

The picrate crystallized from benzene-alcohol in red needles, m. p. 99.2–100.6°.

Anal. Calcd. for $C_{26}H_{19}O_7N_3$: C, 64.33; H, 3.95; N, 8.66. Found: C, 64.33; H, 3.61; N, 8.46.

The *s*-trinitrobenzene derivative crystallized from benzene-alcohol in orange rectangular prisms, m. p. 125.2–125.8°.

Anal. Calcd. for $C_{26}H_{19}O_9N_3$: C, 66.52; H, 4.08; N, 8.95. Found: C, 66.45; H, 3.82; N, 8.76.

Summary

The synthesis of 5-methylchrysene, 5-ethylchrysene, and 5,6-dimethylchrysene is described,

together with a new and more generally applicable synthesis for α,γ -diphenylbutyric acid.

The recovery of a considerable amount of 1,2,3,4-tetrahydro-1-keto-2-phenylnaphthalene from the Reformatsky reaction between this ketone and ethyl α -bromobutyrate despite a large excess of reagents is noted. An explanation is offered involving reaction of the enol form of the ketone with an organozinc intermediate to produce a bromozinc enolate and ethyl butyrate. This explanation is supported by the isolation of ethyl butyrate from the reaction mixture.

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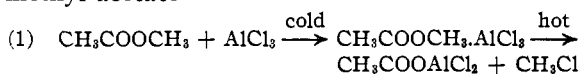
The Condensation of Esters with Aromatic Hydrocarbons by Means of Aluminum Chloride

BY JAMES F. NORRIS AND PAUL ARTHUR, JR.¹

Preliminary results of the study of the condensation of ethyl acetate and of phenyl acetate with benzene were given in a recent paper² from this Laboratory. The work was continued because the reaction appeared to give a new and valuable method for the preparation of aromatic ketones. When the investigation was about completed, an abstract of a German patent,³ bearing on the subject, was published. Our results are not in accord with certain statements in the patent; these will be considered in the experimental part of this paper.

In a communication by Bowden⁴ on the alkylation of benzene by esters by the Friedel-Crafts reaction one phase of the condensation is described. In our work special attention was paid to acylation and the study of the conditions to be used to produce alkylation alone or simultaneous alkylation and acylation.

A study of possible mechanisms of the reactions involved was made in order to gain information to be used as a guide in directing the syntheses. The results led to the following steps in the case of methyl acetate

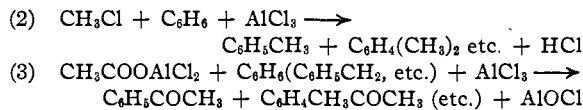


(1) From the thesis presented by Paul Arthur, Jr., in partial fulfillment of the requirements for the degree of Doctor of Philosophy, 1938.

(2) Norris and Sturgis, *THIS JOURNAL*, **61**, 1413 (1939).

(3) *Chem. Abs.*, **51**, 703 (1937).

(4) Everett Bowden, *THIS JOURNAL*, **60**, 645 (1938).



From work to be discussed later it is probable that a third step is involved in the alkylation, namely, the formation of an intermediate which contains three components, the hydrocarbon, the alkyl chloride and aluminum chloride.

One mole of aluminum chloride dissolves in one mole of methyl acetate and forms a compound which melts at about 60°. When this was heated it was stable at 132°, decomposed moderately rapidly at 143°, and rapidly at 170°. The yield of methyl chloride isolated was 0.7 mole. The solid residue ($\text{CH}_3\text{COOAlCl}_2$) obtained after the pyrolysis of the complex made from ethyl acetate and aluminum chloride, was condensed with benzene by aluminum chloride; the yield of acetophenone was 42% of the theoretical.

When methyl acetate, toluene, and aluminum chloride were heated, the products were dimethyl- and trimethylbenzene and a 60% yield of a mixture of methyl acetophenones. Since all of the dimethyl acetophenones have not been described, it was necessary to synthesize certain isomers by methods which gave evidence in regard to structure. The product obtained contained mostly 2,4-dimethylacetophenone; a smaller amount of 4-methylacetophenone was shown to be present.

In the case of ethyl acetate, alkylation alone took place at room temperature; at 90° both alkylation and acylation occurred. By control of the temperature it was possible to obtain as the chief product of the reaction either *m*-diethylbenzene or ethyl derivatives of acetophenone.

Alkylation of benzene was effected by the use of methyl and ethyl formates. Attempts to acylate with these reagents and thus form aldehydes were not successful.

