Summary

1. Ultraviolet absorption spectra measurements are recorded for aqueous solutions of D-glucosyl-N-butylamine and are compared with those for similar solutions of D-glucose in alkali.

2. The above data are interpreted as demonstrating that the incipient coloration appearing when aqueous solutions of D-glucosyl-N-butylamine are allowed to stand at room temperature, is caused by hydrolysis of the compound followed by the action of the liberated hydroxyl ions upon D-glucose. It is probable that this is a general reaction of sugar-amino condensation products in these relatively high *p*H ranges.

COLUMBUS, OHIO RECEIVED JUNE 14, 1946

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY AND CHEMICAL ENGINEERING OF THE UNIVERSITY OF PENNSYLVANIA]

The Willgerodt Reaction. II. A Study of Reaction Conditions with Acetophenone and Other Ketones[1,2]

BY DELOS F. DETAR[3] AND MARVIN CARMACK

Although the Willgerodt reaction[4] has been applied to a large number of ketones for the preparation of carbonamides, no systematic study of the effect of variations of reaction conditions appears to have been published. The attempt of Willgerodt and Scholtz[5] to replace the ammonium polysulfide reagent with colorless ammonium sulfide gave poor results. One useful variant of the original procedure, introduced by Fieser and Kilmer,[6] involves the addition of dioxane to the reaction mixture; the presence of the organic solvent generally permits the use of lower reaction temperatures, and yields are often greatly improved.

In an effort to improve the usefulness of the Willgerodt synthesis of amides and to throw light on the reaction mechanism, we have made a study of the effect of the time, temperature, composition of the reagent, and presence of organic solvents on the reaction of acetophenone to form phenylacetamide. As a result of this study a modified procedure was developed which gave a total of 85.6% of phenylacetamide and phenylacetic acid as compared with the total of 63% by the original procedure of Willgerodt and Merk.[7] The improved methods were applied also to the reactions of a number of other ketones according to the general equation

$$C_6H_5COCH_3 \xrightarrow{(NH_4)_2SS_x} C_6H_5CH_2CONH_2$$

$$\text{Aryl-CO}(CH_2)_nCH_3 \longrightarrow \text{Aryl-}CH_2(CH_2)_nCONH_2$$

The results are summarized in Tables II and III in the Experimental.

According to the classical procedure the ammonium polysulfide reagent is prepared by dissolving an excess of sulfur in concentrated ammonium hydroxide which has been previously "saturated" with hydrogen sulfide. Although the published procedures are rather indefinite the molecular proportions of reactants have probably been of the following order: ketone (1), ammonia (7), hydrogen sulfide (4) and sulfur (2).

Using a standardized procedure for small-scale runs with acetophenone, we determined that the temperature range of 160–190° gives the highest yields within a convenient reaction time of four to six hours. Using combinations of sulfur, ketone, and analyzed solutions of ammonium sulfide–ammonium hydroxide in varying proportions, we found that the highest yields of amide were obtained when a large excess of sulfur was used; the optimum ratio appeared to be approximately 10 gram-atomic weights of sulfur for each mole of ketone.

When the concentration of ammonium hydroxide and the proportions of sulfur and ketone were held approximately constant and the concentration of hydrogen sulfide added to the starting mixture was varied, the interesting result emerged that the best yields of amide were obtained when only low concentrations of hydrogen sulfide were added initially. Higher concentrations of hydrogen sulfide in the reagent markedly lowered the yields of amide. This finding suggested the desirability of omitting hydrogen sulfide entirely from the reagent, a modification which gave very satisfactory results with acetophenone. Runs in which only concentrated ammonium hydroxide, sulfur and acetophenone were present initially produced higher yields than runs using comparable proportions of the same reagents with added hydrogen sulfide.

It is apparent from a consideration of the stoichiometry of the Willgerodt reaction that the over-all process involves a net oxidation which is almost certainly at the expense of the added

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[1] For the previous paper of the series, see Cavalieri, Pattison and Carmack, THIS JOURNAL, **67**, 1783 (1945).

