phenolic hydroxyl in the original spruce lignin sulfonic acid.

3. Evidence has been obtained that vanillin formation occurs as a two-stage reaction, namely, a preliminary hydrolysis of the sulfonic acid radical followed by an intramolecular fission, the latter change consisting of a "reversed aldol" reaction.

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[CONTRIBUTION FROM THE CHEMICAL LABORATORY OF HARVARD UNIVERSITY]

On the Mechanism of the Reactions of Metal Enol Acetoacetic Ester and Related Compounds.[1] III. Copper Enolates

BY ARTHUR MICHAEL AND G. H. CARLSON

Cupric enol acetoacetic ester with chlorine gave cupric chloride,[2] but with bromine, iodine,[2] diphenylmethylene chloride[3] and ethylsulfocyanide[4] cuprous derivatives were produced. The nonexistence of cupric mercaptide[5] and of solid cupric iodide made the appearance of the cupric compounds impossible. However, it seemed theoretically improbable that the chemical course of cupric enolate reactions should vary so markedly with the chemical character of the reagent and we were, therefore, led to reëxamine the reactions in which the formation of cupric derivatives has been accepted.

Experimental Results

The appearance of cupric chloride in the experiment of Schönbrodt[2] must have been due to an excess of chlorine, since we found that the theoretical amount of cuprous chloride was formed by adding a carbon tetrachloride solution of a mole and a half of chlorine to a suspension of a mole of cupric enol acetoacetic ester at 0° and the same result was obtained on repeating the experiment with a solution of the cupric enolate in boiling carbon tetrachloride. As the second product, α-chloroacetoacetic ester was produced. The experimental details are given in Table V.

At ordinary temperature, acetyl chloride reacted readily with cupric enol acetoacetic ester, in ether or benzene suspension, yielding cuprous chloride, O-acetylacetoacetic and α-chloroacetoacetic esters. Diacetoacetic ester could not be isolated and, if C-acylation occurred, the free ester, not the copper enolate, must be formed, since all the available copper appeared as cuprous chloride.[6] The results of three semi-quantitative experiments are tabulated in Table I.

TABLE I

The cupric enolate was suspended in ether (benzene used in III), acetyl chloride added at room temperature, cuprous chloride filtered off, the solvent removed at reduced pressure from the filtrate and the residual oil analyzed for halogen. An aliquot portion of the oil (total in I) was extracted with alkali, the products worked up in the usual way and the results given under alkaline extraction.

Chloroacetoacetic ester calculated is weight of ester equivalent to halogen present in the residual oil: (II) 0.59057 g. subs. gave 0.1231 g. AgCl; (III) 0.4573 g. subs. gave 0.0763 g. AgCl. The chloro ester regenerated after alkaline extraction in I was not pure. The ester was redistilled and the fraction of b. p. 100–105° at 30 mm. analyzed. Calcd. for $C_6H_9O_3Cl$: Cl, 21.6. Found: Cl, 15.3. The redistilled ester (1.5 g.) and 0.75 g. of thiourea gave 1.1 g. of methylaminothiazole carboxylic ester. The regenerated chloro ester in III (1.5 g.), gave 0.8 g. of the thiazole carboxylic ester.

O-Acetylacetoacetic ester calculated is weight of total residual oil less weight of calculated chloroacetoacetic ester. One gram of the O-acyl ester and 1.3 g. of phenylhydrazine gave 0.75 g. of acetphenylhydrazide in I and II.

Cuprous chloride calculated is amount equivalent to copper enolate used. Percentage of products accounted for is total weight of isolated products divided by total weight of reagents used.

Expt. no.				I	II	III
Copper enolate, g.				30	30	10
Acetyl chloride, g.				11	11	3.7
Time, hrs.				48	50	12
Cuprous chloride, g.			calcd.	9.2	9.2	3.1
			found	9.2	9.2	3.4
Products in filtrate	Total g.			29.5	30.1	9.7
	Alkaline extraction	Sample, g.		29.5	24.0	9.0
		O-Acetylacetoacetic ester, g.		19.8	14.0	6.8
		B. p.	°C.	117–119	119–121	114–116
			mm.	32	33	20
		Chloroacetoacetic ester, g.		7.1	4.3	1.5
		B. p.	°C.	95–103	95–107	
			mm.	30	30	
	Total	O-Acyl ester, g.	calcd.		22.9	7.8
			found	19.8	17.6	7.4
		Chloroacetoacetic ester, g.	calcd.		7.3	1.9
			found	7.1	5.4	1.6
Products accounted for, %				95.5	97	95.5

The action of acetyl chloride upon cupric enol

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[1] THIS JOURNAL, 57, 159, 165 (1935).

[2] Schönbrodt, *Ann.*, **253**, 168 (1889).

[3] Klages and Fanto, *Ber.*, **32**, 1433 (1899).

[4] Kohler, *Am. Chem. J.*, **22**, 69 (1899).

[5] Klason [*Ber.*, **20**, 3412 (1887)] showed that cuprous mercaptide is formed from cupric sulfate and ethyl mercaptan.

[6] Nef [*Ann.*, **266**, 52 (1891)] found that the alkali-soluble product contained mainly acetoacetic and a little diacetoacetic ester. The neutral product was shown later [*ibid.*, **276**, 200 (1893)] to be O-acetylacetoacetic ester.

diacetoacetic ester proceeds progressively. Ether or benzene suspensions of the enolate, at ordinary temperature, gave a green insoluble crystalline copper compound containing halogen and mainly the O-acetate of diacetoacetic ester. The green copper derivative was not pure, as it contained a small amount of cupric chloride, but analysis showed that the empirical formula is $C_8H_{11}O_4CuCl$. The results of the experiments with acetyl chloride and cupric enol diacetoacetic ester are given in Table II.

At room temperature, acetyl chloride had no action upon the green, basic enolate in ether suspension. The products formed on heating the basic enolate with an equivalent of acetyl chloride in benzene were cupric chloride, some cuprous chloride and diacetoacetic ester. The basic enolate boiled with benzene (nine hours) or toluene (one hour) underwent a partial (3–5%) decomposition. The experimental details are given in Table V.

Acetyl chloride reacted slowly with cupric enol benzoylacetoacetic ester at ordinary temperature, but an intermediate, basic derivative could not be isolated. With two equivalents of acetyl chloride the cupric enolate, in boiling benzene, gave

TABLE II

Ether used as diluent (benzene used in III). The mixtures were kept in glass-stoppered flasks, stored in vacuum desiccators. In II, the reaction mixture was boiled for twenty hours and then stored as above. The green solid was filtered off, analyzed, the solvent removed from the filtrate and the residual oil distilled. Unless the main fraction gave no coloration with ferric chloride, an ether solution of the ester was washed with 10% alkali, the insoluble O-acetate redistilled and the alkali-soluble ester converted to cupric enol diacetoacetic ester.

The O-acyl ester calculated is that theoretically possible from the enolate involved in the reaction. In II, III and IV, the O-acyl ester (1 g.) and 1.1 g. of phenylhydrazine gave 0.5 g., 0.4 g. and 0.5 g. of acetphenylhydrazide, respectively. In II, III, V and VI, the yield of pure O-acyl ester was 59.5, 82, 55.6 and 52.7% of that calculated for the respective experiments. In view of the ease of hydrolysis and decomposition [Claisen, *Ber.*, **33**, 3778 (1900)] of the O-acyl ester, it is safe to state that more of the ester was actually present in the reaction product than appears from the table, which gives the amounts of pure ester isolated.

In V and VI, the solid product was extracted with hot, dry benzene (75 cc. and 25 cc., respectively) and unchanged enolate recovered. Basic derivative calculated is theoretical yield possible from the enolate involved in the reaction. Samples of the basic derivative (I and VI) were acidified with dilute acid, the liberated ester distilled and converted to cupric enol diacetoacetic ester. Portions of the basic enolate (V and VI) treated with cold water gave cupric enol diacetoacetic ester.