Details of Experiments

Pyrolysis of Molecular Compounds of Esters and Aluminum Chloride.—The pyrolysis was effected in a tube with a side-arm connected to a U-tube containing enough water to cover the bend and to absorb the hydrogen chloride formed. The other gases, after passing through a drying tube, entered a spiral condenser cooled by dry-ice. The condensate was collected in a graduated tube placed in a toluene-bath kept cold by two test-tubes filled with dry-ice. Any permanent gases formed were collected. The tube in which pyrolysis took place was heated by the vapor of a boiling liquid which was selected according to the temperature required.

It has been shown that the compound formed from aluminum chloride and ethyl benzoate contains its components in the molecular ratio of 1:1. One mole of aluminum chloride dissolves in one mole of methyl acetate, with the evolution of heat. The compound solidifies and begins to melt at 60°. When more chloride was added it did not dissolve in the melted complex and no appreciable amount of heat was evolved. A compound was prepared from 4.5 cc. of methyl acetate and 7.8 g. of aluminum chloride (mole ratio 1:1). No methyl chloride was formed when it was heated for fifty minutes at 110°. At 143° in fifty minutes 0.05 mole was collected. When the temperature was held at 170° for two and one-half hours the total yield of methyl chloride was 0.7 mole. Heating was continued at 184° and 220° until the evolution of hydrogen chloride ceased (0.38 mole). No acetyl chloride was found. The titration of the acid and the determination of chloride ion by precipitation gave the same results.

Since ketones are formed from esters, it appeared possible that a compound of acetyl chloride and aluminum chloride was formed along with methyl chloride as the result of pyrolysis. A search for acetyl chloride was made. Combes⁵ has shown that under certain conditions acetyl chloride is converted in part by aluminum chloride into acetylacetone as the result of the loss of hydrogen chloride. The test for the ketone with ferric chloride was applied. The color produced was the same, but not so strong as that produced by a sample of acetylacetone. The behavior was tested of a mixture of acetyl chloride and aluminum chloride when heated to the temperature used in the pyrolysis. No acetyl chloride was recovered, but the product gave a test with ferric chloride. No acetylacetone was separated by using copper sulfate or dinitrophenylhydrazine. It is probable that a compound of the composition $\text{CH}_3\text{COOAlCl}_2$ is involved in the ketone synthesis, which

is similar to a compound derived from benzoic acid and is the intermediate in the formation of benzophenone from the acid.

Pyrolysis of the Compound $\text{CH}_3\text{COOC}_2\text{H}_5 \cdot \text{AlCl}_3$.—The compound began to decompose slowly at 139°; in 9.7 hours 0.67 mole of ethyl chloride was obtained. At 170° there were obtained 0.5 mole in two hours and 0.85 mole in 6.3 hours.

The residue from the pyrolysis (14.1 g.) which appears to have the formula $\text{CH}_3\text{COOAlCl}_2$ was heated on a steam-bath for three hours with benzene and aluminum chloride (mol ratio 1:2:1.2, respectively). The yield of acetophenone melting at 17.5–18° was 42% of the theoretical.

Pyrolysis of the Compound $\text{CH}_3\text{COOC}_4\text{H}_9 \cdot \text{AlCl}_3$.—The compound has been studied.⁶ It is liquid at 0°. When it was heated at 132° hydrogen chloride and a permanent gas were formed fairly rapidly. The liquid formed at 170° was shown to be *n*-butyl chloride (5%); the hydrogen chloride was 1.26 moles. The chief products were evidently butylenes and hydrogen chloride.

Pyrolysis of the Compounds Containing Methyl and Ethyl Formate and Aluminum Chloride.—The compound containing methyl formate decomposed slowly at 110°. When heated at 143°, as long as methyl chloride was formed, the yield of the latter was 88% of the theoretical. The residue when heated at 185° gave practically equivalent amounts of hydrogen chloride and carbon monoxide. The residue obtained at 143° appeared to have the same composition as the compound made from formic acid and aluminum chloride as the result of the loss of hydrogen chloride. The compound prepared in this way, when heated at 185°, yielded carbon monoxide and hydrogen chloride. This residue, obtained at 143°, should condense with benzene to give benzaldehyde, provided it behaved as the analogous residue obtained from an acetate. For this reason it was studied. Zinc chloride lowered the temperature of its pyrolysis to 140°; cuprous chloride had no effect. It did not yield an aldehyde when an attempt was made to condense it with benzene. When anhydrous formic acid was dropped into phosphorus trichloride at room temperature, a steady stream of carbon monoxide was produced.

