfuric acid. It was separated and washed with water and sodium bicarbonate solution and dried over sodium sulfate. After removal of the ether, the product was distilled under reduced pressure. Redistillation gave 9.0 g. of β -ionylidenecetone, b. p. 139.5–133.5° (2 mm.), n_D^{20} 1.5452. *Anal.* Calcd. for $C_{16}H_{24}O$: C, 82.70; H, 10.41. Found: C, 82.07; H, 10.58.

Similar experiments with methylolithium gave products with the same properties and with no improvement in yield.

α -Ionylideneacetonitrile and methylmagnesium iodide gave the same yield of α -ionylidenecetone, b. p. 131.5–135° (3 mm.), n_D^{20} 1.5433. *Anal.* Found: C, 82.09; H, 10.40.

Attempts were made to prepare a solid semicarbazone or oxime of β -ionylidenecetone, but the products obtained were invariably low melting oils. α -Ionylideneacetonitrile gave a crystalline semicarbazone, m. p. 162.5–164° (after recrystallization from aqueous alcohol). *Anal.* Calcd.

for $C_{17}H_{27}N_3O$: C, 70.55; H, 9.40. Found: C, 70.27; H, 9.77. The presence of the carbonyl group in β -ionylidenecetone was demonstrated by reaction with Girard's reagent T according to the procedure of Girard and Sandulesco.¹¹ The ketone was recovered unchanged from the reagent after hydrolysis with aqueous oxalic acid.¹¹

Ozonolysis Experiments.—The ozonolyses were carried out in dilute carbon tetrachloride and glacial acetic acid solution according to Karrer and co-workers.^{12,13} The geronic (or isogeronic) acid was recovered as the semicarbazone. One g. of β -ionone gave about 150 mg. of crude geronic acid semicarbazone which, after recrystallization from ethanol, melted at 161.5–163.5° (softened at 151.5°). Karrer¹² gives m. p. 162°. α -Ionone (1.18 g.) gave about 250 mg. of crude isogeronic acid semicarbazone which was insoluble in hot ethyl acetate and which upon recrystallization from alcohol melted at 191–195° (with decomposition). Strain¹⁵ reports m. p. 193–195° for isogeronic acid semicarbazone. One gram of β -ionylidenecetone gave about 200 mg. of crude geronic acid semicarbazone, soluble in ethyl acetate. After recrystallization from ethanol it melted at 161.5–163° (softened at 150°). A mixed melting point with the product from β -ionone showed no depression. α -Ionylideneacetonitrile (1.06 g.) gave 93 mg. of isogeronic acid semicarbazone. After extraction with hot ethyl acetate and recrystallization from ethanol, it melted at 191–194°. A mixed melting point with the product from α -ionone showed no depression.

Hypochlorite Oxidation of β -Ionylideneacetone.—A solution of sodium hypochlorite was prepared by the method of Bogert and Davidson.¹⁴ To a sample of 1.5 g. (0.0065 mole) of β -ionylidenecetone was added slowly 7.8 ml. (0.0195 mole) of the freshly prepared sodium hypochlorite reagent. The ketone was cooled in an ice-bath and shaken during the addition which took twenty minutes. Ten ml. of methanol was added. The odor of chloroform was noted. After the reaction mixture had stood for one hour in the ice-bath and one hour at room temperature, the solvents were removed at reduced pressure. Dilute phosphoric acid was added to acidify the residue, and the oil was extracted with 40 ml. of ether. The acid was extracted from the ether solution with two 20-ml. portions of 5% aqueous sodium hydroxide solution. The residue in the ether solution was recovered. It had an absorption spectrum and refractive index similar to those of the original ketone. The basic extract was acidified with dilute phosphoric acid, and the liberated acid was extracted with two 10-ml. portions of ether. Removal of the ether under reduced pressure left 0.9 g. of crude tan-colored acid. A portion of this acid was submitted to molecular distillation. The fraction distilling at an air-bath temperature of 140° (2.5 $\times 10^{-3}$ mm.) was an extremely viscous oil which crystallized slowly. Two recrystallizations from aqueous acetic acid gave a white solid, m. p. 122–124°. A mixed melting point with a sample of β -ionylidenecetic acid prepared from β -ionylidenecetonitrile showed no depression.

Quantitative Hydrogenation of β -Ionone and β -Ionylideneacetone.—Quantitative hydrogenations of approximately 0.25-g. samples of β -ionone and of β -ionylidenecetone were carried out using 60 ml. of ethanol and 0.1 g. of platinum oxide.¹⁶ The hydrogenations went nearly to completion within an hour but were usually allowed to run for several hours to insure complete reduction of the olefin bonds.

α - and β -Cyclocitrylideneacetic Acids.—These were prepared by hypochlorite oxidation of the ionones by a procedure similar to that described for the oxidation of β -ionylidenecetone. The crude acid from 2.0 g. of β -ionone was a yellow solid weighing 1.53 g. It was obtained as white needle-like crystals after one recrystallization from aqueous ethanol and two recrystallizations from aqueous acetic acid. The properties of β -cyclocitrylideneacetic acid were as follows: m. p. 106–108°; *Anal.* Calcd. for $C_{12}H_{18}O_2$: C, 74.20; H, 9.34; neut. eq., 194. Found: C, 73.83; H, 9.39; neut. eq., 192. On quantitative hydrogenation

(15) Strain, *J. Biol. Chem.*, **102**, 146 (1933).

