which it was centrifuged. The decantate was concentrated and distilled to give 1.16 g. (27%) of X. The residue from the distillation gave mainly tar from which the only isolable solid was 0.05 g. of an orange powder, m.p. 268–269°, which was relatively insoluble in all solvents except an ethyl acetate–chloroform mixture. *Anal.* Found: C, 83.45; H, 5.69; C_2H_5O, 10.9 (calcd. for $C_{30}H_{24}O_3$: C, 83.31; H, 5.59; 1 C_2H_5O, 10.4). No further study of this material was made.

(**c**).—In a 100-ml. flask, 0.95 g. (0.025 atom) of potassium was dissolved in *t*-butanol; the excess alcohol then was removed and the residue heated to 180° under the vacuum of an oil-pump. To the cooled white residue, 6.5 g. (0.018 mole) of XI was added and the thick mixture heated at 100–110° for one hour, then at 160° for 2.5 hours. Distillation then gave 1.8 g. (0.024 mole) of *t*-butanol, $n^{25}\text{D}$ 1.3848, and as the only other volatile fraction 1.05 g., b.p. 170° (20 mm.) –130° (0.1 mm.), $n^{25}\text{D}$ 1.5705. No pure component could be separated from this material.

When the residue from the distillation was dissolved in an ether-water mixture and the aqueous layer acidified, 2.4 g. (60%) of tan-colored β,β-diphenylpropionic acid was obtained. Two recrystallizations from dilute alcohol gave a white product, m.p. 153–155°; neut. equiv., 229 (calcd. 224). A known sample of this acid was prepared by reduction of β-phenylcinnamic acid[21] (m.p. 158–160.5°) with sodium in ethanol. The acid thus prepared had a m.p. of 153–155.5°, which was not depressed upon mixing with the acid isolated above. Both samples of this acid yielded identical anilides, m.p. 178–179° (lit.[22] m.p. 177–178°).

The following modification of (c) was made: A 50-ml. distilling flask with attached still-head was connected through a Dry Ice–acetone trap to a vacuum pump. A 3.4 g. (0.03 mole) sample of sublimed[8] potassium *t*-butoxide was intimately mixed with 10.8 g. (0.03 mole) of XI and the system then evacuated to 0.1 mm. pressure. Upon heating the mixture a vigorous evolution of *t*-butyl alcohol started and necessitated removal of the heating-bath for several minutes. As soon as possible the oil-bath (at 165°) was replaced and the distillation continued. A temperature of 200° was finally used to give two fractions, both of which were mixtures of X and XI: (a) 2.5 g., b.p. 142–149° (0.1 mm.), $n^{25}\text{D}$ 1.5613 and (b) 1.2 g., b.p. 150–165° (0.1 mm.), $n^{25}\text{D}$ 1.5680, which solidified on standing. Bromide analyses ((a), 5.8%; (b), 15.9%) and refractive indices showed that 2.2 g. (26% yield) of X was present in the combined fractions. Fraction (a) was redistilled to give 1.1 g. of nearly pure X, b.p. 138–140° (0.1 mm.), $n^{25}\text{D}$ 1.5607, with a bromide content of 1.1%. From 22.4 mg. of this fraction, 21.0 mg. of a 2,4-dinitrophenylhydrazone was obtained. Upon recrystallization from ethanol–ethyl acetate, the more soluble portion yielded a product, m.p. 201–202°, which was not depressed when mixed with the authentic derivative of X.

In the cold trap from the above reaction, 2.25 g. (100%) of *t*-butanol, $n^{25}\text{D}$ 1.3841, b.p. 81°, was isolated. An ether-water extract of the residue from the above distillation gave 3 g. of ether-soluble tar, and a small amount of precipitated tar upon acidification of the water extract. Attempted recrystallization of these tars gave only amorphous material, except for about 0.1 g. of an orange solid, m.p. 267.5–268.5°, identical to that isolated in (b). By repeated extraction of these tars with hot water, a small amount (0.1 g.) of β-phenylcinnamic acid was isolated, which had a m.p. of 155–158°, alone or mixed with a known sample.[21]

Madison, Wisconsin Received November 2, 1951

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[21] H. Rupe, *Ann.*, **395**, 141 (1913); T. Posner, *J. prakt. Chem.*, [2] **82**, 439 (1910).

[22] J. F. Eijkman, *Chem. Weekblad*, **5**, 655 (1908).

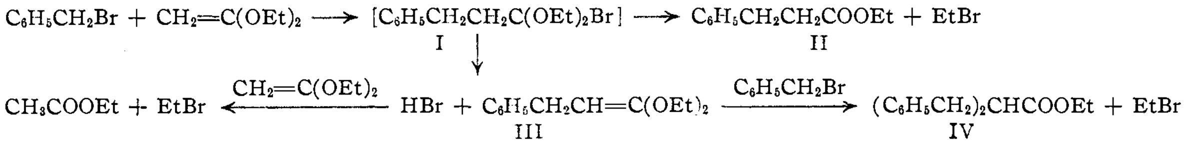
[Contribution from the Laboratory of Organic Chemistry of the University of Wisconsin]

Ketene Acetals. XXIX. The Mechanism of the Reaction of Ketene Acetal with Various Halides

By S. M. McElvain and Herbert F. McShane, Jr.[1]

The reaction of benzyl bromide with excess ketene diethylacetal is found to yield benzylketene acetal as one of the reaction products. However, determinations of the relative reactivities of these ketene acetals show that the substituted ketene acetal is not the intermediate in the formation of the large amount of ethyl dibenzylacetate, which is produced when ketene acetal reacts with benzyl bromide. A reaction mechanism to account for the formation of this dibenzylated product is suggested. The formation of only monoalkylation products from the reaction of benzyl bromide with methylketene diethylacetal and from the reactions of ethyl iodide and trityl chloride with ketene diethylacetal are offered in support of this mechanism. Acetylketene diethylacetal may be directly prepared from the reaction of acetyl chloride with an excess of ketene acetal.