The compound of ethyl formate and aluminum chloride gave 82% of the theoretical yield of ethyl chloride when heated at 110° for one and one-quarter hours. Subsequent heating at 184° yielded 0.93 mole of hydrogen chloride and 0.43 mole of carbon monoxide.

Alkylation of Aromatic Hydrocarbons with Esters.—The pyrolysis of compounds of esters and aluminum chloride showed that the alkyl-oxygen bond broke at a lower temperature than the acyl-oxygen bond; that the compounds which contained ethyl esters decomposed at a lower temperature than those containing methyl esters. It was shown also that one molecular quantity of aluminum chloride is used in the formation of the alkyl halide and as a result an additional mole of aluminum chloride is required for the condensation in which ketones are formed. These facts made it possible to select experimental conditions for the syntheses. The molecular ratios of the reactants used were kept constant in order to determine the influence of factors other than concentration on the products of the reactions.

(5) Combes, *Ann. chim. phys.*, (6) 18, 207 (1887).

(6) Gault and Beloff, *Bull. soc. chim.*, (v) 8, 295 (1938).

Ethylation of Benzene with Ethyl Acetate.—Aluminum chloride (117.3 g.) was added slowly to a mixture of 39.2 cc. of ethyl acetate and 71 cc. of benzene in a flask placed in ice water. The mixture stood at room temperature for about twenty-five hours and was shaken occasionally. After decomposition with ice, the dried product was fractionated through a V-packed column equivalent to 17 theoretical plates. There were obtained 33 cc. of benzene, 6 cc. of ethylbenzene, 16 cc. of *m*-diethylbenzene; 12.3% of the ester was converted into ethylbenzene and 51.3% into diethylbenzene. The latter was shown to be the meta isomer by comparing it and its derivatives with those of an authentic sample, obtained from the Eastman Kodak Company, which furnished details of the method used in its purification. These included fractional sulfonation of the diethylbenzene made from ethylene and benzene, recrystallization of the barium sulfonate, hydrolysis of the sulfonic acid, and distillation of the hydrocarbon. The physical constants obtained are given below: the constants of the *m*-diethylbenzene from the Eastman Kodak Company are given in parentheses and those reported in the literature in brackets: b. p. 181.6° at 751 mm. (181–182°) [180.5°]; m. p. < -55° (< -55°) [< -20°]; n_D^{20} 1.4922 (1.4922) [1.4926]; tetrabromo derivative, m. p. 77.8–78.2° (77.8–78.2°) [74°]. Mixed melting point showed no depression. The tetrabromo derivative of *o*-diethylbenzene melts at 64.5° and that of the para compound at 112°. Benzoylbenzoic acid by condensation with phthalic anhydride, m. p. 121.5–123° (120–121°) [114–116° (uncor.)]; neutralization equivalent of acid 281.2 (theoretical 282).

These results are not in accord with the patent, previously mentioned, which states that the para isomer is formed on alkylation of an aromatic nucleus with which an alkyl group is combined. The method appears to be the best for the preparation of *m*-diethylbenzene because it does not involve a tedious treatment to remove isomers.

Agitation of the reactants during the course of the experiment affects the relative proportions of the products formed. With very little agitation 12.2% of the ester was converted into ethylbenzene, 29% into *m*-diethylbenzene, and 17.8% into triethylbenzene. In an experiment in which the reactants were stirred for eleven hours, the corresponding figures were 18.5% ethylbenzene, 48.5% *m*-diethylbenzene and 8% triethylbenzene.

Ethylation with Ethyl Formate.—The formate was condensed with benzene under the conditions used with ethyl acetate; 11.9% of the ester was converted into ethylbenzene, 24% into diethylbenzene and 23.7% into triethylbenzene. The index of refraction of the diethylbenzene was n_D^{20} 1.4958; that of the meta isomer is n_D^{20} 1.4947. Benzene was ethylated with ethyl formate under the conditions favorable for the formation of *s*-triethylbenzene. The mole ratios used were benzene 1, aluminum chloride 5, ethyl formate 3. The reagents were mixed at the temperature of an ice-bath and then slowly heated during one hour to 70°, and finally at 94° for forty minutes. The hydrocarbon obtained was distilled with steam and fractionated; only 0.5 cc. boiled between 60 and 201°. The yield of *s*-triethylbenzene, boiling at 208–209° (uncor.), was 50.5%. The index of refraction of the part boiling at 209° was n_D^{20} 1.4925. The value is in accord with the index of a sample of *s*-triethylbenzene purified by sulfonation, etc.