(16) Adams, Voothees and Shriner, *Org. Syntheses*, **VIII**, 42 (1928).

over Adams catalyst the acid absorbed 1.96 moles of hydrogen (theoretical value 2.00 moles).

From 4.0 g. of α -ionone was obtained 0.34 g. of a yellow oily acid which would not solidify. No investigation of its physical properties other than its absorption spectrum was made. Considerable unreacted α -ionone (2.57 g.) was recovered in this experiment.

Absorption Spectrum Measurements.—Determinations of the ultraviolet absorption spectra of the polyenes were made on the Beckman Spectrophotometer.

The authors are indebted to Dr. R. O. Clinton and to Mr. J. W. Ralls for the combustion analyses reported in this paper.

Summary

The α - and β -ionylideneacetones have been pre-

pared from both the ethyl ionylideneacetates and the ionylideneacetoneitriles, each of which may be prepared conveniently from the ionones. β -Ionylideneacetone shows an absorption maximum farther toward the ultraviolet than might be expected. A study of the spectra of all the intermediates in the preparation of the ionylideneacetones has been made. The structures of the ionylideneacetones have been established by the application of quantitative hydrogenation, ozonization and hypochlorite oxidation procedures.

LOS ANGELES, CALIFORNIA RECEIVED SEPTEMBER 7, 1943

[CONTRIBUTION FROM THE HAYDEN LABORATORIES OF NORTHEASTERN UNIVERSITY]

Generalized Acid-Base Catalysis. I. Condensation of *o*-Benzoylbenzoic Acid in Sulfuric Acid

By W. F. LUDER AND SAVERIO ZUFFANTI

Many of the catalytic effects observed in organic reactions can be explained readily as instances of simple acid-base catalysis if one adopts the conception of acids and bases proposed by G. N. Lewis.^{1,2,3} One example is the condensation of *o*-benzoylbenzoic acid to anthraquinone, which has been studied by several authors^{4,5,6} without arriving at a completely satisfactory explanation of the effects observed.

Deane and Huffman⁶ have extended rate measurements of the *o*-benzoylbenzoic acid condensation into oleum of concentrations up to 29% SO_3 at 75 and 85°. They found that the velocity constant increased steadily up to their maximum sulfur trioxide percentage. In some work under way in this Laboratory on the acidity curve of oleum (to be reported in a later paper of this series), our preliminary measurements indicate the same steady increase at 40° up to 65% SO_3 , the maximum concentration so far investigated.

This increase in reaction rate with increased concentration of sulfur trioxide in sulfuric acid is readily understood when considered from the Lewis viewpoint. It is merely due to increased over-all acidity. Sulfur trioxide is a stronger acid than sulfuric acid. Lewis and Bigeleisen⁷ have shown that the acidity of sulfuric acid solutions increases with concentration of sulfur trioxide. Close correlation is evident in comparing the Lewis and Bigeleisen plot of Hammett's acidity

function⁸ with the plot of variation in reaction rate with concentration of sulfur trioxide given by Deane and Huffman.⁶ This would indicate that the condensation of *o*-benzoylbenzoic acid is an acid-catalyzed reaction, and that the reaction rate does not depend upon a particular species, but rather upon the acid strength. Probably SO_3 , H_2SO_4 , and H_3O^{+1} are the three principal species involved, but the question of the exact proportion is unimportant since the over-all acidity can be measured experimentally. Of course it is obvious that in 65% oleum the ratio of SO_3 to H_3O^{+1} is very great.

According to this viewpoint the inhibiting effect of the product anthraquinone and of other substances can readily be explained. Anthraquinone is weakly basic. The oxygen atoms each can donate a share in a pair of electrons to a sufficiently strong acid. The presence of the anthraquinone in such a highly acidic medium simply decreases its acidity and therefore its effectiveness as a catalyst. A similar explanation applies to the other inhibitors tested by Deane and Huffman. This is especially interesting since several of these substances such as AlCl_3 , HCl , and CuCl_2 are typical generalized acid catalysts. Even these acids, strong enough to catalyze Friedel-Crafts and similar reactions, are forced to behave as weak bases by the stronger mixture of sulfur trioxide and sulfuric acid.³

In view of this very great acidity of fuming sulfuric acid,⁷ the statement of Deane and Huffman⁶ that, "The effect of definite added amounts of concentrated hydrofluoric acid will more fully indicate the status of this reaction as a case of acid-base catalysis," is not likely to be upheld. They themselves had already tried a stronger acid than HF^3 , namely, AlCl_3 , and found that it did

(1) Lewis, *J. Franklin Inst.*, **226**, 293 (1938).

(2) Luder, *Chem. Rev.*, **27**, 547 (1940).

(3) Luder and Zuffanti, "Catalysis from the Viewpoint of the Electronic Theory of Acids and Bases" presented as a part of the Symposium on Molecular Addition Compounds before the Division of Physical and Inorganic Chemistry of the American Chemical Society, 106th meeting, Pittsburgh, Penna., September 6, 1943, and to be published shortly in *Chemical Reviews*.

(4) Gleason and Dougherty, *THIS JOURNAL*, **51**, 310 (1929).

(5) Newman, *ibid.*, **64**, 2324 (1942).

(6) Deane and Huffman, *Ind. Eng. Chem.*, **35**, 684 (1943).

(7) Lewis and Bigeleisen, *THIS JOURNAL*, **65**, 1144 (1943).

(8) Hammett, "Physical Organic Chemistry," McGraw-Hill Book Company, Inc., New York, N. Y., 1940.