In the seventh paper[2] of this series the allylation and benzylation of ketene diethylacetal by reaction with the respective bromides was reported. A remarkable feature of these reactions was the high ratio of the disubstituted to the monosubstituted acetic esters that was produced in each case. At that time it was suggested that the disubstituted ester (IV) was formed *via* a monosubstituted ketene acetal (III), which resulted from a loss of hydrogen bromide from the intermediate I.



$$C_6H_5CH_2Br + CH_2{=}C(OEt)_2 \longrightarrow \underset{\text{I}}{[C_6H_5CH_2CH_2C(OEt)_2Br]} \longrightarrow \underset{\text{II}}{C_6H_5CH_2CH_2COOEt} + EtBr$$

$$\downarrow$$

$$CH_3COOEt + EtBr \xleftarrow{CH_2{=}C(OEt)_2} HBr + \underset{\text{III}}{C_6H_5CH_2CH{=}C(OEt)_2} \xrightarrow{C_6H_5CH_2Br} \underset{\text{IV}}{(C_6H_5CH_2)_2CHCOOEt} + EtBr$$

Such a reaction course would require that the rate of formation of IV from III should be at least as great as that at which II is formed from the unsubstituted ketene acetal. Later work,[3] however, indicated that certain alkyl- and phenyl-substituted ketene acetals reacted considerably slower with benzyl bromide, as judged by the higher temperature required to evolve the alkyl bromide, than did the unsubstituted ketene acetal. High yields of the monobenzylated esters were obtained, but there was no indication that any of the dibenzylated ester (a trisubstituted acetic ester), was formed. The only monosubstituted ketene acetal that has been found to undergo dibenzyla-

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[1] Wisconsin Alumni Research Foundation Research Assistant 1948–1950; Shell Oil Company Fellow 1950–1951.

[2] S. M. McElvain and D. Kundiger, This Journal, **64**, 254 (1942).

[3] S. M. McElvain, R. E. Kent and C. L. Stevens, *ibid.*, **68**, 1922 (1946).

tion is cyanoketene acetal and this behavior was attributed to the labilization of the α-hydrogen by the cyano group.[4]

It seemed that if the benzylketene acetal (III) were an intermediate in the formation of the dibenzylated ester, it might be prevented from reacting further with the benzyl bromide if a large excess of the unsubstituted ketene acetal were present. It was indeed possible to prepare benzylketene diethylacetal under such conditions, in yields ranging from 11–56% as shown in runs 2–5 Table I. But even under these conditions it may be seen that there was always a considerable amount of the dibenzylacetic ester (IV) formed.

TABLE I

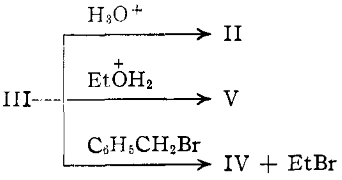
PRODUCTS FROM THE REACTION BENZYL BROMIDE (RBr) WITH KETENE ACETAL

Run no.	Moles of RBr	Moles of K.A.	Reaction Time, hr.	Reaction Temp., °C.	Yields, %, of EtBr	Yields, %, of CH_3COOEt	Yields, %, of II	Yields, %, of III	Yields, %, of IV
1	0.10	0.10	3[a]	125	71	24	16	..	46
2	.2	.9	5[a]	125–135	73	40	28	11	30
3	.34	1.74	6[a]	125–135	77	60	16	26	15
4	.39	2.00	7[b]	125–131	69	43	28	43	19
5	.92	4.12	8[c]	123	67	69	12	56	20
6	.30	0.33	6[d]	140	40	43	16	..	48

[a] Reactants, RBr and K.A., mixed and then heated; the data for run 1, taken from earlier work (ref. 2), were checked in the present work. [b] Dropwise addition of RBr to K.A. (at reaction temp.) over a 4-hr. period followed by heating for an additional 3 hr. [c] Dropwise addition as in (b) over a 6-hr. period. [d] Dropwise addition of K.A. to RBr (at reaction temp.) over a 2-hr. period.

The structure of the benzylketene acetal (III) was confirmed by comparison with a sample obtained by the dealcoholation of ethyl ortho-β-phenylpropionate (V), prepared from hydrocinnamonitrile *via* the iminoester hydrochloride, and by the following characteristic reactions. Hydrolysis converted III to ethyl hydrocinnamate (II) and treatment with alcohol produced the orthoester (V); it reacted slowly (9 hr.) with benzyl bromide at 125° to evolve ethyl bromide and give a 93% yield of ethyl dibenzylacetate.

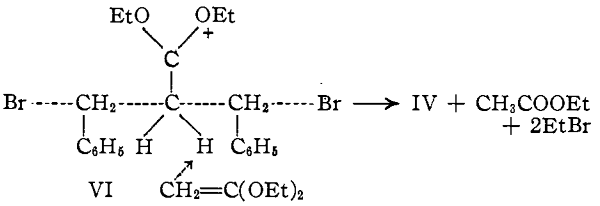
$$C_6H_5CH_2CH_2CN \longrightarrow C_6H_5CH_2CH_2C(OEt){=}NH_2Cl \longrightarrow \underset{V}{C_6H_5CH_2CH_2C(OEt)_3} \longrightarrow III$$



Since benzylketene acetal (III), as well as the previously studied alkyl- and phenylketene acetals,[3] appeared to react more slowly than the unsubstituted ketene acetal with benzyl bromide, it seemed quite unlikely that III was the real intermediate in the formation of the dibenzyl ester IV from ketene acetal. To further substantiate this conclusion, an attempt was made to determine the relative rates of reaction of ketene acetal and benzylketene acetal with benzyl bromide. This was done in a proximate manner by (a) allowing a mixture of equivalent quantities of the two ketene acetals to compete for a single equivalent of the bromide and then determining the nature of the products formed, and (b) following the rate of disappearance of the ketene acetal by bromine titration when each ketene acetal was allowed to react separately with an equivalent of benzyl bromide. Ketene acetal was found by (a) and (b), respectively, to be 2 and 3.7 times as reactive at 125° as benzylketene acetal.