Methylation with Methyl Acetate.—An experiment was made under the condition used with ethyl acetate. No alkylation took place; the result was the same when hydrogen chloride was passed into the reactants or when they were heated at 60° for two and one-half hours. At 90–96° both alkylation and acylation occurred (see later).

Methylation with Methyl Formate.—Benzene and methyl formate yielded only 5% of toluene when condensed at room temperature. The ester was condensed with toluene. To 139.4 g. of aluminum chloride suspended in 88.4 cc. of toluene was added a mixture of 44.2 cc. of toluene and 25 g. of methyl formate (mole ratio methyl formate 1, aluminum chloride 2.5, toluene 3). To the mixture was added 5 g. of cuprous chloride. The mixture stood for 107 hours and then was heated for two periods of one-half hour each at 60° and at 80°. The products recovered were benzene 0.1 mole, toluene 1.7 moles, *m*-xylene 0.45 mole. The xylene was shown to be the meta isomer by condensing it with phthalic anhydride; the aroylbenzoic acid melted at 222–224°, which is the melting point for the compound made from *m*-xylene. This condensation appears to be a good method for preparing *m*-xylene free from its isomers.

Methyl formate was condensed with benzene under favorable conditions for the preparation of mesitylene (mole ratio: C₆H₆ 1, aluminum chloride 5, methyl formate 3; time of heating was one hour at 70–85° and four hours on the steam-bath). The yield of mesitylene (b. p. 165–166°) was 46% of the theoretical. No benzene, toluene, or xylene was obtained.

Acylation of Aromatic Hydrocarbons by Means of Esters.—Acylation with esters requires a higher temperature than alkylation. The effect of the molecular ratio of aluminum chloride to the ester was studied in the case of methyl acetate. With the ratio 1 CH₃COOCH₃ to 0.62 aluminum chloride, the yield of ketones was 19% and with 1 CH₃COOCH₃ to 2.2 aluminum chloride, 51% of the theoretical.

Methyl Acetate and Toluene.—To a cooled mixture of 96 cc. of methyl acetate and 266 cc. of toluene, contained in a 1-liter flask provided with a return condenser and a wide tube, was added slowly 366 g. of aluminum chloride (mole ratio: 1:2:2.2, respectively). The mixture was heated on a steam-bath for two hours; it was left at room temperature for ten hours and finally heated for five and one-half hours. The product, after decomposition with ice and drying, was distilled through a column equivalent to 16 theoretical plates. The fractions up to 180° were collected at atmospheric pressure, the next at 50 mm. up to 180°, and finally at 2 mm. The moles of the products from 1 mole of methyl acetate were as follows: benzene 0.25, toluene 0.36, xylene 0.05, C₆H₅(CH₃)₃ 0.13, ketones 0.60; 9 cc. of high boiling liquids and 2 g. of solid materials were also obtained.

The fraction boiling at 80° was shown to be benzene by its melting point, 4.5–5°. The fraction boiling at 137–139° was condensed with tetrachlorophthalic anhydride; the melting point of the product was 206–215°, showing that it consisted principally of *m*-xylene. The fraction at 164° was nearly pure mesitylene (b. p. 165°). The crude compound prepared from it and phthalic anhydride melted at 200–211°, and after recrystallization at 210–212°, the recorded melting point is 211–212°.

That part of the ketone fraction (b. p. 135–138°) which boiled at 136° was studied. A part was treated with sodium hypochlorite. The neutralization equivalent of the acids obtained was 147.2. Since the equivalent of toluic acid is 136 and dimethylbenzoic acid 150, it appeared that the fraction examined contained about 80% of dimethylacetophenone. A sample of the mixed ketones was treated with 2,4-dinitrophenylhydrazine. Two hydrazones crystallized from the reaction mixture separately, the *p*-methyl derivative first. One compound had the same melting point (174.2–175.2° (cor.)) as the 2,4-dinitrophenylhydrazone prepared from a pure sample of 2,4-dimethylacetophenone. The quantity of hydrazone obtained showed that the original mixture of ketones contained about 80% of 2,4-dimethylacetophenone. When *p*-nitrophenylhydrazine was used, a small amount of the hydrazone of *p*-methylacetophenone was isolated. It melted at 192–193° (cor.). These results are not in accord with the patent mentioned before, which states that the ketone formed from an alkylbenzene and a simple ester is the 2,5-dialkylated ketone.