Expt. no.	I	II	III	IV	V	VI
Copper enolate, g.	10	20	12	10	42	20
Enolate/chloride	1:1.5	1:1	1:1	1:1.5	1:1	1:1
Time, days	21	35	18	14	55	180
Unchanged enolate, g.					4.5	2.0
Basic deriv., g. calcd.	6.7	13.3	7.9	6.7	25.0	12.0
Basic deriv., g. found	6.4	13.0	8.0	6.3	22.5	11.1
Anal. $C_8H_{11}O_4CuCl$ (A) calcd. Cu	23.4					
Anal. $C_8H_{11}O_4CuCl$ (A) calcd. Cl	13.2					
Anal. $C_8H_{11}O_4CuCl$ (A) found Cu	23.4		22.8 22.95		23.8 24.0	23.6
Anal. $C_8H_{11}O_4CuCl$ (A) found Cl	16.4		12.65 12.65	14.05	13.4	13.6
Acidification of (A) Sample, g.	5.0					5.0
Acidification of (A) Diacetoacetic ester, g. calcd.	3.2					3.2
Acidification of (A) Diacetoacetic ester, g. found	2.9					2.9
Acidification of (A) Copper enolate, g. calcd.	3.4					3.4
Acidification of (A) Copper enolate, g. found	3.1					3.1
Products in filtrate Total, g.	6.4					10.0
Products in filtrate Fracs., g. (1)	2.0	3.6	0.8	0.9	0.6	7.4
Products in filtrate Fracs., g. (1) B. p. °C.	>100	>120	100–108	>110	>108	110–125
Products in filtrate Fracs., g. (1) B. p. Mm.	1	5	2	3	2	6
Products in filtrate Fracs., g. (2)	2.6	6.3	5.2	4.1	17.4	0.5
Products in filtrate Fracs., g. (2) B. p. °C.	110–112	120–122	108–110	110–123	108–118	
Products in filtrate Fracs., g. (2) B. p. Mm.	1	5	2	3	2	
Products in filtrate O-Acetyldiacetoacetic ester, g. calcd.	5.3	10.6	6.4	5.3	19.8	9.5
Products in filtrate O-Acetyldiacetoacetic ester, g. found	1.8	6.3	5.2	2.8	11.0	5.0
Products in filtrate O-Acetyldiacetoacetic ester, g. B. p. °C.		120–122	108–110	121–122	112–113	127–128
Products in filtrate O-Acetyldiacetoacetic ester, g. B. p. Mm.		5	2	3	2	6
Copper diacetoacetic ester from fracs. (1) or (2)		2.5		1.9	4.4	1.9
Treatment with water Sample, g.					5.0	2.0
Treatment with water Copper diacetoacetic ester, g. calcd.					3.3	1.5
Treatment with water Copper diacetoacetic ester, g. found					3.4	1.5

O-acetylbenzoylacetoacetic ester,[7] cupric and about 20% of cuprous chloride. The results, tabulated in Table III, show that the main products are cupric chloride and the O-acetate of benzoylacetic ester, but a semi-quantitative isolation of the latter compound was not realized.

TABLE III

Ten grams of cupric enol benzoylacetoacetic ester, 3 g. of acetyl chloride and benzene were heated in an all-glass apparatus protected from moisture. Copper was determined as CuO. The O-acyl ester isolated in a preliminary experiment (b. p., 150–155° at 1 mm.; d_{20} 1.1474; $n^{20}{}_{D}$ 1.5206) was analyzed. Calcd. for $C_{15}H_{16}O_5$: C, 65.2; H, 5.8. Found: C, 64.91; H, 5.77. O-Acyl ester calculated is theoretical yield possible from amount of enolate used. The distilled ester contained 0.46 and 0.67% of halogen in I and II, respectively. The O-acyl ester gave a red coloration with ferric chloride. Cold 5% NaOH rapidly hydrolyzed the ester: 8.3 g. of O-acyl ester (II) gave 4.5 g. of O-acetate and 1.9 g. of benzoylacetoacetic ester. In III, the O-acyl ester (2 g.) and 1.6 g. of phenylhydrazine gave 0.8 g. (74% yield) of acetphenylhydrazide.

Expt. no.			I	II	III
Time, hrs.			8	10	10
Solid product (A) g.			2.8	2.3	2.4
Anal. (A)	Calcd. CuCl$_2$	Cu	47.0		
		Cl	53.0		
	Found	Cu		50.4	50.1
		Cl			47.2
O-Acetyl ester	Calcd., g.		10.5	10.5	10.5
	Found, g.		8.8	9.0	9.4
	B. p.	°C.	151–157	160–170	163–165
		mm.	1	3	2

Nef[6] found that cupric enol acetoacetic ester and benzoyl chloride in large excess gave dibenzoylacetoacetic ester as the neutral reaction product. Later,[8] using one-half as much chloride, he isolated acetoacetic, mono- and dibenzoylacetoacetic esters and the O-benzoate of acetoacetic ester. We found that the relative proportions of these products varied with the amount of chloride used. The semi-quantitative data are summarized in Table IV.

After heating molecular amounts of cupric enol acetoacetic ester with chlorocarbonic ester in benzene for two hours at 100°, Nef[6] obtained cupric enol acetylmalonic ester together with unchanged chloro ester and concluded, therefore, that the latter compounds did not interact. We found that two equivalents of the chloro ester and the enolate, in boiling benzene during one and one-half hours, yielded cupric enol acetylmalonic ester, some free acetylmalonic ester, cuprous chloride and unidentified products. All the available copper appeared as cuprous chloride after prolonged boiling of a reaction mixture containing excess chloro ester. Cupric enol benzoylacetic ester and 1.5 moles of chlorocarbonic ester, in boiling benzene during ten hours, gave cuprous chloride, free benzoylmalonic ester, some unidentified products, but relatively little of the cupric enolate of the benzoylated ester.[9] The results are included in Table V.

The primary action of one equivalent of ethereal hydrogen chloride upon cupric enol acetoacetic ester, in ether suspension and in an atmosphere of dry nitrogen, gave an impure product containing the corresponding insoluble, unstable basic cupric derivative. The product invariably contained cuprous chloride[10] and unchanged cupric enolate. The results of these experiments are summarized in Table VI. Attempts to purify the basic derivative by extraction with warm solvents led to decomposition. With cold water, the derivative gave mainly cupric enol acetoacetic ester and cupric chloride. With benzoyl chloride, at ordinary temperature, cuprous chloride, cupric enol benzoylacetoacetic ester, O-benzoylacetoacetic and α-chloroacetoacetic esters were formed. The experimental details are given in Table V.

It appeared possible, in the above experiment, that ethereal hydrogen chloride acted upon cupric enol acetoacetic ester to form cupric chloride, liberating acetoacetic ester from one-half of the enolate, and that a molecular complex of cupric chloride was formed with the unchanged enolate. At ordinary temperature, however, anhydrous cupric chloride and cupric enol acetoacetic ester, in ether suspension, do not interact, but, in boiling benzene, the enolate reduces cupric to cuprous chloride and simultaneously α-chloroacetoacetic ester is produced. The result of a semi-quantitative experiment is given in Table V.

On adding an equivalent of ethereal hydrogen chloride to a suspension of cupric enol benzoylacetoacetic ester in ether a basic derivative was formed containing unchanged enolate (5–10%).

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(7) Bernhard [*Ann.*, **282**, 165 (1894)] stated that the O-acetate could not be distilled, but we found that the ester distilled with only a slight decomposition.

