

The acid oxalate was formed by combining the theoretical amounts of amine and oxalic acid in ethanol. After recrystallization from acetone, the colorless prisms melted at 90.5–91.0°.

Anal. Calcd. for $C_{10}H_{19}NO_4$: C, 55.28; H, 8.81; N, 6.45. Found: C, 55.48; H, 9.06; N, 6.32.

Clemmensen Reduction of 1,2,2-Trimethyl-3-piperidone.—Eight-tenths of a gram (0.0045 mole) of 1,2,2-trimethyl-3-piperidone hydrochloride was reduced with zinc amalgam and hydrochloric acid, as previously described, affording 0.86 g. (54% yield) of the picrate of a $C_8H_{17}N$ base, m. p. 172–172.5°, after recrystallization from ethanol.

Anal. Calcd. for $C_{14}H_{20}N_4O_7$: C, 47.19; H, 5.66; N, 15.72. Found: C, 47.33; H, 5.72; N, 15.74.

The melting point was not depressed when the picrate was mixed with 1-methyl-2-isopropylpyrrolidine picrate.

The methiodide of the reduction product was prepared by warming an ethereal solution of the amine with a small amount of methyl iodide. The solid derivative was recrystallized from acetone as slender, colorless prisms, m. p. 240–240.5°. The melting point was not depressed on admixture with 1-methyl-2-isopropylpyrrolidine methiodide.

Anal. Calcd. for $C_9H_{20}IN$: C, 40.16; H, 7.49; N, 5.20. Found: C, 40.44; H, 7.77; N, 4.90.

Clemmensen Reduction of 1,2-Dimethyl-2-ethyl-3-piperidone.—The reduction of 2.0 g. (0.01 mole) of 1,2-dimethyl-2-ethyl-3-piperidone hydrochloride with amalgamated zinc and hydrochloric acid led to a basic product which was isolated as the picrate in a yield of 1.93 g. (50%). The picrate was obtained as yellow needles from ethanol, m. p. 125.5–126°.

Anal. Calcd. for $C_{15}H_{22}N_4O_7$: C, 48.64; H, 5.99; N, 15.13. Found: C, 48.80; H, 6.11; N, 15.08.

The identity of the picrate as that of 1-methyl-2-s-butylpyrrolidine was confirmed by analogy to its homolog, by analysis, and by melting point (reported for 1-methyl-2-s-butylpyrrolidine picrate, m. p. 127°¹⁵).

α -Carbethoxyethyl- δ' -cyanobutylmethylamine.—A mixture of 24 g. (0.18 mole) of ethyl α -methylaminopropionate, b. p. 42–43° (7 mm.), n_D^{20} 1.4128 (obtained by treatment of α -methylaminopropionitrile¹⁶ with ethanol and

(15) Men'shikov, *J. Gen. Chem. (U. S. S. R.)*, **7**, 1632 (1937).

(16) Zelinsky, Annenkoff and Kulikoff, *Z. physiol. Chem.*, **73**, 459 (1911).

hydrogen chloride), 29.2 g. (0.18 mole) of δ -bromovaleronitrile and 25 g. (0.18 mole) of potassium carbonate was heated at 110–115° for twenty-four hours and the product was worked up in the usual manner¹⁰; b. p. 125–127° (2.5 mm.); yield, 17.3 g. (45%).

Anal. Calcd. for $C_{11}H_{20}N_2O_2$: C, 62.23; H, 9.50; N, 13.20. Found: C, 61.99; H, 9.51; N, 13.11.

α -Carbethoxyethyl- δ' -carbethoxybutylmethylamine.—Ethanolysis of the cyanoester was carried out in the usual manner to give a 59% yield of the diester, b. p. 120–122° (0.5 mm.); n_D^{20} 1.4421.

Anal. Calcd. for $C_{13}H_{22}NO_4$: C, 60.20; H, 9.72; N, 5.40. Found: C, 60.19; H, 9.86; N, 5.33.

1,2-Dimethyl-1-azacycloheptan-3-one (XIIa).—Compound XIIa was obtained by the same procedure used for the preparation of the 2-ethyl homolog (XII b.).¹⁰ A 46% yield of crude hydrochloride was obtained. A picrate, made from an ethereal solution of the free base, crystallized from ethanol as yellow needles, m. p. 174°.

Anal. Calcd. for $C_{14}H_{18}N_4O_8$: C, 45.41; H, 4.90; N, 15.13. Found: C, 45.64; H, 4.99; N, 15.03.

Clemmensen Reduction of 1,2-Dimethyl-1-azacycloheptan-3-one.—The Clemmensen reduction of XIIa was carried out as described above, and the product was converted to the picrate, which was recrystallized from water; m. p. 174–175°. An authentic sample of 1-methyl-2-ethylpiperidine (XIIIa) was prepared by catalytic hydrogenation of 2-vinylpyridine in two steps to 2-ethylpiperidine followed by N-methylation. A picrate formed from this sample of 1-methyl-2-ethylpiperidine crystallized from water as yellow needles, m. p. 174.5–175° (reported 170–171°¹⁷, 175–176°^{18,19}, 173°²⁰). Melting points of mixtures of the two picrates were not depressed.

Summary

It has been established that Clemmensen reduction of 1-methyl-3-piperidones is accompanied by ring contraction no matter whether the 2-position (α -carbon) is unsubstituted, monoalkyl-substituted, or dialkyl-substituted.

(17) Hess and Corleis, *Ber.*, **54**, 3010 (1921).

(18) Lipp, *ibid.*, **33**, 3513 (1900).

(19) Heidrich, *ibid.*, **34**, 1889 (1901).

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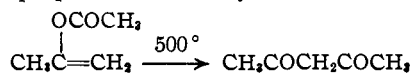
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[CONTRIBUTION FROM THE RESEARCH AND DEVELOPMENT DEPARTMENT OF CARBIDE AND CARBON CHEMICALS CORPORATION AND THE DEPARTMENT OF CHEMISTRY OF DUKE UNIVERSITY]

Conversion of Ketone Enol Esters to β -Diketones by Intramolecular Thermal Rearrangement and by Intermolecular Acylations using Boron Fluoride

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Various ketone enol esters have been converted to β -diketones by passing the ester through a tube at 500°.³ By recycling the enol ester, excellent yields (70–85%) of β -diketones have generally been obtained, the process being used for the commercial preparation of acetylacetone.