These results indicate that the dibenzylated ester must be formed by a mechanism different from that which produces the monobenzylated products II and III. The mechanism for dibenzylation would appear to require the simultaneous attack of two molecules of the bromide on a single molecule of the ketene acetal. The resulting complex does not lose hydrogen bromide as such, as shown by the fact that none of this acid is produced when ketene acetal is added to an excess of benzyl bromide at 125°. In contrast to the rapid reaction at this temperature when these reactants are mixed before heating and to the relatively rapid reaction when the bromide is added to the hot ketene acetal, this inverse order of mixing the reactants gives a quite slow reaction, which does not begin to evolve ethyl bromide until a considerable amount (*ca.* 20%) of the ketene acetal has been added. As may be seen from Table I the same ratio of di- to monobenzylated esters is obtained when equivalent amounts of the reactants are mixed before heating (run 1) as when the ketene acetal is added slowly to the heated benzyl bromide (run 6).

A reaction mechanism which explains these results may be formulated as involving (a) the formation of a termolecular complex by the coordination of two benzyl bromide molecules with a single hetene acetal and (b) the removal of a proton from this complex by a second molecule of ketene acetal to give the reaction products.



VI

This mechanism requires that the halide have a partial ionic character and is consistent with the fact that allyl and benzyl bromides are the only ones that have been observed to give disubstitution. It is also consistent with the observation that the unsubstituted ketene acetal and cyanoketene acetal are the only ketene acetals that have been found to undergo dibenzylation. Those ketene acetals with more bulky substituents on the nucleophilic center are considered sterically prevented from forming the complex VI and consequently yield only the monobenzylated products.

Inasmuch as the substituted ketene acetals previously studied[3] in this reaction contained such relatively large substituents as *n*-propyl, *n*-heptyl and phenyl, it seemed desirable to test the above hypothesis by determination of the benzylation behavior of methylketene diethylacetal, $CH_3CH=$

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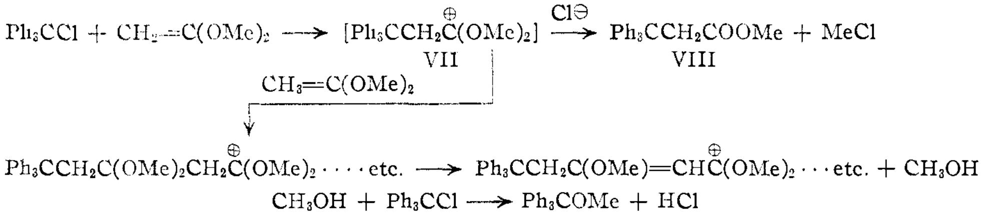
[4] S. M. McElvain and J. P. Schroeder, *ibid.*, **71**, 47 (1949).

$C(OEt)_2$. The methyl substituent not only is the smallest of the alkyl groups, but also would be devoid of the activating influence of the cyano group for the proton removal from such an intermediate as VI. When equivalent quantities of this ketene acetal and benzyl bromide were heated at 140°, ethyl bromide (71%) ethyl α-benzylpropionate (74%) and unreacted benzyl bromide (21%) were obtained; no material corresponding to a dibenzylated product could be found. Thus it appears that the smallest alkyl group as a substituent in the ketene acetal prevents dibenzylation.

To obtain additional information on the effect of the halide on the course of this reaction, the alkylation of ketene acetal with ethyl iodide and with trityl chloride were studied.[5] With the ethyl iodide a large excess of the ketene acetal could readily be used, as the halide is continuously regenerated as the reaction proceeds. When ketene diethylacetal was heated with 7 mole per cent. of ethyl iodide at 170°, there were obtained a practically complete recovery of the ethyl iodide, a 53% yield of ethyl butyrate and an 8% yield of a product, whose analyses corresponded to $CH_3CH_2CH_2C(OEt)_2CH_2COOEt$, resulting from the addition of ethyl iodide across two molecules of the ketene acetal.[6] Hydrolysis converted the latter product to ethyl butyrylacetate. There was no evidence of the formation of a dialkylated acetic ester or of ethylketene acetal. Since this reaction occurs under conditions comparable to those used for the reaction of allyl bromide with ketene acetal,[2] it would appear that the high ratio of diallylated to monoallylated ester obtained in the latter reaction is dependent upon the ability of allyl bromide to form a complex of the type of VI.

Polymerization of the ketene acetal was the main reaction observed when a mixture of ketene dimethylacetal and trityl chloride was heated. Reaction begins at *ca.* 30° and is sufficiently exothermic to raise the temperature of the mixture (which is not homogeneous) to 75°. It is interesting to note that these reactants give no evidence of interaction when heated in refluxing benzene. When the ketene acetal is added to the molten halide at 140°, a 46% yield of methyl β,β,β-triphenylpropionate (VIII) and a 41% of triphenylmethyl methyl ether (IX) were the principal reaction products. This ether doubtless results from the reaction of the trityl chloride with the methanol eliminated from a ketene acetal polymer. It would appear, therefore, that the carbonium ion (VII) formed in the initial reaction of the trityl chloride with the ketene acetal is attacked about as readily by the nucleophilic center of the ketene acetal as by the chloride anion.