(8) Nef, *ibid.*, **276**, 200 (1893).

(9) Bernhard [*ibid.*, **282**, 165 (1894)] obtained the acidic products, benzoylmalonic and benzoylacetic esters, along with a neutral oil, which contained dibenzoylsuccinic ester, but consisted mainly of O-carbethoxybenzoylacetic ester.

(10) The liquid product contained besides acetoacetic, some chloroacetoacetic ester and a small amount of non-volatile oil, possibly diacetosuccinic ester. The appearance of the chloro ester and the fact that some cupric enolate remained unchanged shows that a secondary reaction occurred in which, possibly, the hydrogen chloride acted upon two molecules of the basic derivative with formation of cuprous chloride, acetoacetic and chloroacetoacetic esters.

TABLE IV

Experiments I–III were made at room temperature, using ether as diluent. Aliquot portions of the solid products were acidified to determine the amounts of copper halide and enolate present. Ether solutions of the fraction (2) were washed with 10% NaOH and the O-acyl ester redistilled. II. Cuprous chloride analyzed electrolytically. Calcd. for Cu_2Cl_2: Cu, 64.16. Found: Cu, 63.96. Two grams of fraction (1) and 2 g. of thiourea gave 0.55 g. of methylaminothiazole carboxylic ester.

The cupric enolate was added to boiling benzoyl chloride solutions by the extraction method ["Organic Syntheses," Vol. XIII, 1933, p. 60] in IV and V. V. Unchanged chloride was estimated by heating 3 g. of fraction (1) with excess alcoholic potash, acidifying and weighing the liberated benzoic acid (2.1 g.). Free benzoylacetoacetic ester in fraction (2) was separated as the cupric enolate. The neutral oil was washed with 10% NaOH and redistilled. Two grams of the O-acyl ester and 2 g. of phenylhydrazine gave 1.7 g. of benzoylphenylhydrazide.

The chloride was added during one to two minutes (except in VI when the time was thirty minutes) to boiling, mechanically stirred benzene solutions of the cupric enolate in VI–IX. The mixtures were stirred one-half to three-quarter hour at the boiling point, filtered hot to remove the cuprous chloride, cooled and the cupric enol benzoylacetoactic ester collected by filtration.

VI. An ether solution of 1 g. of fraction (1) with aniline and K_2CO_3 gave 0.5 g. of benzanilide. An ether solution of fraction (2) was extracted with 10% NaOH, the alkaline extract acidified and the liberated oil converted to cupric enol benzoylacetoacetic ester. The neutral ester (0.5 g. and 0.5 g. of phenylhydrazine) gave 0.3 g. of benzoylphenylhydrazide.

VII. One gram of fraction (1) gave 0.2 g. of benzanilide.

VII–IX. The C-acyl ester in fraction (2) was isolated directly by extracting with aqueous copper acetate. The neutral oils in VII, VIII and IX gave 1 g., 0.4 g. and 0.4 g. of benzoylphenylhydrazide, respectively.

VIII. Halogen determination of fraction (1): 0.6295 g. subs. gave 0.213 g. AgCl.

IX. One gram of fraction (1) gave 0.3 g. of methylaminothiazole carboxylic ester: 4.1 g. of the fraction gave 1.6 g. of cupric enol acetoacetic ester and 1.6 g. of a mixture of the cupric enolates of chloroacetoacetic and acetoacetic ester.

Percentage of products accounted for is total weight of isolated products divided by the total weight of the reagents used.

Expt. no.			I	II	III	IV	V	VI	VII	VIII	IX
Copper enolate, g.			50	50	50	20	15	15	15	15	15
Enolate/chloride			1:2	1:1	1:1	1:2	1:3	1:1.5	1:1.5	1:1	1:1
Time, hours			24	96	84	3	3	1	0.75	0.75	0.75
Solid products		Total, g.	29.0	39.6	39.5	5.8	4.7	8.0	7.9	10.0	11.5
	Acidification	Solid, g.	25.0	30.0	30.0						
		Benzoylacetoacetic ester, g.	11.8	19.2	19.6						
		B. p. °C.	141–142	143–145	142–143						
		B. p. Mm.	3	2	1.5						
		Total cuprous chloride, g.	13.5	11.0	10.4	5.8	4.7	3.7	4.0	2.9	3.2
		Total cupric enol benzoylacetoacetic ester, g.	15.5	28.6	29.1			4.3	3.9	7.1	8.3
Fractions from filtrate	(1)	Total g.	35.4	23.9	23.6	11.8	15.6	6.6	6.1	6.3	5.4
		B. p. °C.	93–105	95–100	95–110	97–103	80–85	70–80	72–82	68–80	68–72
		B. p. Mm.	30	35	32	35	5	6	5	6	4
		Recovered chloride, g.					12.6	2.4	0.9		
		Chloroacetoacetic ester, g.		8.4						2.5	
	(2)	Total, g.	17.3	7.2		9.7	7.9	8.9	9.6	4.3	2.9
		B. p. °C.	165–168	145–148		165–173	165–185	150–158	150–160	158–160	155–158
		B. p. Mm.	3	3		5	5	5	5	6	4
		Cupric enol benzoyl acetoacetic ester, g.				1.6	0.7	6.7	7.1	3.1	2.0
		C-Acyl ester, g.	3.8			1.4	.6	5.9	6.3	2.8	1.8
		B. p., °C.	142–143 at 3 mm.								
		O-Acyl ester, g.	10.8	6.6	6.6	6.4	5.1	2.1	1.9	0.6	0.8
		B. p. °C.	146–147	145–148	138–139	148–149	154–155				
		B. p. Mm.	1.5	3	2	1	4				
	(3)	Non-volatile oil, g.	11.4	0.2		8.7	5.7	1.0	1.0	0.3	0.3
Products accounted for, %			99	98.5	97	96	97	98	98	96.7	93

A basic enolate, containing about 5% of cupric chloride was obtained from cupric enol benzoylacetone. However, the cupric enolates of diacetoacetic ester and acetylacetone with an equivalent of ethereal hydrogen chloride yielded readily the pure basic cupric derivatives as green, insoluble, crystalline compounds. When acidified, the basic enolates gave cupric chloride and liberated the theoretical amount of diacetoacetic ester and acetylacetone, respectively. At ordinary temperature, water converted the basic compounds to the original cupric enolates. The results are tabulated in Table VI.

Discussion

Until 1888, organic substitution was considered to always proceed by direct replacement of an atom or group in an organic molecule by an equivalent atom or group of a reactant. It was then shown[11] that sodium enol acetoacetic ester has an O-Na structure and, to explain the formation of C-alkyl products with an alkyl iodide, it was assumed that iodine and alkyl added at the unsaturated α,β-carbon atoms of the enolate, followed by a spontaneous elimination of sodium

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[11] Michael, *J. prakt. Chem.*, **37**, 473 (1888); *Am. Chem. J.*, **10**, 158 (1888); **14**, 481 (1892).

TABLE V

Solutions of chlorine in CCl_4 added to mechanically stirred suspensions of the cupric enolate in CCl_4. I. Two grams of distillate gave 1.9 g. of methylaminothiazole carboxylic ester: 11 g. of chloro ester gave 8.3 g. of crude cupric enol chloroacetoacetic ester.

II. *Anal.* Calcd. for $C_6H_9O_3Cl$: Cl, 21.6. Found: Cl, 19.7. One gram of chloro ester gave 1.2 g. of methylaminothiazole carboxylic ester.

III. *Anal.* of fraction (2). Calcd. for $C_6H_9O_3Cl$: Cl, 21.6. Found: Cl, 22.4. Two grams. of chloro ester gave 1.8 g. of thiazole ester.