[2] From the Ph.D. Dissertation of DeLos F. DeTar, University of Pennsylvania, 1944.

[3] Present address: Chemistry Department, Cornell University, Ithaca, N. Y.

[4] Willgerodt, *Ber.*, **20**, 2467 (1887); **21**, 534 (1888).

[5] Willgerodt and Scholtz, *J. prakt. Chem.*, [2] **81**, 382 (1910).

[6] Fieser and Kilmer, THIS JOURNAL, **62**, 1354 (1940); a bibliography of earlier references to the Willgerodt reaction appears in this paper.

[7] Willgerodt and Merk, *J. prakt. Chem.*, [2] **80**, 192 (1909).

sulfur. Some hydrogen sulfide is therefore formed as a reaction product, and will be present during most of the reaction period whether any is added to the mixture initially or not. It is not surprising therefore that the results obtained with low (0–1 *M*) initial concentrations of hydrogen sulfide were not greatly different from those obtained with concentrated ammonium hydroxide and no added hydrogen sulfide.

It is not known whether hydrogen sulfide plays an essential role in the course of the Willgerodt reaction. If it is a necessary component of the reaction mixture the evidence indicates clearly that the amount of hydrogen sulfide generated by the reaction itself is sufficient in the case of acetophenone. This does not appear to be true for all types of ketones since it was shown[1] that the best yields of amide were obtained from purely aliphatic ketones when the reagent initially contained enough hydrogen sulfide to convert all of the ammonium hydroxide to ammonium sulfide.

With alkyl aryl ketones derived from phenanthrene, pyrene, biphenyl and similar polycyclic hydrocarbons, a reagent containing approximately 0.7 *M* hydrogen sulfide (or the equivalent in ammonium sulfide) gave very satisfactory results and is convenient to prepare. The presence of low concentrations of sulfide greatly increases the solubility of sulfur in comparison with the solubility in ammonium hydroxide, and it is possible that the increase in the solubility of sulfur partially offsets the tendency of hydrogen sulfide to decrease the yields of amide.

A study of the effect of the concentration of ammonia on the yield of phenylacetamide from acetophenone showed that the yields increased with increasing concentration and leveled off in the range of 12 to 15 moles of ammonia (or ammonium salt) per liter of reagent.

The effect of ethanol, pyridine or dioxane added to the reaction mixtures was investigated. Ethanol improved the yields slightly, but pyridine and dioxane were more effective. There is no evidence that organic solvents take part in the chemical reactions, and it is assumed that their effect is due to the increased solubility of the starting ketones in the mixture of organic solvent and aqueous reagent. In runs with certain acyl derivatives of the higher polycyclic hydrocarbons a practical advantage in the use of dioxane rather than pyridine was noted. The amides often separated in fairly pure crystalline state directly from the cooled reaction mixtures containing dioxane, but remained mostly in solution in the pyridine mixtures, necessitating a slightly more elaborate method of isolation.

Experimental

Reagents.—Hydrogen sulfide gas was passed with cooling into concentrated ammonium hydroxide (15 *M*) to form solutions of colorless ammonium sulfide.[8] A dispersing disk consisting of a coarse fritted glass disk was found to increase the rate of solution. Stock solutions containing different relative concentrations of ammonia and hydrogen sulfide were made up and analyzed in order to give a range of concentrations for the experiments with acetophenone. The concentration of ammonia in the various solutions was determined by titration with standard hydrochloric acid, using methyl red as indicator. Concentrations of sulfide were determined by a procedure similar to that described by Treadwell and Hall.[9]

The colored solutions formed by mixing ammonium hydroxide, hydrogen sulfide, and sulfur are extremely complex mixtures containing many molecular and ionic species and a number of equilibrium systems which are not well understood. In order to express the composition of our reagents in a simple, if somewhat empirical, manner, we have recorded the total "molarity of ammonia" and "molarity of hydrogen sulfide" in the solutions of ammonium sulfide, as determined directly in the titrations, without attempting to evaluate the relative amounts of these substances with respect to their salt forms.