(1) Carbide and Carbon Chemicals Corp. Fellow, 1949.

(2) Carbide and Carbon Chemicals Corp. Fellow, 1946–1948.

(3) Boese and Young, U. S. Patent 2,395,800 (1946); *C. A.*, **40**, 1310 (1946).

The conversion of the enol acetate of cyclohexanone to 2-acetylcyclohexanone by boron fluoride at low temperatures has also been reported,⁴ but the details have not been available.

In the present investigation, evidence is presented that the thermal conversion involves an intramolecular rearrangement and the conversion by boron fluoride, an intermolecular acylation. The scope of the latter conversion has been extended considerably and certain analogous acylations

(4) Kastner, in "Newer Methods of Preparative Organic Chemistry," Interscience Publishers, Inc., New York, N. Y., 1948, p. 289.

TABLE I
 KETONE ENOL ACETATES FROM KETONES AND KETENE

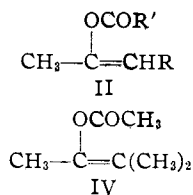
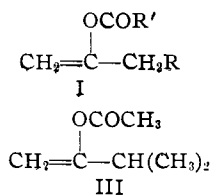
Ketone enol acetate	Structure ^a	Yield, %	B. p., °C.	Mm.	<i>d</i> ₄ ²⁰ , g./ml.	<i>n</i> _D ²⁰	Analyses, %		Hydrogen	
							Calcd. Carbon	Found	Calcd.	Found
Methyl ethyl	II	95	53	50	0.924	1.4111	63.2	63.0	8.8	9.0
Methyl isopropyl	III and IV ^b	72	58-63	50	0.898	1.4092 ^{32°}	65.6	65.3	9.4	9.7
Methyl isobutyl	II	90	72-74	50	0.886	1.4168	67.7	67.6	10.0	10.0
Methyl <i>n</i> -amyl	90% II 10% I	90	63-64	10	0.877	1.4200 ^{30°}	69.2	69.3	10.3	9.9
Acetophenone	78	93	4	1.067	1.5310	74.1	74.1	6.2	6.5

^a Determined by ozonization. ^b Ratio of isomers unknown.

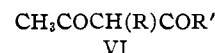
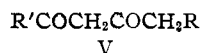
with acid anhydrides and acyl halides have been effected.

Ketone Enol Esters.—The enol acetates were prepared by the acid catalyzed O-acetylation of ketones with ketene⁵ (Table I) or with acetic anhydride⁶ or by an exchange method with the ketone and the enol acetate of acetone.⁷ The enol benzoates were prepared by the O-benzoylation of ketones with benzoyl chloride⁸ or by an exchange method with benzoyl chloride and an enol acetate.

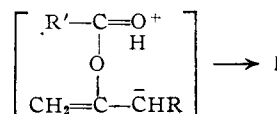
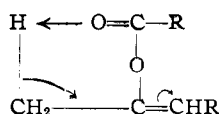
Unsymmetrical methyl-methylene ketones may form two isomeric enol esters, (I) and (II), depending on whether the methyl or the methylene hydrogen is enolized. In such cases, the products were ozonized and the relative amounts of formaldehyde from (I) and higher aldehyde from (II) were determined (see experimental). From the results obtained, it was concluded that the enol acetates of methyl ethyl and methyl isobutyl ketones prepared with ketene and also the enol acetate of methyl *n*-amyl ketone prepared with acetic anhydride⁶ or by the exchange method consisted essentially only of the corresponding methylene isomers (II). However, the product from methyl *n*-amyl ketone and ketene consisted of a little (10%) of the methyl derivative (I) along with the methylene derivative (II) (90%).⁹ The enol benzoates of phenylacetone and methyl *n*-amyl ketone prepared with benzoyl chloride consisted apparently only of the corresponding methylene isomers (II). The product from methyl isopropyl ketone and ketene was found by ozonization to consist of both the methyl and methinyl isomers, (III) and (IV), respectively, but the method for determining the ratio of isomers failed.



Thermal Rearrangements.—The excellent yields produced with little if any side reaction products in the thermal conversion of ketone enol esters to β -diketones³ indicated that the reaction involved an intramolecular rearrangement. On this basis, the methylene structure (II) of the enol ester would be expected to form the β -diketone having the corresponding methylene structure (VI), and the methyl structure (I), the β -diketone having the methyl structure (V).



Therefore we were somewhat surprised to find that the enol acetates of methyl ethyl and methyl isobutyl ketones having entirely the methylene structure (II) on undergoing thermal rearrangement produced mixtures of isomeric β -diketones which, on analysis by the alkali extraction method,¹⁰ were found to contain more of the methyl (V) than methylene (VI) isomer. For example, the mixture of isomeric β -diketones from the enol acetate of methyl isobutyl ketone was found to consist of three parts of isovalerylacetone (X) and one part of isopropylacetylacetone (IX). However, we then found by ozonization that, in contrast to the original ester, the enol ester recovered after the thermal treatment consisted of a mixture of the two isomers in the ratio of two parts methyl (VIII) to three parts methylene (VII). Evidently, under the conditions of the thermal rearrangement, part of the methylene enol structure isomerized¹¹ to the methyl struc-



ture which then underwent rearrangement. Although the relative amounts of isomeric β -diketones produced did not correspond to those of the recovered isomeric enol esters, the result may be accounted for by an intramolecular process on

(10) Hauser and Adams, *THIS JOURNAL*, **66**, 345 (1944).

(11) This partial isomerization, which is presumably reversible, appears to involve a prototropic change which might occur within the molecule.

(5) Young, U. S. Patent 2,641,016 (1949).