IV. Liquid products extracted with alkali left 1 g. of unidentified, insoluble oil. Liberated oil from alkaline extract distilled as summarized in table. A portion (1.4 g.) of (1) gave 1.1 g. of cupric enol acetoacetic ester; 1 g. of (2) gave 0.6 g. of cupric enol acetyl malonic ester.

V. Liquid products extracted with alkali left 1.3 g. of unidentified, insoluble oil. Acidified alkaline extract gave benzoylmalonic ester which gave 12.4 g. of cupric enolate.

VI. Fraction (1) extracted with alkali left 0.85 g. of unidentified, insoluble oil. Acidified extract gave 8.4 g. of oil (b. p., 160–165° at 2 mm.) which gave 7.5 g. of cupric enol benzoylmalonic ester.

VII. Fraction (2) gave 5.2 g. of O-benzoylacetoacetic ester (b. p. 144–146° at 2 mm.) and an oil which gave 1.6 g. of cupric enol benzoylacetoacetic ester.

VIII. Two grams of (1) gave 1.1 g. of methylaminothiazole carboxylic ester.

IX. Two grams of diacetoacetic ester gave 2 g. of cupric enolate.

X. Two grams of solid extracted with cold water left 0.7 g. of insoluble residue. *Anal.* Calcd. for Cu_2Cl_2: Cu, 64.0. Found: Cu, 57.8. Fraction (1) gave 5.5 g. of cupric enol diacetoacetic ester.

XI. Crude product analyzed (1) and after crystallization from benzene (2). Calcd. for $C_{16}H_{22}O_8CuCl$: Cu, 15.51. Found: Cu, (1) 16.32; (2) 15.50.

XII. *Anal.* of recovered solid. Calcd. for $C_8H_{11}O_4CuCl$: Cu, 23.4. Found: Cu, 24.15.

XIV. Basic derivative heated in sealed ampoule. *Anal.* recovered solid. Calcd. for $C_5H_7O_2CuCl$: Cu, 31.9. Found: Cu, 31.7

Expt.	Cupric Enolate	G.	Reagent	G.	Solvent	Temp., °C.	Time, hrs.	Solid products	G.	Liquid products	G.	°C.	B. P. mm.
I	Cupric enol acetoacetic ester	15	Cl_2	4.98	CCl_4	0°	18	Cu_2Cl_2	4.7	α-Chloroacetoacetic ester	13.7	108–120	44
II	Cupric enol acetoacetic ester	5	Cl_2	1.6	CCl_4	B. p.	0.25	Cu_2Cl_2	1.5		4.0	96–101	23
III	Cupric enol acetoacetic ester	8	$CuCl_2$	10	Bz	B. p.	4	Cu_2Cl_2	10	(1) (2) Non-volatile (3)	0.5 6.2 0.5	Up to 92 92–98	22 28
IV	Cupric enol acetoacetic ester	20	ClCOOEt	13.5	Bz	B. p.	1.5	Cu_2Cl_2 cupric enol acetyl malonic ester	3.5 9.8	(1) (2)	2.4 2.3	80–100 100–135	17 17
V	Cupric enol benzoylacetic ester	20	ClCOOEt	9.8	Bz	B. p.	10	Cu_2Cl_2 cupric enol benzoylmalonic ester	4.0 2.5	Benzoyl malonic ester	11.5	155–167	2
VI	Cupric enol benzoylacetic ester	14	ClCOOEt	6.9	Bz	B. p.	10	Cu_2Cl_2 cupric enol benzoylmalonic ester	2.7 2.1	(1) Non-volatile (2)	11.1 1.7	160–175	3
VII	Chloro-cupric enol acetoacetic ester	30	Benzoyl chloride	18.6	Ether	Room	24	Cu_2Cl_2 cupric enol benzoylacetoacetic ester	11.4 6.9	(1) (2) Non-volatile (3)	18.5 9.2 2.1	72–80 160–170	4 4
VIII	Chloro-cupric enol acetoacetic ester	36	Benzoyl chloride	11.1	Ether	Room	100	Cu_2Cl_2 cupric enol benzoylacetoacetic ester	13.6 6.7	(1) (2)	17.3 6.3	60–65 150–156	2 2
IX	Chloro-cupric enol	10	CH_3COCl	3	Bz	B. p.	6	$CuCl_2$	5.1	Diacetoacetic ester	4.6	78–80	2
X	diaceto acetic ester	15	CH_3COCl	4.4	Bz	B. p.	6	$CuCl_2 + Cu_2Cl_2$	8.6	Diacetoacetic ester Non-volatile	7.1 1.5	79–110	3
XI	Chloro-cupric enol diaceto acetic ester	2	H_2O	20		Room		Cupric enol diacetoacetic ester	1.7				
XII	Chloro-cupric enol diaceto acetic ester	1	Heat		Bz	B. p.	9	Partially decomposed subs.					
XIII	Chloro-cupric enol diaceto acetic ester	2.7	Heat		Tol.	B. p.	1	Unchanged subs.; cupric enol diacetoacetic ester	0.1				
XIV	Chloro-cupric-enol acetylacetone	0.5	Heat		Bz	100	12	Unchanged subs.					
XV	Chloro-cupric enol benzoylacetone	2	H_2O	20		Room		Cupric enol benzoylacetone	1.2				

TABLE VI

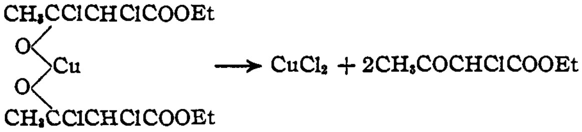
Ethereal hydrogen chloride was added to mechanically stirred ether suspensions of the enolates. In II, III and V the apparatus, equipped with a stirrer and a sealed-in, sintered filter plate arranged to permit of a separation of the products in an atmosphere of nitrogen, was maintained under a pressure (3 cm.) of dry nitrogen. In II and III, the liberated ester contained chloroacetoacetic ester (3.7 g. and 0.4 g., respectively) as indicated by a halogen determination. The liberated ester in II deposited 1 g. of an unidentified, blue copper enolate. The basic derivative in IV was analyzed. Calcd. for $C_8H_{11}O_4CuCl$: Cl, 13.12. Found: Cl, 13.24.

V. Basic derivative analyzed. Calcd. for $C_5H_7O_2CuCl$: Cl, 17.95. Found: Cl, 19.0. The ether solution of the liberated acetylacetone was concentrated, treated with aqueous copper acetate and gave 0.3 g. of cupric enol acetylacetone. In two experiments similar to V, using the reagents in the same proportions, the basic derivative contained unchanged enolate (9–18%). The product was extracted with hot benzene and then analyzed correctly.