Immediately before use in a reaction, a known volume of analyzed ammonium sulfide solution was mixed with a weighed quantity of finely powdered sulfur to form the polysulfide reagent. Since hydrogen sulfide was not always used and since consequently the sulfur was not always completely in solution, it seemed preferable not to express the amount of added sulfur in terms of molarity or an empirical formula for polysulfide. Instead, the ratio of gram-atoms of sulfur to moles of ketone was recorded. This value has been referred to as the "mole ratio of sulfur" in the subsequent discussion.

Procedure for the Small-Scale Runs with Acetophenone.—Redistilled acetophenone (Eastman Kodak Co.) (1.000 g.) was weighed into a 5-inch soft-glass test-tube, the appropriate weight (±0.02 g.) of flowers of sulfur was added and 5.00 ml. of analyzed ammonium sulfide of the desired composition was introduced. Organic solvent, when used, was pipetted into the mixture at this point. The tubes were sealed and heated in a gas-heated Carius furnace, the temperature of which was held within ±5°. Usually a number of tubes in a given series were heated simultaneously in the furnace so that results would be directly comparable in spite of possible fluctuations in the temperature. Unless otherwise specified, the time of heating was four hours, not counting the time required to reach the stated temperature or cool to room temperature.

The tubes were allowed to cool to room temperature in the furnace. In experiments with acetophenone no residual pressures were observed after the tubes had cooled. The contents of each tube were evaporated to dryness in a 400-ml. beaker on a water-bath to remove volatile ammonium sulfide, leaving as a residue phenylacetamide, sulfur, ammonium phenylacetate, and small amounts of by-products. It was determined that losses of amide by volatilization were negligible. The residue in each beaker was extracted with six 10-ml. portions of boiling water, the hot solutions were clarified with charcoal, filtered, and evaporated to dryness in a tared flask. The crystalline residue was found to consist of phenylacetamide with very small amounts of phenylacetic acid and ammonium phenylacetate. The values in duplicate runs showed good reproducibility.

Determination of Optimum Time and Temperature.—In a series of preliminary runs with acetophenone, following the procedure described above, it was determined that at temperatures of 160° and higher the maximum yield of amide was obtained in a heating period of two to three hours, and that longer heating in most cases did not change the yield of amide greatly. A standard reaction time of four hours was adopted to ensure complete reaction without unnecessarily prolonging the period of heating and promoting hydrolysis of the amide. It is not certain that the runs at temperatures of 130° were complete within the four-hour periods, but at 160° and higher there seems little

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(8) As hydrogen sulfide dissolves the titer of ammonia falls slowly from approximately 15 *M* to about 12 *M* and the concentration of sulfide rises gradually to about 7 *M*.

(9) Treadwell and Hall, "Analytical Chemistry," Vol. 11, John Wiley and Sons, New York, N. Y., 1935, p. 630.

reason to believe that longer heating would have increased the amount of amide.

Effect of the Mole Ratio of Sulfur:Acetophenone.—The experiments shown graphically in Fig. 1 were made with an ammonium sulfide solution which was 12.8 *M* in ammonia and 2.4 *M* in hydrogen sulfide and to which varying proportions of sulfur were added to give the mole ratios shown in the abscissa. The three curves in Fig. 1 represent, in ascending order, the results at 130 ± 5°, 160 ± 5° and 190 ± 5°, respectively, all runs involving a heating period of four hours. The highest yield was obtained at 190° with a sulfur:ketone ratio of 10.

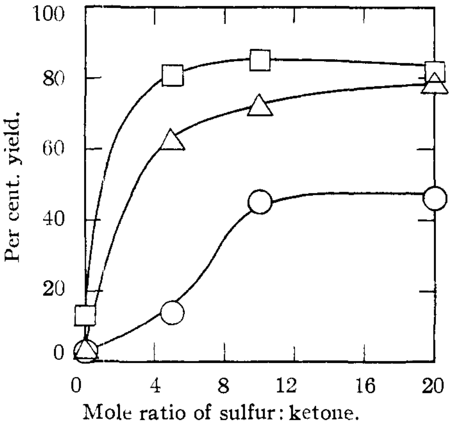

Fig. 1.—Effect of mole ratio of sulfur to ketone: O, 130 ± 5°; Δ, 160 ± 5°; □, 190 ± 5°. All experiments with 1.000 g. of $C_6H_5COCH_3$ and 5.00 ml. of ammonium sulfide solution (12.8 *M* in NH_3 and 2.4 *M*, in H_2S_5) with added sulfur as indicated; time, four hours.