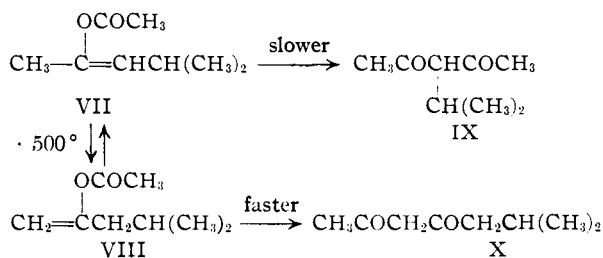
(6) Bedoukian, *THIS JOURNAL*, **67**, 1430 (1945).

(7) See Quattlebaum and Noffsinger, U. S. Patent 2,466,737 (1949); *C. A.*, **43**, 7037 (1949).

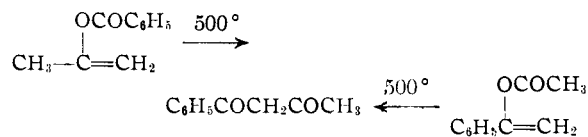
(8) Lees, *J. Chem. Soc.*, **83**, 145 (1903).

(9) The formation of some of (I) with methyl *n*-amyl ketone seems somewhat surprising since similar conditions have produced only (II) with methyl ethyl and methyl isobutyl ketones.

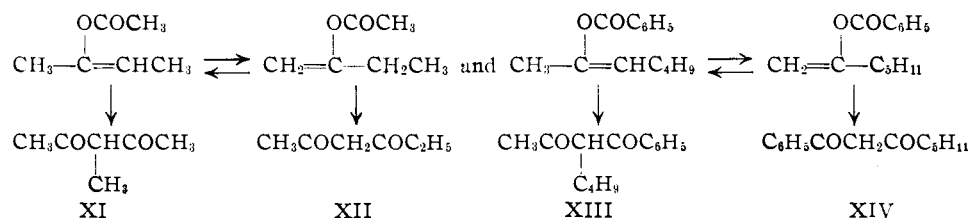
the reasonable assumption that the enol ester having the methyl structure (VIII) underwent rearrangement more rapidly than that having the methylene structure (VII).



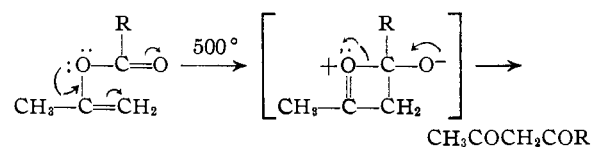
That the rearrangement occurs intramolecularly is shown by the essentially exclusive formation of benzoylacetone from the pyrolysis of a mixture of the enol benzoate of acetone and the enol acetate of acetophenone. No dibenzoylmethane and little if any acetylacetone, the two possible intermolecular reaction products, could be detected.



Similarly, a mixture of the enol acetate of methyl ethyl ketone and the enol benzoate of methyl *n*-amyl ketone yielded on pyrolysis all four of the possible intramolecular products (XI, XII, XIII and XIV) and apparently none of the intermolecular products such as *n*-butylacetylacetone which, however, was obtained in considerable amount in the presence of boron fluoride (see below). Presumably, under the conditions of the thermal rearrangement, each of the enol esters isomerizes to a mixture of the methyl and methylene structures (I and II, respectively).



The mechanism for the intramolecular acylation of the olefinic portion of the enol ester by the acyl portion evidently involves an α,γ -shift possibly through the intermediate formation of a four-atom ephemeral ring.

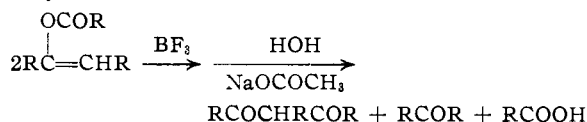


Intermolecular Acylations by Boron Fluoride.

—Various ketone enol acetates and benzoates

were converted to β -diketones by saturating the enol ester with boron fluoride at 0–20° and hydrolyzing the resulting mixture with aqueous sodium acetate. The percentage conversions and other data are given in Table II. It can be seen from this table that the enol esters of unsymmetrical methyl-methylene ketones consisting of only the methylene structures (II) gave, within limits of experimental error, β -diketones having the corresponding methylene structure (VI). Moreover, samples of the enol acetate of methyl *n*-amyl ketone consisting of various proportions of the methylene (II) and methyl (I) structures yielded β -diketones consisting of the same proportions of the methylene (VI) and methyl (V) structures, *n*-butylacetylacetone and caproylacetone.

In addition to the β -diketone, the parent ketone and benzoic acid (from the benzoates) were generally obtained; in one case, the yields of these products were equal (33%). The ketone and acid were evidently by-products in the boron fluoride reaction since blank experiments showed that they were not formed merely by subsequent hydrolysis of unreacted enol ester or by cleavage of the β -diketone. Therefore, in contrast to the thermal rearrangement, the conversion of ketone enol esters to β -diketones by boron fluoride involves evidently an intermolecular acylation of one molecule by another. The over-all reaction may be indicated as



On this basis, the yields would be double the percentage conversions given in Table II. The fact that, in certain cases, yields greater than 100% would then be obtained is explained below.

In support of the intermolecular nature of the acylation, a mixture of the enol acetate of methyl ethyl ketone and the enol benzoate of methyl *n*-amyl ketone gave mainly (33%) the mixed acylation product, *n*-butylacetylacetone,¹² and much less (12 and 6%, respectively) of the self-acylation products of the two enol esters. The main reaction may be formulated as shown. A mixture of the enol acetate of acetophenone and the enol benzoate of acetone gave some of the mixed acylation products, acetylacetone and di-

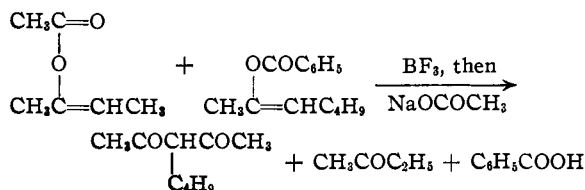
(12) Although the *n*-butylacetylacetone might conceivably arise from an acyl exchange followed by the self-acylation of the resulting enol acetate, this explanation seems unlikely since the self-acylation product from the enol benzoate of methyl ethyl ketone (which would also be produced by the exchange) was not found. Actually, no appreciable amount of ester exchange should be expected under the conditions employed.