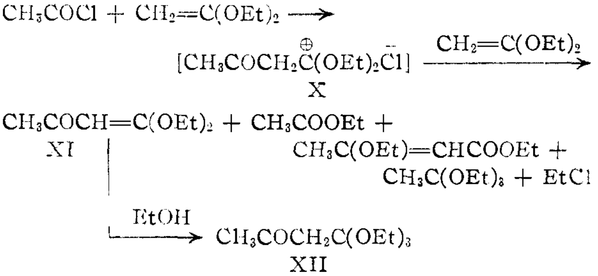
$$\mathrm{Ph_3CCl + CH_2{=}C(OMe)_2 \longrightarrow \underset{VII}{[Ph_3CCH_2\overset{\oplus}{C}(OMe)_2]} \xrightarrow{Cl^{\ominus}} \underset{VIII}{Ph_3CCH_2COOMe} + MeCl}$$

$$\mathrm{VII} \xrightarrow{\mathrm{CH_3{=}C(OMe)_2}} \mathrm{Ph_3CCH_2C(OMe)_2CH_2\overset{\oplus}{C}(OMe)_2 \cdots etc. \longrightarrow Ph_3CCH_2C(OMe){=}CH\overset{\oplus}{C}(OMe)_2 \cdots etc. + CH_3OH}$$

$$\mathrm{CH_3OH + Ph_3CCl \longrightarrow Ph_3COMe + HCl}$$

These reactions indicate that a single trityl halide may readily coördinate with the ketene acetal, but that the size of the trityl substituent prevents any further reaction at the methylene carbon of the complex VII. Reaction of the complex is thereby limited to the carbonium center to form polymeric material by coördination with other ketene acetal molecules or an attack of a chloride anion at the methoxyl substituent to yield VIII.

To further explore the preparation of a substituted ketene acetal by the direct action of a halide on the unsubstituted ketene acetal, the reaction of acetyl chloride with ketene diethylacetal was reinvestigated. It was previously observed[2] that these reactants in equivalent quantities yielded ethyl O-acetylacetoacetate as the principal reaction product. By the addition of acetyl chloride to an excess of ketene diethyl acetal it was possible to obtain acetylketene acetal (XI) in 61% yield, this product was accompanied by ethyl acetate, ethyl β-ethoxycrotonate, and ethyl orthoacetate resulting from the reaction of the excess ketene acetal with hydrogen chloride[2] extracted from the complex X. The ketene acetal XI was converted to ethyl orthoacetoacetate (XII) by reaction with alcohol.

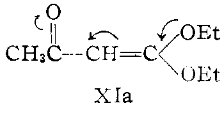


$$\mathrm{CH_3COCl + CH_2{=}C(OEt)_2 \longrightarrow \underset{X}{[CH_3COCH_2\overset{\oplus}{C}(OEt)_2\overset{-}{C}l]} \xrightarrow{CH_2{=}C(OEt)_2}}$$

$$\mathrm{\underset{XI}{CH_3COCH{=}C(OEt)_2} + CH_3COOEt + CH_3C(OEt){=}CHCOOEt + CH_3C(OEt)_3 + EtCl}$$

$$\mathrm{XI \xrightarrow{EtOH} \underset{XII}{CH_3COCH_2C(OEt)_3}}$$

It is possible that acetylketene acetal (XI) is an intermediate in the formation of the ethyl O-acetylacetoacetate from ketene acetal and acetyl chloride observed in the earlier work,[2] as the usual nucleophilic center of a ketene acetal could be readily transferred to the oxygen (XIa) from which point it would attack the acetyl chloride. This and other aspects of the acylation of ketene acetals are currently under investigation.



XIa

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[5] In the earlier work (ref. 2) a reaction between *n*-butyl bromide and ketene diethylacetal was carried out. The conditions (72 hr. at 250°) used for this reaction caused extensive pyrolysis of the ketene acetal to ethyl acetate and ethylene. However, the only alkylation product isolated was ethyl caproate (13%).

[6] In a manner similar to the formation of ethyl β-ethoxycrotonate by the addition of acids to ketene diethylacetal (*cf.* H. M. Barnes, D. Kundiger and S. M. McElvain, This Journal, **62**, 1281 (1940)).

Experimental

Ethyl Orthohydrocinnamate.—Ethyl iminohydrocinnamate hydrochloride was prepared by the addition of 1.1 equivalent of hydrogen chloride gas to an ethereal solution of 164 g. (1.25 moles) of hydrocinnamonitrile[7] and 57.5 g. (1.30 moles) of ethanol at 0°. The solution was allowed to stand for three days after which time the precipitate which formed was removed and dried under diminished pressure over sodium hydroxide. The dried product was 100 g. (38%) of **ethyl iminohydrocinnamate hydrochloride**, m.p. 130° (dec.).

This compound has been reported[8] previously and the physical properties and analyses agreed with those found in this work, but it was found that no orthoester could be obtained from the iminoester salt formed in reactions where a large excess of hydrogen chloride was used although this salt had the proper melting point and analysis.

A mixture of 100 g. of ethyl iminohydrocinnamate hydrochloride and 200 ml. of absolute ethanol was allowed to stand for two days, after which time it was filtered, the filtrate neutralized with alcoholic sodium ethoxide and fractionated. A fraction (55 g.) consisting of a mixture of ethyl hydrocinnamate and the corresponding orthoester was separated. Two such fractions were combined and refractionated to yield (a) 35 g. of ethyl hydrocinnamate, b.p. 115–122° (9 mm.); (b) 70 g. (30%) of ethyl orthocinnamate, b.p. 136–138.5° (10 mm.), n^{25}_{D} 1.4738.

Refractionation of (b) to constant refractive index gave 50 g., b.p. 138–139° (10 mm.), n^{25}_{D} 1.4722, which agreed in its physical properties with those of the ethyl orthohydrocinnamate prepared from benzylketene diethylacetal by addition of ethyl alcohol (see below for this reaction and the properties and analyses of the orthoester).