Expt. no.			I	II	III	IV	V	VI	VII
Cupric enolate of	Acetoacetic ester, g.		10	50	50				
	Diacetoacetic ester, g.					6.9			
	Benzoylacetoacetic ester, g.						5		
	Acetylacetone, g.							1.4	
	Benzoylacetone, g.								5
HCl, g., in			1.14	5.69	5.69	0.62	0.34	0.20	0.55
cc. solution			32	44.2	44.2	7.9	5.0	12	15
Ether suspension, cc.			40	100	100	50	25	50	50
Basic deriv. (A)	calcd., g.		7.1	35.4	35.4	4.6	3.1	1.1	3.4
	found, g.		7.1	31.0	36.0	4.6	3.2	1.1	3.1
Anal. of (A)	Cu calcd. for	$C_6H_9O_3CuCl$	27.8						
		$C_8H_{11}O_4CuCl$				23.37			
		$C_{18}H_{18}O_4CuCl$					19.01		
		$C_5H_7O_2CuCl$						31.9	
		$C_{10}H_9O_2CuCl$							24.3
	Found Cu		30.3			23.05	18.38	31.75	25.6
Liberated	Ester calcd., g.		4.05	24.9	24.9	2.9	2.2		
	Ketone calcd., g.							0.5	2.1
	Ester (a) found, g.		3.7	21.4	16.5	2.6	2.1		
	Ketone (b) found, g.								2.6
	B. p.	°C.	78–80	87–88	102–104	112–115			
		Mm.	15	30	50	30			
Cupric enolate	from sample	(a) g.	1			2	2.1		
		(b) g.						0.5	
	calcd., g.		1.2			2.4	2.4	0.65	
	found, g.		1.3			2.0	2.3	0.3	

iodide.[12] The viewpoint was later developed for a large number of organic reactions involving groups of unsaturated atoms.[13]

According to all chemical precedent, each of the two Δ-α-β-carbon systems of cupric enol acetoacetic ester should unite with a molecule of chlorine and the addition compound should spontaneously break up



The above experimental results prove, however, that the reaction proceeds to completion with a molecule and a half of chlorine and yields cuprous, not cupric, chloride. This course shows that the reaction does not take place by addition of chlorine to the two unsaturated carbon systems, nor by direct union with the copper. Indeed, the formation of α-chloroacetoacetic ester and cuprous chloride in the action of cupric chloride upon cupric enol acetoacetic ester shows that the affinity of one of the chlorine atoms of cupric chloride for copper is less developed than for the unsaturated α-carbon atoms of the enolate. It might appear that the primary action of chlorine upon cupric enol acetoacetic ester results in the formation of cupric chloride and that the latter, subsequently, is reduced by unchanged enolate. However, the reduction was only observed in boiling benzene and cannot account for the production of cuprous chloride in the reactions of the cupric enolate at ordinary temperature. The conclusion, there-

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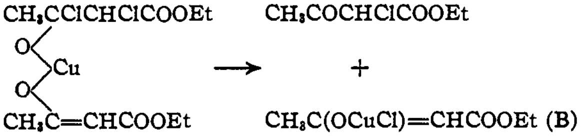
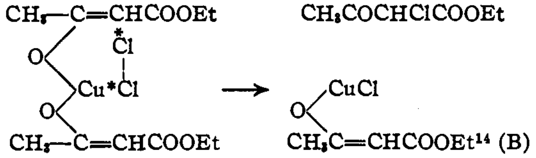
[12] This interpretation was based on the assumption that the Δ-β-C of the enolate was relatively the most positive atom in the molecule. This was a wrong conclusion, since the polar and free chemical energy relations at the slightly neutralized sodium atom must be far more developed and the reaction should, therefore, proceed through direct union of the halogen at this atom. Recently[1] the formation of C-alkyl derivatives was explained from this viewpoint, assuming the preliminary formation of a hexacyclic polymolecule.

[13] For literature see, THIS JOURNAL, **32**, 990 (1910); **53**, 2394 (1931); **54**, 387 (1932).

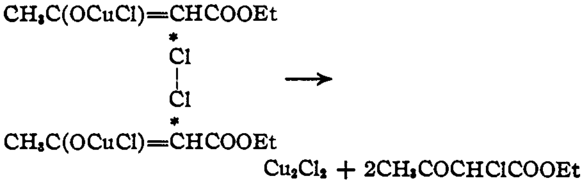
fore, seems unequivocal that cuprous chloride is formed through a basic intermediate. The chemical behavior of cupric enolates toward other reagents also shows unmistakably that the reaction proceeds in two stages. The first phase may take place by addition of the halogen to one of the Δ-α-β-carbon systems



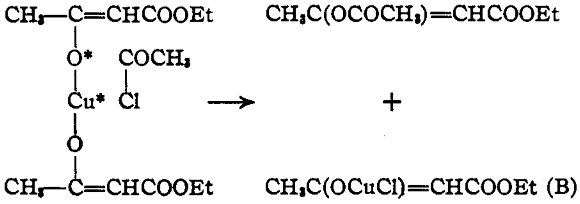
or, far more likely, directly through formation of a hexacyclic polymolecule.[1]



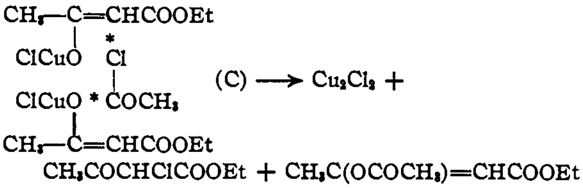
Although basic derivative B could not be separated in a pure state in any of the reactions studied with cupric enol acetoacetic ester, pure compounds, corresponding to B, were isolated in the action of acetyl chloride and hydrogen chloride upon related cupric enolates. The results afford evidence that these reactions proceed progressively through basic, intermediate compounds analogous to B. Evidently, halogen does not act upon derivative B as it does in the first stage on the neutral cupric enolate, but in a chemically unique manner. The appearance of cuprous chloride shows that the affinity of the Δ-α-C of the basic enolate for chlorine is so developed, in comparison with that at the copper, or the Δ-β-C, that, with the union of the halogen at the α-C atoms, cuprous chloride is forced out of the system



Corresponding to the above reaction with chlorine, only a molecule and a half of acetyl chloride is required to complete the reaction with cupric enol acetoacetic ester. An intermediate, basic derivative could not be isolated, because the reaction was rapid, but the characteristic color changes assumed by the reaction mixture, the formation of cuprous chloride and the proportion of acetyl chloride required show that the course of the reaction is analogous to that of chlorine. The relatively slightly positive copper in cupric enol acetoacetic ester should reduce the negative influence upon the Δ-α-carbon much less than the sodium in the sodium enolate. There should be, therefore, far less tendency to form a C-acyl derivative[1] and the reaction should proceed primarily as follows



The basic intermediate B should show less tendency than the neutral enolate to yield a C-acyl derivative with acetyl chloride, since the influence of positive energy of the metal in B upon the Δ-α-carbon is less than in the neutral enolate. In the second phase, two molecules of the basic enolate function with one of the chloride to form polymolecule C, in which, due to affinity relations, the chlorine is in contact with the Δ-α-carbon atoms, the acetyl with the enolic oxygen and cuprous chloride is forced out of the system



The primary phase of the action of acetyl chloride upon cupric enol acetoacetic and diacetoacetic esters is analogous, although the reaction proceeds more slowly with the latter enolate and, besides the O-acetyl ester, the intermediate basic derivative could be isolated. The behavior of the respective, intermediate, basic derivatives with acetyl chloride differs; cupric chloride, not cuprous, was obtained along with the O-acetyl ester from the basic derivative of diacetoacetic ester. Replacing the α-hydrogen in the basic intermediate by the negative acetyl group, must greatly decrease the affinity of the α-carbon for chlorine. For this reason, in the polymolecule with acetyl chloride the chlorine is in contact with the copper and cupric chloride is formed on decomposition of the complex. Similar affinity relations be-

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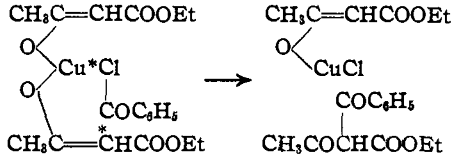
(14) The tendency to form basic cupric enolates, *e. g.*, B, seems to be a characteristic property of cupric enolates, as Wislicenus [*Ber.*, **35**, 539 (1902)] obtained corresponding basic cupric derivatives by heating cupric enol acetoacetic ester with alcohols.

tween halogen and the α-carbon of analogously structured basic cupric enolates should always lead to the appearance of cupric chloride.