TABLE II

 β -DIKETONES FROM THE SELF-ACYLATION OF KETONE ENOL ACETATES AND BENZOATES BY BORON FLUORIDE

Ketone enol acetate	Structure ^a	β -Diketone	$^{\circ}$ C.	B. p. Mm.	Conversion, ^b %	Structure ^c
Acetone		Acetylacetone ^d	130-135	760	22	
Methyl ethyl	II	Methylacetylacetone ^k	75-80	30	17	VI ^f
Methyl isopropyl	III and IV ^g	Mixture	66-69	20	20	.. ^g
Methyl isobutyl ^d	II	Isopropylacetylacetone ^l	80-82	20	50	VI ^h
Methyl isobutyl ^e	.. ⁱ	Mixture	79-82	20	20	83% VI ^h 17% V ^w
Methyl <i>n</i> -amyl ^f	II	<i>n</i> -Butylacetylacetone ^m	102-106	20	44	VI
Methyl <i>n</i> -amyl ^d	90% II 10% I	Mixture	102-105	20	45	90% VI ^h 10% V ^w
Methyl <i>n</i> -amyl ^e	50% II 50% I	Mixture	102-105	20	38	50% VI ^h 50% V ^w
Cyclohexanone		2-Acetylcyclohexanone ⁿ	94-96	10	38	
Acetophenone ^g		Benzoylacetone ^o	128-129	10	22	
Acetone ^h		Benzoylacetone ^o	146-150	20	35	
Methyl <i>n</i> -amyl ^h	II	<i>n</i> -Butylbenzoylacetone ^p	148-151	5	52	VI
Acetophenone ^{g,h}		Dibenzoylmethane ^q	216-220	18	24	
Phenylacetone ^{g,h}	II	Phenylbenzoylacetone ^r	145-152	1	45	VI

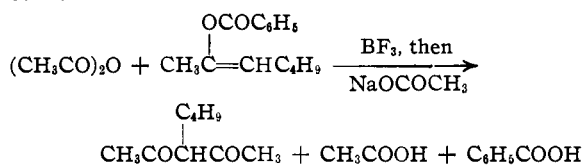
^a Determined by ozonolysis. ^b Intermolecular yield, twice these values. ^c Determined by alkali extraction method unless noted otherwise. ^d Prepared by ketene method. ^e Recovered after heating to high temperature. ^f Prepared by exchange method. ^g Ethylene chloride solvent used. ^h Enol benzoate. ⁱ Ratio of isomers unknown. ^j Red enol test, blue copper complex, dec. above 230° (ref. 28). ^k Purple enol test, grey copper complex, dec. 223° (see ref. 10). ^l No enol test or copper complex (Adams and Hauser, THIS JOURNAL, 67, 284 (1945)). ^m Purple enol test, grey copper complex, m. p. 185-186° (ref. 10). ⁿ See ref. in note 1. ^o Melts at 60° (ref. 27). ^p *Anal.*¹⁸ Calcd. for C₁₄H₁₈O₂: C, 77.03; H, 8.31. Found: C, 77.09; H, 8.15. Forms a light green copper complex, m. p. 176-177°. ^q Melts at 77-78° (Wislicenus, *Ann.*, 308, 229 (1898)). ^r Melts at 76-77°. *Anal.*¹⁸ Calcd. for C₁₆H₁₄O₂: C, 80.65; H, 5.92. Found: C, 80.47; H, 5.78. ^s Trace of methyl derivative, propionylacetone, indicated by a red-purple enol test on first alkali extraction. ^t Mixture (red enol test) gave blue copper complex (m. p. 169-170°; see ref. 10) of isobutylacetylacetone (67%); dimethylacetylacetone, 33% estimated by difference (see ref. 10). ^u Trace of methyl derivative, isovalerylacetone, isolated as blue copper complex, m. p. 154-155° (ref. 25). ^v Isopropylacetylacetone, b. p. 80-83° at 20 mm., no enol test or copper complex (ref. in note 1). ^w Isovalerylacetone, b. p. 75-79° at 20 mm., red enol test, blue copper complex, m. p. 154-155° (ref. 25). ^x *n*-Butylacetylacetone, identified as in note *m*. ^y Caproylacetone, red enol test, blue copper complex, m. p. 136-137° (ref. 10).



benzoylmethane, but the main product was benzoylacetone, which presumably resulted from the self-condensations of both enol esters.

As should be expected, ketone enol esters may be acylated not only with the same enol ester (self-acylation) or with a different enol ester (mixed ester acylation), but also with acid anhydrides (Table III) or acid chlorides. Reactions have been carried out both when the acyl groups are the same in the enol ester and the acid anhydride or acid chloride and when they are different. When the acyl groups are the same, as, for example, with the enol acetate of methyl *n*-amyl ketone and acetic anhydride or acetyl chloride, the conversion to β -diketone was considerably greater than that obtained from the enol ester alone by self-acylation. When the acyl group of the anhydride is different from that of the enol ester, the β -diketone resulting from the acylation by the anhydride has been obtained exclusively in certain cases. Thus, with *n*-butyric anhydride and the enol ace-

tate of cyclohexanone, there has been obtained a 64% yield of *n*-butyrylcyclohexanone, and with acetic anhydride and the enol benzoate of methyl *n*-amyl ketone, a 73% yield of *n*-butylacetylacetone.



However, benzoic anhydride failed to benzoylate the enol acetate of cyclohexanone; instead, the enol ester self-condensed. Acetyl chloride acetylated the enol benzoate of methyl *n*-amyl ketone, but some of the self-benzoylation product of the enol ester also was obtained.