Sah[9] reported the preparation of this compound by this method and gave the following physical properties: b.p. 242°, n^{25}_{D} 1.4961, d^{25}_{4} 1.0375.

Ketene Acetals (a) Ketene Dimethylacetal.—In a 5-l. flask fitted with a mechanical stirrer and short fractionating column, which in turn was fitted with a fractionating head of the partial take-off total reflux type, were placed 3 l. of anhydrous pinacol, m.p. 43°, 138 g. (6 atoms) of sodium metal, and several boiling chips. Heating was commenced but when the sodium had melted and the stirring action had produced fine particles the reaction became strongly exothermic and it was often necessary to discontinue heating until the rapid refluxing ceased. Then the last of the sodium was brought into solution by heating at 190° with stirring. The reaction of the sodium usually took about 15 minutes. The solution was cooled to 160°, with stirring to prevent caking of the solid that separated, and 620 g. (5 moles) of chlorodimethylacetal was added through the fractionating head. Stirring and heating were resumed and the ketene dimethylacetal was removed as it reached the head. After the addition of the chloroacetal the head temperature drops fairly rapidly from *ca.* 130° (b.p. of the chloroacetal) to 89° (b.p. of ketene dimethylacetal). Fractionation of the crude products from the reaction gave 220 g. (50%) of ketene dimethylacetal, b.p. 89–93°, n^{25}_{D} 1.4035, and also a higher boiling fraction, b.p. 108–110°, n^{25}_{D} 1.3880, probably methyl orthoacetate, b.p. 107–109°, n^{25}_{D} 1.3859. The ketene dimethylacetal was fractionated to constant refractive index and found to have the following physical constants: b.p. 89–89.5° (740 mm.), n^{25}_{D} 1.4050, d^{25}_{4} 0.9294.

This compound, previously prepared by the action of sodium on methyl orthobromoacetate, was reported[10] to have the following properties: b.p. 89–91°, n^{25}_{D} 1.3962, d^{25}_{4} 0.9274.

(b) **Ketene Diethylacetal.**—Ketene diethylacetal was prepared by the dehydrobromination of bromoacetal.[11]

(c) **Benzylketene Diethylacetal.**—In a round-bottomed flask was placed 25.2 g. (0.1 mole) of ethyl orthohydrocinnamate and 24.6 g. (0.1 mole) of aluminum *t*-butoxide was added with stirring. The flask was then fitted with a fractionating column and head and heated to reflux under 10 mm. of pressure (b.p. 138°). After three hours, distillation of the remaining material gave 20 g. (97%), of benzylketene diethylacetal slightly contaminated with aluminum compounds, b.p. 128–129° (8 mm.), n^{25}_{D} 1.4980. Refractionation of this material gave the following fractions: (a) 7.8 g., b.p. 128–129° (8 mm.), n^{25}_{D} 1.4983; (b) 6.8 g., b.p. 128–129° (8 mm.), n^{25}_{D} 1.4990; (c) 4.0 g., b.p. 129–130° (8 mm.), n^{25}_{D} 1.4997; (d) 1.1 g., b.p. 129–130° (8 mm.), n^{25}_{D} 1.4992.

Analytical data for this compound are reported in the following section.

Reaction of Benzyl Bromide with Excess Ketene Diethylacetal (i) Run 3, Table I.—A mixture of 58 g. (0.34 mole) of benzyl bromide and 200 g. (1.74 mole) of ketene diethylacetal was heated for 5 hours at 125° and then for 1 hour at 135° in a modified Claisen flask, which was connected through a water-cooled receiver to Dry Ice–acetone cold trap. After the heating period the material that had collected in the receiver and the cold trap was fractionated to yield 28.3 g. (77%) of ethyl bromide and 18 g. (60%) of ethyl acetate. Fractionation of the remaining reaction product through a 70-cm. Vigreux column gave: (1) 120 g. of ketene acetal, b.p. 84–90° (200 mm.); (2) 11 g. of an intermediate fraction, b.p. 40–107° (15–10 mm.); (3) 10.8 g. of ethyl hydrocinnamate, b.p. 107–128° (10 mm.); (4) 18.8 g. of benzylketene diethylacetal, b.p. 129–131° (10 mm.); (5) 11.6 g., b.p. 75–110° (0.5 mm.); (6) 11.7 g., b.p. 115–145° (0.5 mm.).

Redistillation of (3) gave 9.7 g. (16%) of ethyl hydrocinnamate b.p. 239–246°, n^{25}_{D} 1.4922; fraction (6) contained 6.1 g. (25.4%) of ethyl dibenzylacetate as determined by the isolation of dibenzylacetic acid. Refractionation of (4) gave 17.9 g. (26%) of **benzylketene diethylacetal**, b.p. 131–132° (10 mm.), n^{25}_{D} 1.5005, d^{25}_{4} 0.9775.

Anal. Calcd. for $C_{13}H_{18}O_2$: C, 75.33; H, 8.75; C_2H_5O, 43.6. Found: C, 75.16; H, 8.79; C_2H_5O, 42.3.

In a 15-ml. distilling flask was placed 6.1 g. of benzylketene diethylacetal and 4 g. of ethanol. The temperature, on mixing the reactants, rose from 28 to 87°. After cooling, a thermometer which had been dipped in concentrated hydrochloric acid was used to stir the liquid. There was no observable change in temperature produced by this treatment. The mixture was heated for 20 minutes at 84° and then the major portion of the excess ethanol was removed under vacuum. The remaining crude orthoester was treated with an excess of sodium ethoxide in ethanol. Distillation of this alcoholic solution gave 4.10 g. (54%) of pure ethyl orthohydrocinnamate, b.p. 125–125.8° (5 mm.), n^{25}_{D} 1.4720, d^{25}_{4} 0.9760; *MR* calcd. 72.51; found: 72.17.