It was not possible to isolate an intermediate, basic cupric compound in the action of benzoyl chloride upon cupric enol acetoacetic ester, but it seems probable from the color changes and reaction products that the reaction proceeds mainly through the formation of a polymolecule, which undergoes primarily the following retrogression



The free enol benzoylacetoacetic ester, being more acidic than enol acetoacetic ester, displaced some of the latter ester from unchanged cupric enolate and, consequently, cupric enol benzoylacetoacetic ester competed in the reaction. At ordinary temperature (Table IV, I–III), the relatively inert benzoyl chloride reacted slowly upon cupric enol benzoylacetoacetic ester, but with excess chloride at the boiling point of benzene (IV and V), the reaction proceeded rapidly, with the result that the enolate did not appear in the product and practically all free benzoylacetoacetic ester was replaced by a non-volatile oil, probably the corresponding O-benzoate. This secondary reaction is less pronounced (VI and VII) with decreasing concentration of the chloride.

With the relatively inert benzoyl chloride, at ordinary temperature (I–III), comparatively little O-benzoylacetoacetic ester is produced from cupric enol acetoacetic ester. This part of the reaction proceeds undoubtedly analogously to that formulated above for acetyl chloride. Increasing the temperature of the reaction increases the reactivity of the chloride and it appears that under conditions which lead to rapid reaction less C-acyl product is formed. Thus addition of hot benzene solutions of the cupric enolate (IV and V) to boiling solutions of benzoyl chloride in benzene increased the yield of O-acyl ester about 2.5 times. Relatively little C-acyl ester was isolated, but more of the non-volatile oil and all of the copper appeared as cuprous chloride. The main course of the primary reaction, however, always leads to the formation of a C-acyl derivative, either as the free ester or as the cupric enolate. With the appearance of the latter, especially in the presence of excess chloride at higher temperatures (IV–VII), the reaction proceeds further, resulting in the production of non-volatile products. The cupric enolate reacted in boiling benzene (VIII and IX) with even one equivalent of chloride to give more non-volatile oil than at room temperature and only one-third as much O-acyl ester appeared at the higher temperature. Similarly, with the cupric enolates of benzoylacetic and acetoacetic esters, the relatively inactive chlorocarbonic ester yields mainly a C-acyl ester; the free ester with the former and cupric enol acetylmalonic ester with the latter. In contrast, acetyl chloride rapidly yields an O-acyl ester with cupric enol acetoacetic ester. It appears, therefore, that reactive acyl halides yield O-acyl derivatives in rapid reactions and that C-acyl derivatives are mainly produced from relatively inert chlorides in reactions proceeding slowly. Although acetyl chloride acts only slowly upon cupric enolates of diacyl acetic esters the formation of an O-acyl derivative is inevitable because, as stated above, adverse affinity relations between chlorine and the unsaturated α-carbon of the enolate preclude the formation of a C-acyl derivative.

Theoretically, stereomeric O-benzoates of acetoacetic ester should exist and by treating a mixture of acetoacetic ester and pyridine with benzoyl chloride a liquid O-benzoylacetoacetic ester was obtained, which is isomeric with the solid ester formed from cupric enol acetoacetic ester and benzoyl chloride.[8] The ester prepared by the latter reaction melts at 42° and is less soluble in petroleum ether than the ester prepared with pyridine. Under comparable conditions, the latter ester is rearranged by sodium enol acetoacetic ester to sodium enol benzoylacetoacetic ester somewhat faster than the solid ester, but the rates are not very different. Both esters absorb hydrogen and react with bromine at about the same rate. The esters have the same boiling point and refractive index, but the density of the solid ester is slightly greater than that of the liquid ester. Attempts to interconvert the isomers by heat,[15] or by exposure to sunlight, failed; in strong ultraviolet light the liquid ester decomposed after 125 hours while the solid ester remained unchanged. Whether the O-benzoates of acetoacetic ester should be classed as ordinary stereomers is open to doubt because they seem, rather, to belong to

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(15) Claisen [*Ann.*, **291**, 108 (1896)] obtained an O-benzoate in the benzoylation of benzoyldiacetylmethane with pyridine, which he considered stereomeric with the compound formed with potassium carbonate. These compounds were readily interconverted by heat.

that considerable class of isomeric substances, whose isomerism depends undoubtedly upon the spatial arrangement of atoms in molecules, but which cannot be explained from the current stereochemical viewpoint.[16]

The above experimental results are of general interest for organic theory. The Kekulé conception of doubly-linked carbon atoms assumes that two atoms are joined by two valences and implies that the strength of the union, the nature and amount of the free chemical energy at each of the unsaturated carbons are independent of atoms or radicals directly attached. One of us[17] pointed out that linked carbon atoms only possess the same chemical character when each is under identical chemical influences, otherwise their chemical properties differ, but this difference usually becomes manifest only with the use of mild reagents as addenda. The behavior of basic cupric enolates affords strong experimental support of this view. Notwithstanding the appearance of an unsaturated α-β-carbon group in the basic cupric enolate of acetoacetic ester, a mole of the extremely additive chlorine unites only with the Δ-α-carbons of two enolate molecules, with severance of cuprous chloride and appearance of double linkages between the β-carbons and attached oxygens. This unilateral course of addition is equally clear in the reaction with acetyl chloride, a reagent that never adds bilaterally to doubly-linked carbon atoms; functioning here, however, with union of chlorine at the Δ-α-carbon and with acetyl at the enolic oxygen, thus forcing the formation of cuprous chloride. Benzoyl chloride acts similarly, with the appearance of some O-benzoate, but more largely with union of benzoyl to the energetic Δ-α-carbon of a second molecule of the basic enolate. The course of these singular reactions is probably connected with the slight chemical hindrance to the separation of -CuCl from the enolic oxygen and the large heat of formation of cuprous chloride and α-chloroacetoacetic ester.[18] These reactions show unmistakably that the representations of double linkages in terms of valence are crude and unscientific.[19]

The progressive chemical breaking up of cupric enolate molecules are excellent illustrations of a general rule: *viz.*, that polysubstitutions, or polypseudosubstitutions, proceed progressively; independently whether the several like or unlike atoms or groups are attached to different carbons[20] or to a single carbon.[21] The important rule of *progressive substitution* has received little attention in organic theory. To illustrate its importance, three characteristic, wrongly interpreted reactions will be considered from its standpoint. The formation of ketene, trimethylene and carbon monoxide from bromoacetyl bromide, trimethylene dibromide and chloroform, respectively. Aliphatic α-bromo esters, but not acyl halides, react readily with zinc, and zinc alkyl halide derivatives react violently upon acyl halides. The current explanation that the halogen atoms in bromoacetyl bromide are removed simultaneously is, therefore, obviously impossible and the reaction must proceed in steps: $CH_2BrCOBr + Zn \longrightarrow CH_2(ZnBr)COBr \longrightarrow CH_2{=}CO + ZnBr_2$. The same objection may be raised against the simultaneous removal of the two bromine atoms from trimethylene dibromide; here, too, the reaction must be progressive with the primary formation of $CH_2(ZnBr)CH_2CH_2Br$. Then, because the Zn of -ZnBr has a strong affinity for bromine, favored by their close spatial disposition (1,5), the free chemical energy at the zinc can overcome the very considerable chemical hindrance to the formation of trimethylene, which is energetically inconceivable from the usual point of view. Equally improbable is the direct replacement of two chlorine atoms of chloroform by hydroxyl; a more logical interpretation is the primary appearance of $C(OH)Cl_2H$, which, because the hydroxyl greatly decreases the affinity of carbon for chlorine and hydrogen, decomposes spontaneously. $HCClCl_2 + H_2O \longrightarrow HC(OH)Cl_2 \longrightarrow HCOCl \longrightarrow CO + HCl$.

Of general interest too, is the bearing of the experimental results in this and previous papers[1] on the mechanism of intermolecular chemical changes. The chemical behavior of the enolates can hardly

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(16) Michael, THIS JOURNAL, **55**, 1638, footnote 17 (1933).