In acylations of enol esters with enol esters, acid anhydrides or acid chlorides, the β -diketone is evidently first produced in the form of its boron difluoride complex (XV), and the carboxylic acid (from the acyl portion of the enol ester), as its acid fluoride.¹³ The former intermediate [XV, R and R' = CH₃, R'' = CH(CH₃)₂] has been iso-

(13) Similar eliminations of acid fluorides from O-acyl derivatives of β -diketones in the presence of boron trifluoride to form boron difluoride complexes (XV) have been observed in the laboratory of Duke University.

acetyl chloride (96.5% of theory), was collected. The residue was flash-distilled at 100° at 40–50 mm. to free it from catalyst by dropping on a steam-heated glass-coil. Redistillation gave 404 g. of recovered enol acetate of acetone, 7 g. of benzoyl chloride, and 409 g. (95.5% yield based on benzoyl chloride consumed) of the enol benzoate of acetone, b. p. 81° at 5 mm., sp. gr.²⁰_{15.5} 1.051, n_{D}^{20} 1.5125.

*Anal.*¹⁹ Calcd. for C₁₀H₁₀O₂: C, 74.1; H, 6.2. Found: C, 74.0; H, 6.3. The enol benzoate of acetone was also prepared by a modification of the method of Phillips.²⁰ The enol acetate of acetone (1400 g., 14.0 moles) was added below the surface of melted benzoic anhydride (903 g., 4 moles) containing concd. sulfuric acid (13 g., 1%) and heated above 160°. The issuing vapors were passed to a distilling column for separation of the enol acetate from the enol benzoate, the former being recycled. After forty-five hours operation, 156 g. (39% based on the benzoic anhydride consumed) of the enol benzoate and 619 g. of benzoic anhydride were recovered.

Ozonization of Enol Esters.—The enol esters from unsymmetrical methyl-methylene or methyl-methinyl ketones were analyzed by a modification and extension of the method employed by Bedoukian⁹ with the enol acetate of methyl *n*-amyl ketone. A solution of 10 g. of enol ester in 200 ml. of chloroform at 0° was ozonized with a 50% excess of ozone introduced as a 3% mixture in air. The ozonide was stirred at 0° with 8 g. of zinc dust and 80 ml. of 50% acetic acid. The excess metal was filtered off, washed with 30 ml. of water, and the aqueous and chloroform layers were separated. Suitable aliquots of the two layers were refluxed with 0.5 g. of 2,4-dinitrophenylhydrazine and 2 ml. of concd. hydrochloric acid for one-half hour. The formaldehyde derivative from the aqueous layer and the higher aldehyde (or ketone) derivative from the chloroform layer were identified by the mixed melting point method. In most cases, no formaldehyde derivative could be isolated, and, since blank experiments showed that even 10 mg. of formaldehyde gave a precipitate, less than this amount (corresponding in most cases to less than 1% of the original ester) must have been present.

When the derivatives of both formaldehyde and higher aldehyde were obtained, the molecular ratio of the aldehydes was determined by the following method. Suitable aliquots of the original aqueous layer and the chloroform layer (after extracting several times with 10% sodium bicarbonate solution)²¹ were exactly neutralized to bromophenol blue with 0.1 *N* sodium hydroxide. To each was added 50 ml. of neutral 0.5 *N* aq. hydroxylamine hydrochloride solution and 50 ml. of 0.1 *N* sodium hydroxide. The solutions were left standing for two hours and then the excess alkali not required to neutralize the hydrochloric acid set free in the oximation in each case was titrated with 0.1 *N* hydrochloric acid. The total amount of the two aldehydes determined in this manner usually corresponded to almost quantitative yields based on the original ester.

Thermal Rearrangement of Enol Esters.³—The enol ester was vaporized and preheated to 350° in a 2.5 × 91 cm. unpacked 40% chrome-iron tube heated by means of a pressure-jacket containing boiling "Dowtherm." The vapors were then passed at a uniform rate into a 2.5 × 53 cm. 40% chrome-iron tube isomerization chamber²² packed with 4 mesh "Aloxite"²³ and electrically heated

to 500°. The product vapors were collected and fractionated through a 30 × 900 mm. glass helix-packed column and unreacted enol ester was separated. The β -diketones were isolated by refractionation and, when necessary, isomers were further separated by the alkali extraction method.¹⁰

The enol acetate of methyl ethyl ketone (1283 g., 11.2 moles), fed at the rate of 110 g. per hour, yielded on fractionation 372 g. (29%) of unreacted enol acetate, b. p. 48–51° at 50 mm., and 820 g. (64% yield) of the isomeric hexanediones, b. p. 52–73° at 20 mm. The latter fraction was found to consist of 65% propionylacetone (red enol test and blue copper complex, m. p. 196–197°)²⁴ and 35% methylacetylacetone (purple enol test and grey copper complex of indefinite melting point).¹⁰

The enol acetate of methyl isobutyl ketone (1877 g., 13.2 moles), fed at 160 g. per hour, yielded 1160 g. (62% recovery) of unchanged enol ester and 592 g. (33% yield) of mixed isomeric β -diketones, b. p. 69–74° at 13 mm. The latter fraction consisted of 75% isovalerylacetone (X) (red enol test and blue copper complex, m. p. 154–155°)²⁵ and 25% isopropylacetylacetone (IX) (no enol test or copper complex).¹⁰ A 22-g. sample of the recovered enol acetate was ozonized. The aqueous layer gave a 2,4-dinitrophenylhydrazone of formaldehyde, m. p. and mixed m. p. 162–164°²⁶ and the chloroform layer, the 2,4-dinitrophenylhydrazone of isobutyraldehyde, m. p. and mixed m. p. 180.4°²⁶ Analysis of the two layers by the hydroxylamine method showed a ratio of 2 parts of methyl (VIII) to 3 parts of methylene (VII) isomer.