Effect of Initial Concentration of Hydrogen Sulfide.—The experiments shown in Fig. 2 were made at 160° for four hours. The initial concentration of ammonia in the ammonium sulfide solution was in every case within the range 11.3–11.9 *M*, but the concentrations of hydrogen sulfide varied from 0 to slightly over 5. The three curves, in ascending order, represent sulfur:ketone mole ratios of 2, 5, and 10, respectively. It can be seen that for initial concentrations of hydrogen sulfide in the range 0–1 *M* there is little change in the yield of amide, but at higher concentrations of sulfide the yields fall off sharply.

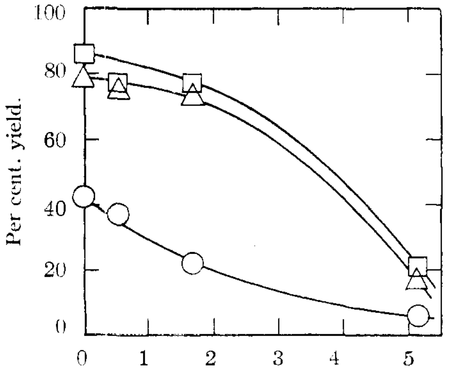

Fig. 2.—Effect of initial concentration of hydrogen sulfide: O, S:$C_6H_5COCH_3$ mole ratio 2:1; Δ, S:C_6H_5-$COCH_3$ mole ratio 5:1; □, S:$C_6H_5COCH_3$ mole ratio 10:1. All experiments with 1.000 g. of $C_6H_5COCH_3$, 5.00 ml. of ammonium sulfide solution (11.3–11.9 *M* in NH_3 and as indicated in H_2S), and sulfur in the ratios shown; 160° for four hours.

Effect of the Initial Concentration of Ammonia.—The experiments shown in Fig. 3 were carried out at 160° for four hours in concentrated ammonium hydroxide (15 *M*) without hydrogen sulfide. The three curves represent, in ascending order, mole ratios of sulfur:ketone of 2, 5, and 10, respectively. The yields are seen to reach a maximum in the concentration range of reagent ammonium hydroxide (12–15 *M*). Under the conditions of these experiments a solution initially 1.67 *M* in ammonia would contain exactly the theoretical amount of ammonia to convert all of the acetophenone to amide.

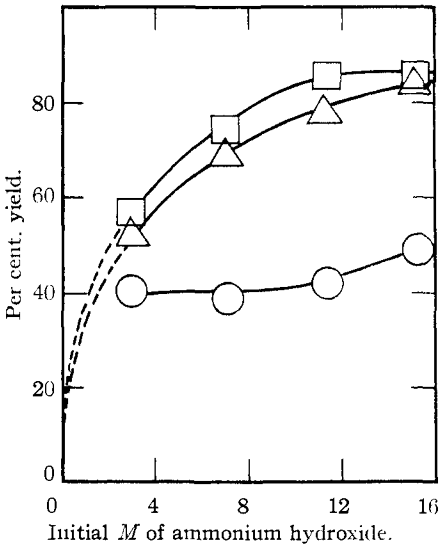

Fig. 3.—Effect of initial concentration of ammonium hydroxide: O, S:$C_6H_5COCH_3$ mole ratio 2:1; Δ, S:$C_6H_5COCH_3$ mole ratio 5:1; □, S:$C_6H_5COCH_3$ mole ratio 10:1. All experiments with 1.000 g. of $C_6H_5COCH_3$, 5.00 ml. of ammonium hydroxide of indicated *M*, and sulfur in ratios shown; 160° for four hours.