(17) Michael, *J. prakt. Chem.*, **37**, 473 (1888); **60**, 414, 479 (1899).

(18) The heat of formation of α-chloroacetoacetic ester is not known, but its value must be considerably larger than that of acetoacetic ester. Calculating the heat of formation for the products obtained in the action of 4.98 g. of chlorine upon 15 g. of cupric enol acetoacetic ester, the amounts of these reagents required for complete reaction, and substituting the value of acetoacetic for that of α-chloroacetoacetic ester, gives the value 15.9 kcal., whereas 13.1 kcal., is obtained if the given quantity of chlorine reacted to give cupric chloride. It would seem, therefore, that in this, as in the great majority of organic reactions, the heats of formation of the reaction products determine the maximum degradation of energy and thus the course of the reaction.

(19) It has not been possible to correctly represent carbon unsaturation stereometrically in terms of valence linkage or electrons. See, THIS JOURNAL, **55**, 1638, footnote 17 (1933).

(20) Michael, *J. prakt. Chem.*, **60**, 415 (1899).

(21) Michael, *Ber.*, **34**, 4028 (1901).

be rationally explained without assuming that double molecules, or polymolecules, possess definite intermolecular, atomic structures,[22] *i. e.*, they owe their formation, not to the affinity between molecules as reacting units, but to the developed affinity of atoms in one molecule for atoms in the associating molecule.[23] The results also give strong experimental support to theoretical views explaining the formation of organic isomers from unsaturated compounds on the basis of the polar and energy relations of the unsaturated atoms for the reactants, functioning as addenda,[24] since they show that such chemical forces exert strong directive influences upon the course of the reaction.

Experimental

Preparation and Properties of O-Benzoylacetoacetic Ester. (A) Liquid Ester.—A mixture of 24 g. of pyridine, 32.5 g. of acetoacetic ester and 35.1 g. of benzoyl chloride was allowed to react for two days, diluted with ether and solid removed. The filtrate was washed with hydrochloric acid, 10% alkali and the solvent removed. The residual oil gave fractions: (1) 5.4 g., b. p. up to 153° at 3 mm.; (2) 39.6 g., b. p. 153–155° at 3 mm.; (3) 6.8 g. residue.

Fraction (2) gave no color with ferric chloride and did not solidify after two to three days at −20°, even after a crystal of the solid isomer had been added.

Anal. Calcd. for $C_{13}H_{14}O_4$: C, 66.64; H, 6.03. Found: C, 66.53; H, 6.42.

One gram of the ester and 0.9 g. of phenylhydrazine in ether solution gave 0.75 g. of benzoylphenylhydrazide.

(B) Solid Ester.—Fifty grams of cupric enol acetoacetic ester and 43.7 g. of benzoyl chloride in 150 cc. of ether were allowed to react for two hours at room temperature and the mixture then boiled for two hours. The solvent was distilled off, the residue treated with water and the solid separated by filtration. The filtrate was extracted with ether, and the extract fractionated; (1) 5.3 g., b. p. up to 150° at 3 mm.; (2) 9.2 g., b. p. 150–155° at 3 mm.; (3) 5.2 g., b. p. 180–185° at 2 mm.; (4) 2–3 g. residue.

Fraction (2) redistilled gave 7 g. of O-benzoylacetoacetic ester, b. p. 142° at 2 mm., which gave no color with ferric chloride. *Anal.* Calcd. for $C_{13}H_{14}O_4$: C, 66.64; H, 6.03. Found: C, 66.87; H, 6.23. One gram of the ester and 0.9 g. of phenylhydrazine in ether solution gave 0.7 g. of benzoylphenylhydrazide.

(C) Comparison of Properties.—The boiling points determined under identical conditions were 139° at 1.5 mm., bath at 175°. Both esters have the same refractive index, n^{40}_{D} 1.15100. The densities at 40° were

	Liquid ester		Solid ester	
	density	mol. refr.	density	mol. refr.
I	1.1055	63.33	1.1088	63.15
II	1.1049	63.36	1.1091	63.12

Mol. refr. calcd. 61.47.

Determination II was made after the liquid ester had been redistilled and the solid ester recrystallized and subsequently distilled.

Molecular weight by freezing point in benzene: calcd. 234; found (a) liquid ester 223; (b) solid ester 220.

Solubility.—The ester was dissolved in petroleum ether (b. p. 32°) at room temperature, the solution cooled to the required temperature, 1-cc. portions of the supernatant solution pipetted into a weighed flask and the solvent removed.

Expt.	Residue, g.	Av. soly./cc.	Temp., °C.
	Liquid		
1	0.11520		−20
2	.10685	0.111	
3	.17839		0
4	.17730	.178	
	Solid		
5	0.00891		−20
6	.00851	0.009	
7	.03353		0
8	.03463	.034	
9	.02865		0
10	.02868	.029	
11	.01045	.010	−19

Ester used in determination 7 and 8 was six months old; ester recrystallized for determinations 9–11.

Rate of Rearrangement with Sodium Enol Acetoacetic Ester.—Solutions of 1.95 g. of sodium enol acetoacetic ester in 10 cc. of acetic ester were treated at 30° with 3 g. of each of the O-benzoates. The time of appearance of solid was noted and the yield at the end of forty-two hours. In the first experiments the solid was filtered off, acidified and converted into the cupric enolate. The observations are summarized.

Ester used	Liquid	Solid	Liquid	Solid
Solid after mixing, hours	3.75	5.75	0.33	3.5
Na salt after 42 hours, g.	2.6	2.0	2.65	1.85
Yield of Cu salt, g.	2.5	1.9		
Calcd. yield Cu salt, g.	2.6	2.0		
Cu salt m. p., °C.	226–227	223–224		

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[22] For literature see, THIS JOURNAL, **57**, 159 (1935).

[23] Hückel, "Theoretische Grundl. d. org. Chemie.," 1931, Vol. I, p. 232, Vol. II, pp. 223, 226, 236, questions the intermediate formation of polymolecules in chemical reactions, mainly on the ground that "although such compounds are quickly formed at ordinary temperatures, substitutions then proceed immeasurably slowly" and that polymolecules "perhaps no longer practically exist" at temperatures sufficiently high for rapid substitution. Even if one accepts the latter, unproven, statement, Hückel's conclusion is fallacious. He considers that the polymolecules of organic compounds and reactants "are in balanced equilibrium at temperatures when the reaction proceeds fast, or moderately slowly," but overlooks that, if one component of such a balanced system undergoes change, a balanced equilibrium is again instantaneously reëstablished. Evidently, a reaction may proceed quickly and entirely through one component, even if it exists only in traces under the conditions of fast decomposition. Indeed, Hückel [*ibid.*, Vol. I, p. 181] advances this, generally accepted relationship to explain the C-alkylation of sodium enolates [see, THIS JOURNAL, **57**, 160 (1935)]. Further, Hückel's assumption regarding the relative quantity of the decomposing constituent of a polymolecule is entirely without experimental support and the relative facility of polymolecular decompositions evidently depends upon the chemical character of its constituents.—(A. M.)

[24] Michael, *J. prak. Chem.*, **60**, 319 (1899); **68**, 489 (1903); THIS JOURNAL, **32**, 1003 (1910).

Summary

1. The action of one and a half moles of chlorine upon a mole of cupric enol acetoacetic ester yields one mole of cuprous chloride and two moles of α-chloroacetoacetic ester.