A mixture of 235 g. (1.45 moles) of the enol benzoate of acetone and 235 g. (1.45 moles) of the enol acetate of acetophenone after isomerization yielded 93 g. (40% recovery) of the enol benzoate of acetone, 91 g. (39% recovery) of the enol acetate of acetophenone, and 212 g. (45% yield) of benzoylacetone, b. p. 110–133° (5 mm.) and m. p. 60°.²⁷ Material collected in the cold traps yielded largely acetic acid and a 2.4 g. fraction, b. p. 122–125°, which gave a bright red color with ferric chloride and a blue copper complex (1.4 g.) which failed to melt at 400°.²⁸

A mixture of the enol acetate of methyl ethyl ketone (228 g., 2 moles) and the enol benzoate of methyl *n*-amyl ketone (436 g., 2 moles), fed at 175 g. per hr., gave the following fractions: Recovered enol acetate of methyl ethyl ketone, 138 g. (66%), b. p. 43–50° at 50 mm., n_{D}^{20} 1.4058, sp. gr.²⁰₂₀ 0.902, negative enol test; a mixture of isomeric hexanediones, 72 g. (93% yield based on ester consumed), b. p. 52–75° at 20 mm., n_{D}^{20} 1.4460, sp. gr.²⁰₂₀ 0.967; recovered enol benzoate of methyl *n*-amyl ketone, 355 g. (92% recovery), b. p. 119–125° at 5 mm., n_{D}^{20} 1.5006, sp. gr.²⁰₂₀ 0.986, negative enol test; and 35.5 g. (88% yield based on the ester consumed) of a mixture of phenyl octanediones, b. p. 144–150° at 5 mm. From 20 g. of the hexanediones, there was separated 13 g. (65%) of propionylacetone (XII) giving a red enol test and blue copper complex, m. p. 195.5–196.5°²⁴ and 4 g. (20%) of methylacetylacetone (XI) purple enol test and gray copper complex with no sharp m. p.¹⁰ From 20 g. of the phenyl octanedione fraction, there was separated 2 g. (10%) of caproylacetophenone (XIV), m. p. 20°, red enol test, and green copper complex, m. p. 109–110°²⁹ and 12 g. (60%) of *n*-butylbenzoylacetone (XIII), purple enol test and light green copper complex, m. p. 176° (dec.).

Self-Acylations of Ketone Enol Esters by Boron Fluoride.—The enol ester (0.2–0.6 mole) was placed in a three-necked flask fitted with a mercury-sealed stirrer, a ther-

(19) Analysis by Carbide and Carbon Chemicals Corp., Works Control Laboratory.

(20) Phillips, U. S. Patent 2,466,738; C. A., **43**, 7038 (1949).

(21) In cases where formaldehyde was formed on ozonolysis, acidification of this bicarbonate extract yielded the expected carboxylic acid which was identified by suitable derivatives.

(22) A quartz tube which also resists the corrosive action of the β -diketones may be used instead.

(23) An empty tube may be used, but the yields are generally somewhat lower. With the filling, the yield of β -diketone was initially poor, but improved with use as the "Aloxite" became coated with a thin deposit of a lustrous carbon film formed from the decomposition of a small part of the ester, indicating that the isomerization is a surface reaction.

(24) Griner, *Ann. chim. phys.*, [6] **26**, 362 (1892).

(25) Morgan and Drew, *J. Chem. Soc.*, **125**, 731 (1924).

(26) Shriner and Fuson, "The Systematic Identification of Organic Compounds," John Wiley and Sons, Inc., New York, N. Y., 3rd ed., 1948.

(27) Meerwein and Vossen, *J. prakt. Chem.*, **141**, 149 (1934).

(28) Claisen (*Ann.*, **227**, 170 (1893)) reports that the copper complex of acetylacetone decomposes above 230°.

(29) Andre, *Compt. rend.*, **182**, 1488 (1911); *Ann. chem.*, [8] **29**, 581 (1913).

meter immersed in the reaction mixture, a boron fluoride inlet tube adjusted so that the gas was delivered 1-2 cm. above the surface of the liquid, and an outlet tube with an attached calcium chloride drying tube. Boron fluoride gas (bubbled first through 95% sulfuric acid) was passed into the reaction flask above the rapidly stirred reaction mixture as fast as it could be absorbed while maintaining the temperature at 0-20° by means of a Dry Ice-acetone-bath or an ice-water-bath.³⁰ Absorption of the gas is rapid for about ten minutes and then apparently abruptly drops to a very low rate which continues as long as the reaction proceeds.³¹ For maximum yields of β -diketones, a boron fluoride atmosphere over the stirred reaction mixture was maintained during the whole reaction time as evidenced by the escape of a few white fumes through the drying tube. At the end of four hours, the reaction mixture (containing in certain cases some solid material) was poured into a solution of sodium acetate (two moles per mole of enol ester) in three or four parts of water. The mixture was refluxed thirty minutes to one hour until the boron fluoride complexes were hydrolyzed. The longer time was found necessary for the enol acetates of cyclohexanone and acetophenone and for the enol benzoates. The mixture was chilled and extracted with ether. The ether extracts were washed free of acid with saturated sodium bicarbonate solution and dried over Drierite. The β -diketones were isolated by distillation. When isomeric β -diketones were obtained, they were separated by the alkali extraction method.¹⁰

In certain cases, the reaction was carried out in the presence of dry ethylene chloride as solvent. After mixing with sodium acetate solution, the ethylene chloride was removed by distillation until the vapor temperature rose above 90°. The residue was refluxed and worked up as described above.

The data for the β -diketones are summarized in Table II.

In the isolation of the β -diketones by distillation, considerable amounts of the parent ketone were generally obtained in the foreruns. Acidification of the bicarbonate extracts from the benzoates precipitated benzoic acid in yields of 20-40%. These two products were obtained in equal yields in the following experiment. The enol benzoate of methyl *n*-amyl ketone (65.5 g., 0.3 mole) was treated with boron fluoride for one hour at 10-20° and the reaction mixture worked up. From the ether layer, there was isolated on distillation 11.3 g. (33% conversion yield) of methyl *n*-amyl ketone, b. p. 52-56° at 20 mm. (semicarbazone, m. p. 122-123°)³² and 30.2 g. (46% conversion yield) of *n*-butylbenzoylacetone, b. p. 148-151° at 5 mm. (copper complex, m. p. 177.5-178°). In addition, there was a small amount of recovered enol benzoate (approx. 10%) and 3 g. of non-distillable material. From the bicarbonate extracts, there was obtained, after acidification, 11.9 g. (33% conversion yield) of benzoic acid, m. p. and mixed m. p. 121-122°.