Effect of Added Organic Solvents.—Table I shows the results of a series of experiments with 1-g. quantities of acetophenone and 5-ml. quantities of ammonium sulfide. In all runs except the one with dioxane the ammonium sulfide contained 12.8 *M* ammonia and 2.4 *M* hydrogen sulfide, with sulfur:ketone ratios as shown; 2.5 ml. of

TABLE I

EFFECT OF ADDED ORGANIC SOLVENTS IN THE WILLGERODT REACTION WITH ACETOPHENONE

Temp., °C.	Mole ratio sulfur: ketone	Organic solvent added	Yield of phenylacetamide, %
130 ± 5°	5	None	14
130 ± 5°	3	Ethanol	15
130 ± 5°	3	Pyridine	27
130 ± 5°	10	None	45
130 ± 5°	12	Ethanol	73
130 ± 5°	12	Pyridine	90
158 ± 5°	5	None	62
158 ± 5°	3	Ethanol	60
158 ± 5°	5	Dioxane	76
158 ± 5°	3	Pyridine	77
158 ± 5°	10	None	72
158 ± 5°	12	Ethanol	90
158 ± 5°	12	Pyridine	99+

ethanol or pyridine was added, where indicated. In the experiment with dioxane, the ammonium sulfide was initially 12.3 *M* in ammonia and 0.69 *M* in hydrogen sulfide, and 2.0 ml. of dioxane was used. The best yield was obtained with a sulfur ratio of 12, at 158 ± 5°, in the presence of added pyridine.

Phenylacetamide from Acetophenone (Preparative Procedure).—Acetophenone (25.0 g., 0.208 mole), 37.5 g. of sulfur (1.17 gram atomic weights), 50 ml. (0.76 mole) of concentrated (15 *M*) ammonium hydroxide, and 30 ml. of pyridine were sealed in a 22-mm. o. d. hard glass (not Pyrex) bomb tube and heated to 157 ± 6° for approximately four and one-half hours. The tube was allowed to cool to room temperature and opened (no residual pressure). The reaction mixture was transferred to an evaporating dish and evaporated to dryness on a water-bath. The dry residue of sulfur and reaction product was leached with a total of about 500 ml. of boiling water in several portions. The clarified filtrate was cooled, whereupon 20.0 g. of phenylacetamide, m. p. 156–158° cor., separated from the solution. Concentration of the filtrate yielded a second crop of 2.7 g. of amide. The filtrate from the second crop was evaporated to dryness and extracted with ether, yielding an additional 0.32 g. of amide and 1.2 g. (4.2%) of phenylacetic acid. The combined yields of phenylacetamide and phenylacetic acid amounted to 85.8%. The acid, after crystallization from water, melted at 76.3–77.3° cor.

Table II

Alkyl Phenyl Ketones in the Willgerodt Reaction

Ketone	Amide obtained	M. p., °C. (cor.) amide	% Yield amide	M. p., °C. (cor.) acid
Propiophenone	β-Phenylpropionamide	97.5– 98.5[a]	82	
n-Butyrophenone	γ-Phenylbutyramide	83 – 84[b]	42	49–50[c]
n-Valerophenone	δ-Phenylvaleramide	107.5–108[d]	29	

[a] A sample prepared by another method melted at 99.5–100.2° cor. [b] Reported m. p. 84.5°.[7] A specimen of the acid, m. p. 49–50° cor., was prepared by hydrolysis and decarboxylation of ethyl β-phenethylmalonate, then converted to the amide, m. p. 83–83.5° cor., not depressed by admixture with the product of the Willgerodt reaction. [c] Reported m. p. 51°, Fischer and Schmitz, *Ber.*, **39**, 2212 (1906). [d] Reported m. p. 104–105°, Eijkman, *Chem. Weekblad*, **5**, 655 (1908); *Chem. Zentr.*, **79**, II, 1100 (1908).