Anal. Calcd. for $C_{15}H_{24}O_3$: C, 71.38; H, 9.59; C_2H_5O, 53.6. Found: C, 71.43; H, 9.53; C_2H_5O, 51.0.

This ethyl orthohydrocinnamate after treatment with aqueous hydrogen chloride followed by saponification with sodium hydroxide gave practically a quantitative yield of crude hydrocinnamic acid, which after one recrystallization melted at 46–47.5°.

(ii) **Run 5, Table I.**—In a 1-l. flask, fitted with a thermometer, a dropping funnel and a 70-cm. Vigreux column, 478 g. (4.12 moles) of ketene diethylacetal was heated to reflux (*ca.* 125°). Then 158 g. (0.92 mole) of benzyl bromide was added dropwise over a 6-hour period while the temperature of the reaction was kept at 125°. After the addition of the halide this reaction temperature was maintained for another 2 hours. During the addition of the benzyl bromide, ethyl bromide and ethyl acetate distilled from the reaction and collected in the water cooled condenser and Dry Ice cold trap, which was attached to the fractionating column.

Fractionation and work-up of the reaction products as in (i) gave the yield of products shown in Table I and a recovery of 202 g. of unchanged ketene diethylacetal.

Relative Reactivities of Ketene Diethylacetal and Benzylketene Diethylacetal with Benzyl Bromide (i).—A mixture of 21.7 g. (0.105 mole) of benzylketene diethylacetal, 12.0 g. (0.104 mole) of ketene diethylacetal, and 17.8 g. (0.104 mole) of benzyl bromide was heated to 125° in a 125-ml. modified Claisen flask for five hours. Fractionation of the products through the 15-cm. Vigreux column yielded: (a) 7.80 g. (69%) of ethyl bromide, b.p. 36–40°; (b) 2.0 g. of ethyl acetate, b.p. 76–80°; (c) 1.3 g. of recovered ketene diethylacetal, b.p. 83° (200 mm.); (d) 17.5 g. of a mixture of 14.25 g. of benzylketene diethylacetal and 3.25 g. of ethyl hydrocinnamate (as determined by refractive index

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and bromine titration), b.p. 115–120° (6 mm.); (e) 16.40 g. of ethyl dibenzylacetate, b.p. 130–140° (0.7 mm.).

The fact that the ketene diethylacetal was in large measure consumed in the reaction while the benzylketene diethylacetal was largely recovered shows the greater reactivity of the former. However, the more reactive ketene diethylacetal readily undergoes side reactions that would prevent its recovery, so the most accurate way to ascertain the relative reactivities of the two ketene acetals would be a comparison of the ratios of products formed in the above competitive reaction with those produced when the ketene acetals react separately with benzyl bromide. From the results of the latter experiments (*cf.* run 1, Table I and reaction of benzyl bromide with benzylketene acetal described below), it would be expected that from the amounts of reactants used in the above competitive reaction 3.5 g. of ethyl hydrocinnamate, 21.7 g. of unchanged benzylketene diethylacetal, and 10.0 g. of ethyl dibenzylacetate would be obtained *if only* the ketene diethylacetal had reacted with the benzyl bromide; thus, the ethyl hydrocinnamate and the recovered 21.7 g. of benzylketene diethylacetal would form a 25.2-g. fraction of monobenzyl products (b.p. approximately 120° (6 mm.)) and there would be a 10.0-g. fraction of the dibenzylacetic ester. However, *if only* the benzylketene diethylacetal were to react with the benzyl bromide, 27.9 g. of ethyl dibenzylacetate would be the sole reaction product. Actually 17.5 g. of the monobenzylated products and 16.4 g. of the dibenzylated product were obtained. The fraction, F, of ketene acetal reacting ($1 - F$ = fraction of benzylketene acetal reacting) to form mono- and dibenzylated products may, therefore, be calculated:

$25.2\ F = 17.5$; $F = 0.695$ (to produce monobenzylated products) $10F + 27.9\,(1 - F) = 16.4$; $F = 0.643$ (to produce dibenzylated product) Average $F = 0.669$; $F/1 - F = 2$.

It thus appears from the amounts of benzylated products isolated from the competitive experiment that ketene acetal is approximately twice as reactive as the benzylketene acetal.

(ii).—A mixture of 66 g. (0.57 mole) of ketene diethylacetal and 100 g. (0.585 mole) of benzyl bromide was heated to 125° in a flask, fitted with a reflux condenser and a thermometer extending into the liquid. Aliquots of ten drops of the reaction mixture were removed and titrated against a standard bromine solution in carbon tetrachloride as the reaction progressed to determine the rate of disappearance of the ketene acetal. The following results were obtained:

Time, min.	Ml. of bromine used
0	1.76
15	1.20
50	0.60
65	.44
67	.40
120	.40 (end-point)

Twenty grams (0.099 mole) of benzylketene diethylacetal and 16.6 g. (0.097 mole) of benzyl bromide were treated in a similar manner and the following results were obtained:

Time, min.	Ml. of bromine used
0	1.46
65	0.76
125	.42
155	.34
230	.20

A plot of these results as % reaction *vs.* time showed that ketene diethylacetal was approximately 4 times as reactive at 20% reaction and 3.6 times as reactive at 50% reaction as benzylketene acetal.

Reaction of Benzyl Bromide and Benzylketene Diethylacetal.—A mixture of 24.5 g. of benzylketene diethylacetal and 17.4 g. of benzyl bromide was heated to 125° in a 50-ml. flask. The slow evolution of ethyl bromide ceased after nine hours; 25.4 g. (93%) of the ethyl dibenzylacetate, b.p. 140–141° (1 mm.), $n^{25}\text{D}$ 1.5354, was obtained after fractionation of the remaining material through a 30-cm. Vigreux column.