In a blank experiment, the enol benzoate of methyl *n*-amyl ketone (0.1 mole) was added to a mixture of 0.2 mole of sodium acetate in 300 ml. of water and 14.5 g. of 45% boron fluoride-ether solution (0.1 mole of boron fluoride).

(30) Higher temperature or slowing up the addition of boron fluoride increases the amount of non-distillable residue and lowers the yield of desired products.

(31) Maximum absorption of boron fluoride runs up somewhat above 150 mole per cent. With the enol acetate of cyclohexanone, the addition of 30, 105 and 150 mole per cent. of boron fluoride (determined by the increase in weight of the reaction flask and contents) gave conversions to β -diketone of 10, 37 and 38 per cent., respectively. With the enol acetate of methyl isobutyl ketone, 27 and 105 mole per cent. of boron fluoride absorbed gave 20 and 50% conversion to the β -diketones compared with a maximum absorption conversion of 60%. The conversions to β -diketones from the enol acetate of methyl *n*-amyl ketone were 35, 39 and 44% when the absorption of boron fluoride was 72 mole per cent, 130 mole per cent., and maximum, respectively.

(32) McElvain, "The Characterization of Organic Compounds," The Macmillan Company, New York, N. Y., 1946.

The ether was evaporated and the mixture refluxed for one hour. On working up, 87% of the original enol ester was recovered. In another blank experiment, 85% of *n*-butylbenzoylacetone was recovered after treatment with boron fluoride followed by sodium acetate as described above. No ketone or benzoic acid could be isolated in either of the blank experiments.

Isolation of the Cyclic Boron Difluoride Complex (XV).—The enol acetate of methyl isobutyl ketone was saturated with boron fluoride at 10° for four hours. Solid material separated during this time. The reaction mixture was then poured into sodium acetate solution and shaken vigorously. The solid remaining was filtered off and recrystallized four times from glacial acetic acid, yielding the boron difluoride complex of isopropylacetylacetone, m. p. 113-113.5°.

*Anal.*¹⁸ Calcd. for $C_8H_{12}O_2BF_2$: C, 50.57; H, 6.90; F, 20.0. Found: C, 50.80, 50.53; H, 6.76, 6.63; F, 19.9.³³

The same boron difluoride complex (m. p. and mixed m. p. 113-113.5°) has been obtained by saturation of a mixture of the enol acetate of methyl isobutyl ketone and acetic anhydride with boron fluoride in eleven minutes at 0-5°.

Isolation of Benzoyl Fluoride.—The enol benzoate of acetone (0.2 mole) dissolved in 35 ml. of dry ethylene chloride was treated with boron fluoride for one hour at 10-15°. The reaction mixture was poured into a solution of sodium acetate (0.4 mole) dissolved in 300 ml. of water and steam distilled as rapidly as possible until no more organic material would come over. The distillate was extracted with ether and the ether extracts washed with saturated sodium bicarbonate solution and then once with water and dried over Drierite. On distillation there was obtained 1.6 g. (6% yield) of benzoyl fluoride, b. p. 53-56° at 20 mm.³⁴ and 11.2 g. (35% conversion) of benzoylacetone, b. p. 146-150° at 20 mm. The benzoyl fluoride was identified by its strong lachrymatory property and by its vigorous reaction with concentrated ammonium hydroxide to form benzamide, m. p. and mixed m. p. 125-126°.²⁵

In a similar experiment with the enol benzoate of methyl *n*-amyl ketone (0.3 mole), an 8.8-g. fraction, b. p. 56-58° at 20 mm. was collected from the ether extract after steam distillation. This fraction was strongly lachrymatory and consisted apparently of a mixture of benzoyl fluoride and methyl *n*-amyl ketone. The presence of benzoyl fluoride was indicated by its vigorous reaction with concd. ammonium hydroxide solution to form 1.0 g. of benzamide, m. p. and mixed m. p. 124-126°.²⁵

Mixed Acylations of Ketone Enol Esters by Boron Fluoride.—A mixture of the enol benzoate of methyl *n*-amyl ketone (42.9 g., 0.195 mole) and the enol acetate of methyl ethyl ketone (22.3 g., 0.195 mole) in 25 ml. of dry ethylene chloride was saturated with boron fluoride at 10-20° for two hours. The reaction mixture was worked up as described for self-acylations. From the ether solution was separated by distillation the following products: *n*-butylacetylacetone (10.0 g., 33%), b. p. 102-106° at 20 mm., copper complex, m. p. 184-185°¹⁰; methylacetylacetone (2.6 g., 12% conversion), b. p. 75-80° at 30 mm.,¹⁰ copper complex, dec. point 223-224°; *n*-butylbenzoylacetone (2.5 g., 6% conversion), b. p. 147-153° at 5 mm., copper complex dec. point 176-177°; and methyl *n*-amyl ketone (3.1 g., 14% yield), b. p. 147-152°.²⁶ From the bicarbonate extracts was obtained 14.4 g. (60% yield) of benzoic acid, m. p. 120.5-121.5°.

A mixture of 32.4 g. (0.2 mole) each of the enol benzoate of acetone and the enol acetate of acetophenone in 64.8 g. of dry ethylene chloride was treated with boron fluoride at -5° to +10° for one and one-quarter hours. On working up the reaction mixture there were isolated: acetylacetone (2.1 g., 11% yield), b. p. 133-140°, mono-2,4-

(33) Fluorine analysis by Mrs. A. R. Gilbert according to method of Gilbert and Saylor, *Anal. Chem.*, **22**, 196 (1950).