2. The action of acetyl and benzoyl chloride upon cupric enol acetoacetic ester was investigated semi-quantitatively, under varying conditions. In the former, rapid reaction all of the available copper appears in the reaction products as cuprous chloride and the O-acetyl ester is produced along with α-chloroacetoacetic ester. The course of the latter reaction depends upon the experimental conditions: at room temperature, some O-benzoyl but mainly C-benzoylacetoacetic ester is formed, together with cuprous chloride, acetoacetic and α-chloroacetoacetic esters. The relative amount of the O- to that of the C-derivative decidedly increases when temperature conditions favor less slow reactions, *e. g.*, at the boiling point of benzene, 2.5 times more O-benzoylacetoacetic ester is produced than at room temperature.

3. The action of acetyl chloride upon cupric enol diacetoacetic ester is progressive, yielding, at first, the basic, chloro-cupric derivative together with the O-acetate of diacetoacetic ester. In the second phase of reaction, the products are cupric chloride together with some cuprous chloride and, apparently, a second molecule of the O-acyl ester.

4. At ordinary temperature, acetyl chloride acts slowly upon cupric enol benzoylacetoacetic ester: in boiling benzene, cupric chloride, together with about 20% cuprous chloride and, mainly, O-acetyl benzoylacetoacetic ester are produced.

5. Contrary to Nef, an excess of chlorocarbonic ester reacts upon cupric enol acetylmalonic ester, in hot benzene solution, to form high boiling oils and cuprous chloride. Chlorocarbonic ester and cupric enol acetoacetic ester, during one and one-half hours in boiling benzene solution, yield mainly the cupric enolate of acetylmalonic ester, whereas free benzoylmalonic ester is produced from cupric enol benzoylacetic ester.

6. The above experimental results show that the chemical behavior of cupric enolates toward chlorine and acetyl chloride is entirely different from the accepted viewpoint. Although basic, chloro-cupric enolates could not be isolated in the cupric acetoacetic and benzoylacetoacetic ester reactions, the appearance of cuprous chloride shows that the reactions must proceed through such intermediates. Even the so strongly additive chlorine does not combine with both Δ-α-β-carbons of the intermediate, but adds only to the Δ-α-carbons of two enolate molecules, with formation of α-chloroacetoacetic ester and with expulsion of cuprous chloride. Substituting the α-hydrogen of cupric enol acetoacetic ester by negative acetyl causes not only a better neutralization of the copper in the new molecule, but also a decrease in the affinities of the α-carbons for acyl groups. With the diacetoacetic ester enolate and acetyl chloride, this change manifests itself in a decrease in the α-carbon reactivity and in a greater stability of the isolatable, basic chloro-cupric intermediate. Benzoyl is more negative than acetyl and this, more negative, influence upon the Δ-α-carbon shows itself decidedly in the behavior of the benzoylacetoacetic ester enolate toward acetyl chloride. The affinities of the Δ-α-carbon in the intermediate for chlorine and for acetyl are now so reduced that, to the extent of about 80%, the chlorine reacts with the copper, to form cupric chloride and the O-acetate of benzoylacetoacetic ester appears as the second product.

7. The action of ethereal hydrogen chloride upon cupric enolates is progressive, yielding primarily the basic chloro-cupric enolates. Pure basic derivatives could be obtained from the cupric enolates of acetylacetone and diacetoacetic ester, but not from the enolates of benzoylacetone, acetoacetic, or benzoylacetoacetic esters. The behavior of the basic enolate of diacetoacetic ester toward heat, water and acetyl chloride was examined. The impure derivative obtained from cupric enol acetoacetic ester was treated with benzoyl chloride and the products determined.

8. It was found that cupric is reduced to cuprous chloride by the action of cupric enol acetoacetic ester in hot benzene solution. This reduction is attributed to the smaller affinity of one of the chlorines of cupric chloride for copper than for the Δ-α-carbon of the cupric enolate.

9. On account of the high heat of formation of cuprous chloride and the production of considerably more α-chloroacetoacetic ester from a given amount of chlorine in a reaction leading to the formation of cuprous rather than cupric chloride, a decidedly larger heat of formation is generated in the former reaction. This thermal factor undoubtedly determines the possible maximum degradation of chemical energy and thus accounts for the apparently abnormal course of the reactions.

10. Two isomeric O-benzoates of acetoacetic ester were prepared and examined. It is suggested that the spatial structures of the esters must differ from those expressed in the usual type of stereomers.

11. The results in the progressive chemical retrogressions of enolates are interpreted by the primary formation of polymolecules with definite intermolecular structures. The reactions illustrate the general rule "that all substitutions, or pseudosubstitutions, proceed progressively, whether the several like or unlike replaced atoms or groups are attached to different carbons or to a single carbon." Thus, the synthesis of ketene and trimethylene by the action of zinc on bromoacetyl bromide and trimethylene bromide proceed through $CH_2(ZnBr)COBr$ and $CH_2(ZnBr)CH_2CH_2Br$, respectively, as intermediates with subsequent elimination of zinc bromide.

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A Qualitative Test for Linolenic Acid, its Value and Limitations

BY GUSTAV J. MARTIN

A new reaction which affords a qualitative test for linolenic acid has been found in the behavior of this acid toward arsenophosphotungstic acid. The reagent, arsenophosphotungstic acid, is prepared as for the determination of uric acid by the method of Benedict.[1] The test is applied by layering 1 cc. of oil over 5 cc. of the reagent, heating for one hour in a boiling water-bath, and noting the color developed in the reagent layer. A positive reaction is indicated by the development of a deep blue color. The reaction will not take place in a medium such as acetone, alcohol or ether.

TABLE I

RESULTS OBTAINED WITH THE TEST WHEN APPLIED TO VARIOUS MATERIALS

Material	Reaction		
	Qual.	Quant., %	Linolenic content, %
Methyl linolenate (prepared by method of Rollett[2])	+++++	Used as standard	99.8
Methyl linolate (prepared by method of Rollett[2])	....	......	0
Methyl linolate (crude)	+++	9 ± 3	?
Sodium oleate (Merck's U. S. P.)	....	......	0
Linseed oil	++++	81 ± 9	34[2]
Perilla oil	++++	36 ± 6	41[2]
Soya bean oil	+	3 ± 1	2.2[2]
Corn oil	....	......	0
Cotton seed oil	....	......	0

The reaction would probably be given by acids more highly unsaturated than linolenic acid, but as such acids do not occur in vegetable oils, the test is specific for linolenic acid or its esters in these oils. In applying the color test to fats or oils of animal origin, it may well be that arachidonic acid, and perhaps other highly unsaturated acids, would make the test non-specific.

The application of this color test in the determination of an unknown oil is easily recognized. There are only four vegetable oils considered in Jamieson's monograph[3] which would give an intense color with arsenophosphotungstic acid—linseed, perilla, chia seed and hemp seed oils. Another class, containing about 2% of linolenic acid would give a weak color test. Included in this group are such oils as soya bean, lumbang, mustard seed and rape seed oils. Only a total of about twenty vegetable oils would give a positive reaction and these could be subdivided as indicated. The test might be used to indicate adulteration or rancidity in the oils of the group, as linolenate content would primarily be affected in either case. It would only be necessary to compare the color developed by the oil in question to that developed by a known sample of the oil.

It is of interest to note that arsenic acid, phosphoric acid, sodium tungstate and phosphomolybdic acid do not give this reaction with linolenic acid.

Quantitative Value.—The reaction is to be regarded, at present, as being only roughly quantitative. The difficulty in obtaining adequate miscibility of oil and reagent preclude to a certain degree the application of the reaction to exact quantitative measurements. Using a purified methyl linolenate as a standard, a series of determinations was made on various materials as indi-

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(1) S. R. Benedict, *J. Biol. Chem.*, **92**, 161 (1931).

(2) E. T. Rollett, *Z. physiol. Chem.*, **62**, 410, 422 (1909).

(3) G. S. Jamieson, "Vegetable Fats and Oils," Chemical Catalog Co., New York, 1932.