Reaction of Benzyl Bromide and Methylketene Diethylacetal.—A mixture of 88 g. (0.68 mole) of the methylketene acetal[12] and 116 g. (0.68 mole) of benzyl bromide was heated under a reflux condenser, attached at the top to a cold trap, at 140° for 8 hours. The material collected in the cold trap consisted of 52 g. (71%) of ethyl bromide. Fractionation of the remaining material yielded: (a) 15 g. (22%) of ethyl propionate b.p. 95–100°; (b) 24.4 g. (21%) of benzyl bromide, b.p. 91° (17 mm.); (c) 96.2 g. (74%) of ethyl α-methylhydrocinnamate,[13] b.p. 130–131° (17 mm.) and (d) 2.8 g., b.p. 180–222° (18 mm.).

All efforts to separate a dibenzylated propionic acid from (d), either after saponification or acidolysis with concentrated sulfuric acid, were unsuccessful.

Reaction of Ketene Diethylacetal with Ethyl Iodide.—In a glass stoppered Pyrex bottle was placed 21 g. (0.14 mole) of ethyl iodide and 240 g. (2.07 mole) of ketene diethylacetal. The bottle was stoppered and the stopper wired in. The stoppered bottle was then placed in an autoclave containing a mixture of toluene and benzene to act as a pressure balance, the autoclave sealed and heated in an oil-bath for two days. After cooling, the bottle was removed and its contents fractionated to yield the following fractions: (1) 49.6 g., b.p. 70–76°; (2) 2 g., b.p. 100–110°; (3) 127.4 g. (53%) of ethyl butyrate, b.p. 110–121°, $n^{25}\text{D}$ 1.3908; (4) 16 g. (4.8%) of ethyl orthoacetate, b.p. 89–90° (100 mm.); (5) 10 g., b.p. 65–102° (8 mm.); (6) 20 g., b.p. 104–105° (8 mm.), $n^{25}\text{D}$ 1.4220, $d^{25}{}_4$ 0.994, m.p. −19 to −17.5°; (7) 20 g. of residue.

Fraction (1) contained 20.6 g. (98% recovery) of ethyl iodide and 29 g. of ethyl acetate, as determined by refractive index. Fraction (6) on hydrolysis with dilute acid yielded ethyl α-butyrylacetate, m.p. of copper enolate[14] 125–126°; m.p. after mixing with an authentic sample, 125–126°. This behavior and analyses indicated fraction (6) to be ethyl 3,3-diethoxyhexanoate.

Anal. Calcd. for $C_6H_9O(OC_2H_5)_3$: C, 62.04; H, 10.41; OC_2H_5, 58.2. Found: C, 62.70; H, 10.45; OC_2H_5, 54.1.

Reaction of Trityl Chloride and Ketene Dimethylacetal.—In a flask carrying a thermometer, dropping funnel and a reflux condenser attached at the top to a cold trap, 28.3 g. (0.101 mole) of trityl chloride, m.p. 133°, was heated to 140°. To the molten halide 10 g. (0.113 mole) of the ketene acetal was added over a period of 20 minutes. The reaction product was a dark red semi-solid; 3 g. (59%) of methyl chloride had collected in the cold trap. The reaction product was distilled at 0.2 mm. and several fractions were collected. The lower boiling fractions were rich in trityl methyl ether while the higher boiling fractions contained, for the most part, methyl β,β,β-triphenylpropionate. Trituration with diethyl ether removed a large percentage of the ether from these latter fractions leaving reasonably pure ester. Fractional crystallizations of the ether soluble portion of the various fractions from benzene–petroleum ether (60°) finally gave a total of 11.3 g. (41%) of trityl methyl ether, m.p. 82–84°, and 14.1 g. (46%) of methyl β,β,β-triphenylpropionate, m.p. 120–121.5°. The ester was independently synthesized from the corresponding acid chloride β,β,β-triphenylpropionyl chloride[15] (m.p. 126–128°), in 96% yield by warming for five minutes in excess methyl alcohol in the presence of a trace of pyridine. The two samples of ester were identical (mixed melting point).

Anal. Calcd. for $C_{22}H_{20}O_2$: C, 83.51; H, 6.37. Found: C, 83.36; H, 6.46.

Acetylketene Diethylacetal.—In a three-necked flask fitted with stirrer, dropping funnel, and a condenser connected to a Dry Ice trap was placed 257 g. (2.22 moles) of ketene diethylacetal under an atmosphere of nitrogen. Then 43.5 g. (0.55 mole) of acetyl chloride was added from the dropping funnel at a rate sufficient to prevent too violent reaction. Fractionation of the products gave: (1) 25.6 g. (72%) of ethyl chloride, b.p. 10–15° (cold trap); (2) 26 g. (54%) of ethyl acetate, b.p. 70–78°; (3) 85 g. of recovered ketene diethylacetal, b.p. 79–84° (150 mm.); (4) 42 g. (47%) of ethyl orthoacetate, b.p. 96° (130 mm.); (5) 28 g. (34%) of ethyl β-ethoxycrotonate, b.p. 97° (21 mm.); (6) 6 g., b.p. 110–128° (21 mm.); (7) 53 g. (61%) of acetylketene diethylacetal, b.p. 130–140°; (8) 15 g. of residue.

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[13] W. Dieckmann and A. Kron, *Ber.*, **41**, 1269 (1908).

[14] C. Moureu and R. Delange, *Bull. soc. chim.*, [3] **29**, 667 (1903).

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Fraction (7) was refractionated to give an analytical sample of acetylketene diethylacetal: b.p. 138.5–140.5° (21 mm.), n^{25}D 1.4720, d^{25}_4 1.000, m.p. 7°.