(34) Simons and Herman, *This Journal*, **65**, 2064 (1943), report b. p. of 74-79° at 30 mm.

dinitrophenylhydrazone, m. p. 121–122²⁶; acetophenone (7.6 g., 32% yield), b. p. 198–201°; benzoylacetone (15.6 g., 24% conversion), b. p. 141–144° at 19 mm., m. p. 54–58²⁷; and from the residue, was obtained after recrystallization from methanol, 0.8 g. (2% yield) of dibenzoylmethane, m. p. 75–77° and mixed m. p. with a known sample of 76–78°. ²⁸

Acylation of Ketone Enol Esters with Anhydrides by Boron Fluoride.—A mixture of the anhydride and ketone enol ester (1.5:1 molar ratio) was saturated with boron fluoride at 0–20° for one to two hours and then hydrolyzed with sodium acetate solution and worked up as described for the self-acylations of enol esters. The results are summarized in Table III.

Acylation with Acetyl Chloride.—A mixture of the enol acetate of methyl *n*-amyl ketone and acetyl chloride (0.15 mole each) was saturated with boron fluoride for one hour at 10–20°. On working up the reaction mixture, there was obtained 16.2 g. (69% conversion) of *n*-butylacetylacetone, b. p. 103–105° at 20 mm., m. p. of copper complex 184–185°. ¹⁰

A mixture of 43.6 g. (0.2 mole) of the enol benzoate of methyl *n*-amyl ketone and 15.7 g. (0.2 mole) of acetyl chloride on saturation with boron fluoride at 0–20° for one

(35) Levine, Conroy, Adams and Hauser, *THIS JOURNAL*, **67**, 1510 (1945).

hour, yielded 5.8 g. (25% conversion) of methyl *n*-amyl ketone, b. p. 148–154°, ²² 9.9 g. (32% yield) of *n*-butylacetylacetone, b. p. 102–105° at 20 mm. (copper complex, m. p. 184–185°), ¹⁰ and 8.4 g. (19% conversion) of *n*-butylbenzoylacetone, b. p. 148–152° at 5 mm.

Summary

1. Evidence has been obtained that the thermal conversion of ketone enol esters to β -diketones involves an intramolecular rearrangement and that the conversion by boron fluoride at low temperatures consists of an intermolecular acylation of one molecule by another.

2. Ketone enol esters have been acylated with enol esters, acid anhydrides and acid chlorides by means of boron fluoride to form β -diketones.

3. Certain new enol esters have been prepared and the structure of enol esters of unsymmetrical methyl-methylene ketones were determined by ozonolysis.

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[CONTRIBUTION FROM THE RESEARCH LABORATORIES, K-25 PLANT, CARBIDE AND CARBON CHEMICALS CORPORATION]

Reactions of Polyfluoro Olefins. I. Preparation of Sulfides and Sulfones^{1,2}

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The reactions of chlorotrifluoroethylene, 1,1-dichloro-2,2-difluoroethylene and hexafluorocyclobutene with compounds containing a thiol group were investigated as a part of a study of the reactions of polyfluoro olefins. Hanford³ has reported that ethanethiol reacted with tetrafluoroethylene on heating eight hours at 110° in the presence of benzoyl peroxide to form a mixture of liquid and solid products believed to have the general formula $H(CF_2CF_2)_n C_2H_4SH$, where *n* ranges from 1 to 25. The principal product boiled at 84–86° and the analytical data agreed with the above formula where *n* = 1. Catalysts mentioned included "organic and inorganic peroxy compounds, basic catalysts, various acid catalysts, oxygen, ozone and iodine." Hanford stated further, "No appreciable reaction is obtained below 75° and it is usually necessary to heat the reaction mixture to 100° or higher in order to obtain a substantial reaction in a reasonable time." These observations are especially interesting in view of the fact that polyfluoro olefins were found to react readily with thiols near room temperature under the influence of basic catalysts to form polyfluoro sulfides.

(1) Presented at the 116th Meeting of the American Chemical Society, Atlantic City, New Jersey, September, 1949.

(2) This document is based on work performed for the Atomic Energy Commission by Carbide and Carbon Chemicals Corporation at Oak Ridge, Tennessee.

(3) Hanford, U. S. Patent 2,443,003 (1948); cf. E. I. du Pont de Nemours and Company, British Patent 583,874 (1947).

The reactions of thiols with polyfluoro ethylenes was one of simple addition. Although addition to chlorotrifluoroethylene could result in the formation of two isomers, only one was indicated by the distillation curve of $C_2H_5SC_2F_3ClH$ using a seven-foot column packed with glass helices. A mass spectrograph scan⁴ of this distilled material showed an ion with a mass to charge ratio corresponding to an SCF_2 fragment and one corresponding to $C_2H_5SCF_2$, but none corresponding to either an $SCFCl$ or a C_2H_5SCFCl fragment. On the other hand, lower peaks were found at mass to charge ratios corresponding to both $CFCIH$ and CF_2H fragments. In view of the fact that the last fragment easily could be a result of recombination, it appears that the reaction produces only the α, α -difluoro sulfide. This is in agreement with analogous reactions with alcohols to form polyfluoro ethers.⁵

2-Mercaptoethanol, having both an –OH and an –SH group, provided a means of determining whether an alcohol or a thiol would add preferentially to a polyfluoro olefin. The product formed with chlorotrifluoroethylene did not have the

(4) Mass spectrograph scan by Miss Jeanne Pemberton and Mr. W. G. Schwab of the Mass Spectrometer Section of the Physical Research Department.

(5) Hanford and Rigby, U. S. Patent 2,409,274 (1946); Miller, Fager and Griswold, *THIS JOURNAL*, **70**, 431 (1948); Park, Vail, Lea and Lacher, *ibid.*, **70**, 1550 (1948); Hurwitz and Miller, "Reactions of Chlorofluoro Olefins with Anionic Reagents," Abstracts of Papers, American Chemical Society, Washington, D. C., August, 1948, p. 4L; Young and Tarrant, *ibid.*, **71**, 2432 (1949).