Methyl Acetate and Benzene.—The moles of reactants used were benzene 2, methyl acetate 1, aluminum chloride 2.2. The mixture was heated at 60–70° for one hour; at 70–80° for one hour, and at the reflux temperature for six and one-half hours. There was obtained a 45% yield of a mixture of ketones of which about 83% was *p*-methylacetophenone; the latter was identified by the melting point of its 2,4-dinitrophenylhydrazone and the mixed melting point of the compound and an authentic sample; the rest of the mixture was principally 2,4-dimethylacetophenone.

Ethyl Acetate and Benzene.—The mole ratio used was benzene 2; ethyl acetate 1; aluminum chloride 2.2. The mixture was heated gradually to 90° and refluxed for 2.6 hours. The yield of mixed ketones was 48%. The fraction boiling at 242–243° contained 70% *p*-ethylacetophenone; the fraction boiling at 252–262° contained 25% *p*-ethylacetophenone; the higher boiling ketone was not identified.

Phenylhydrazones Used in Identification.—Several of these derivatives, some of which have not been described, were prepared from ketones synthesized by methods that furnished evidence of structure.

4-Nitrophenylhydrazone of 2,4-Dimethylacetophenone.—The compound was prepared from a sample of the ketone, made in this Laboratory by Dr. J. N. Ingraham by condensing pure *m*-xylene with acetyl chloride. The hydrazone prepared in the usual way consisted of bright yellow crystals. The product was recrystallized from a mixture of dichloromethane and petroleum ether and melted at 154.6–154.8° (cor.). % N found, 14.9 and 14.8; theory, 14.83.

2,4-Dinitrophenylhydrazone of 2,4-Dimethylacetophenone.—After crystallization from alcohol and water, the compound was obtained as long needles that matted to-

gether; m. p. 174.2–175.2°; % N found, 16.8 and 16.8; theory, 17.07.

4-Nitrophenylhydrazone of 2,5-Dimethylacetophenone.—The ketone was prepared from *p*-xylene, acetyl chloride, and aluminum chloride. The reaction took place at 15°, with stirring for two and one-half hours, and standing at 25° for twenty minutes. That no rearrangement of the alkyl groups took place was shown by the fact that the hydrocarbon recovered was *p*-xylene which melted at 11–12°. The 4-nitrophenylhydrazone prepared from the ketone melted at 159.8–160.1° (cor.); % N found, 14.95 and 14.83; theory, 14.83. The mixed melting point of this compound with the corresponding derivative of 2,4-dimethylacetophenone (m. p. 154.4–154.8°) was 135–142°.

2,4-Dinitrophenylhydrazone of 2,5-Dimethylacetophenone.—The compound was recrystallized from alcohol; m. p. 174.2–175.2° (cor.); % N found, 17.0 and 16.9; theory, 17.07. The melting point of a mixture of this compound and the 2,4-dinitrophenylhydrazone of 2,5-dimethylacetophenone (m. p. 174.2–175.2°) was 155–162°.

2,4-Dinitrophenylhydrazone of 3,4-Dimethylacetophenone.—The ketone was prepared from *o*-xylene, acetyl chloride and aluminum chloride in the presence of carbon disulfide; the time of reaction was forty minutes at room temperature. The index of refraction of the ketone was n_D^{20} 1.5390 (literature 1.5388). The 2,4-dinitrophenylhydrazone of the ketone melted at 255.2–255.8° (cor.). A mixed melting point with the 2,4-dinitrophenylhydrazone of 4-methylacetophenone (258.6–259.4°) gave 245–250° with decomposition.

Summary

1. The condensations of methyl and ethyl formates and acetates with benzene and toluene by means of aluminum chloride have been investigated. At lower temperatures alkylation alone takes place; at higher temperatures the acetates yield derivatives of acetophenone, the structures of which have been determined.

2. The pyrolysis of the compounds of the esters and aluminum chloride has been studied. The first decomposition yielded alkyl chlorides with excellent yields. The residue obtained in this way from ethyl acetate gave acetophenone when it was condensed with benzene.

3. A number of new 4-nitro- and 2,4-dinitrophenylhydrazones of 2,4-, 2,5- and 3,4-dimethylacetophenones have been prepared and used in the identification of the ketones formed from methyl acetate.

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