Anal. Calcd. for $C_4H_4O(C_2H_5O)_2$: C, 60.74; H, 8.92; OC_2H_5, 56.9. Found: C, 60.78; H, 8.65; OC_2H_5, 53.3.

Treatment of acetylketene diethylacetal with ethanol containing a trace of acid, followed by heating and neutralization of the acidic catalyst by sodium ethoxide, gave after distillation ethyl orthoacetoacetate, b.p. 104–105° (21 mm.), d^{25}_4 0.962, n^{25}D 1.4175.

Anal. Calcd. for $C_4H_5O(OC_2H_5)_3$: C, 58.80; H, 9.87; OC_2H_5, 66.1. Found: C, 58.33; H, 9.74; OC_2H_5, 66.3.

MADISON, WISCONSIN RECEIVED DECEMBER 8, 1951

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, UNIVERSITY OF COLORADO]

The Diels–Alder Reaction of Isoprene with Styrene and 2-Vinylpyridine[1]

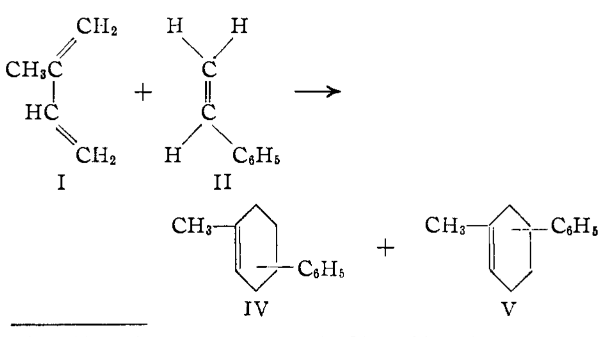
BY JOHN S. MEEK, RAYMOND T. MERROW AND STANLEY J. CRISTOL

When a monosubstituted ethylene is condensed with a monosubstituted diene in the Diels–Alder reaction, two or more isomers are possible as adducts. In reactions of this type, almost no work has been done with monoarylethylenes to determine which isomer will predominate in a given reaction. Therefore, the condensation of styrene and 2-vinylpyridine with isoprene was studied. Isoprene and styrene gave mainly 4-methyl-1,2,3,6-tetrahydrobiphenyl with a trace of 3-methyl-1,2,5,6-tetrahydrobiphenyl. The only adduct of isoprene and 2-vinylpyridine found was 1-methyl-4-(α-pyridyl)-cyclohexene.

The use of monoarylethylenes as dienophiles in the Diels–Alder reaction has been quite limited. Styrene has been found to condense with butadiene,[2] 2,3-dimethylbutadiene,[2] piperylcyclone,[3] tetraphenylcyclopentadienone[4] and hexachlorocyclopentadiene[5] to give Diels–Alder adducts. Since all of these dienes are symmetrical, no possibility exists for positional isomerism in the adducts, and the *exo–endo* isomerism was not determined. Since the presentation of our work, Alder and Haydn have reported the condensation of 2-phenyl-1,3-butadiene with styrene gives 1,4-diphenylcyclohexene and they did not isolate any isomeric 1,5-diphenylcyclohexene.[6]

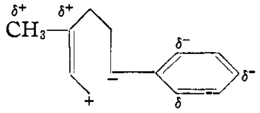
As a continuance of the work in our laboratory on the structure of Diels–Alder adducts, isoprene (I) was condensed with styrene (II), and with 2-vinylpyridine (III).

The condensation of I and II gave a 20% yield of oily adduct. On dehydrogenation with sulfur, followed by oxidation with permanganate, there was obtained a mixture of acids which consisted mainly of *p*-phenylbenzoic acid with a trace of the *m*-isomer. This showed that both 4-methyl-1,2,3,6-tetrahydrobiphenyl (IV) and 3-methyl-2,2,5,6-tetrahydrobiphenyl (V) were formed in the original Diels–Alder reaction.

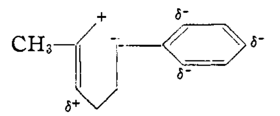


The reaction of I with III gave an adduct in 33% yield. Dehydrogenation converted the adduct to 2-(p-tolyl)-pyridine, which was identified through the picrate. None of the *m*-isomer was found in the dehydrogenation product. Since the tolylpyridines were unknown, they were synthesized by the reaction of the corresponding lithium compound with pyridine.

The predominance of 1,4-disubstituted adducts with 2-substituted dienes and monosubstituted dienophiles is reasonable when one assumes transition states such as VI and VII. The transition state VI would be stabilized to a greater degree by resonance than VII. Transition states similar to VI and VII in the Diels–Alder reaction have been discussed by Branch and Calvin,[7] Dewar[8] and Remick.[9]



VI



VII

Experimental

The isoprene used was purchased from the Phillips Petroleum Company, the styrene was a gift from the Dow Chemical Company, and the 2-vinylpyridine was bought from the Reilly Tar and Chemical Corporation. The styrene was distilled just before using, and the 2-vinylpyridine was purified by steam distillation and was then dried over magnesium sulfate.

Condensation of I and II.—Thirty-four grams (0.5 mole) of I, 52.0 g. (0.5 mole) of II and 1 g. of p-t-butylcatechol were heated to 150–160° in a Parr hydrogenation bomb for 24 hours under autogenous pressure. Distillation of the reaction mixture yielded 17.0 g. (19.7%) of crude adduct, b.p. 118–119° (6 mm.), n^{20}D 1.5351.

Anal. Calcd. for $C_{13}H_{16}$: C, 90.64; H, 9.36. Found: C, 90.19; H, 9.05.

Dehydrogenation of the Condensation Product of I and II.—Three grams of the adduct mixture and 1.15 g. of sul-

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[1] This work was supported by the Office of Naval Research and was presented in part at the 115th Meeting of the American Chemical Society, March, 1949.

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