The residue of sulfur remaining from the original reaction mixture after extraction with hot water was extracted further with alcohol. A small amount of oil was isolated from the alcohol, and treatment of the oil with successive portions of ether, petroleum ether, and methanol eventually afforded a few milligrams of powdery crystalline material, m. p. 141–143° cor. Recrystallization of the solid from methanol gave pale yellow plates, m. p. 145–146°, which were insufficient for further purification. The material behaved, however, very much like a mixture of 2,4- and 2,5-diphenylthiophenes prepared by heating phenylacetylene with sulfur.[10]

Reactions of Alkyl Phenyl Ketones.—Several straight-chain alkyl phenyl ketones were treated according to the modified Willgerodt procedure using concentrated ammonium hydroxide, sulfur, and pyridine under conditions found to be optimum for acetophenone, *i. e.*, approximately 5 ml. of concentrated ammonium hydroxide, 2.66 g. of sulfur and 2.5 ml. of pyridine for each gram of ketone, at 165° for four to five hours. The products were isolated as described for phenylacetamide, and were purified by recrystallization from appropriate solvents. In one case the amide was converted to the solid acid. The results are shown in Table II.

Reactions of Acyl Derivatives of Polycyclic Hydrocarbons.—Several acyl derivatives of polycyclic hydrocarbons were treated with a reagent prepared in the following manner. Powdered sulfur was suspended in ten times its weight of concentrated ammonium hydroxide and hydrogen sulfide was passed into the suspension with agitation just long enough to cause all of the sulfur to dissolve. Analysis of a typical solution showed that it contained 12.3 *M* of ammonia and 0.69 *M* hydrogen sulfide. In each of the experiments from one to three grams of ketone was heated with the reagent and dioxane in a sealed glass tube at 160° for approximately six hours. The proportions were usually 5 ml. of polysulfide reagent and 4–6 ml. of dioxane for each gram of ketone. The amide generally crystallized partially or completely upon cooling, but additional product could be recovered after evaporation of the filtrate to dryness to destroy ammonium sulfide. Some of the amides were hydrolyzed to the crystalline acids. The results of several typical experiments are summarized in Table III. Melting points are given for the purified specimens.

It is to be noted that the products in all cases had the structures expected from the usual formulation of the Willgerodt reaction, *i. e.*, no rearrangement of the carbon skeleton or loss of carbon atoms was noted, with one interesting exception: in the case of 9-propionylanthracene the side chain was lost and anthracene was recovered in 85% yield. No similar example of the complete loss of a side chain appears to have been noted previously in the Willgerodt reaction.

Table III

Acyl Derivatives of Polycyclic Hydrocarbons in the Willgerodt Reaction

Ketone	Amide obtained	M. p., °C. (cor.) amide	% Yield amide	M. p., °C. (cor.), acid
2-Acetylphenanthrene[a]	2-Phenanthreneacetamide[b]	247 –248	82	
2-Propionylphenanthrene[c]	β-(2-Phenanthrene)-propionamide[d]	189.3–189.5[e]	66	176 –178[f]
4-Acetylbiphenyl[g]	4-Biphenylacetamide[h]	242.5–243.5[i]	84	160.8–161.8[j]
9-Propionylanthracene[k]	None[l]			

[a] Prepared by the procedure of Mosettig and van de Kamp, This Journal, **55**, 3444 (1933). [b] *Anal.* Calcd. for $C_{16}H_{13}NO$: N, 5.95. Found: N, 5.89, 5.87. [c] Prepared by the procedure of Bachmann and Struve, This Journal, **58**, 1659 (1936). [d] *Anal.* Calcd. for $C_{17}H_{15}NO$: N, 5.62. Found: N, 5.65, 5.57. [e] M. p. in an evacuated capillary. [f] Reported m. p. 177.2–178.4°, Riegel, Gold, and Kubico, This Journal, **65**, 1775 (1943); reported m. p. 177–177.5°, Bachmann, *ibid.*, **57**, 1381 (1935). [g] Prepared by the procedure of Long and Henze, *ibid.*, **63**, 1939 (1940). [h] *Anal.* Calcd. for $C_{14}H_{13}NO$: N, 6.63. Found: N, 6.51, 6.56. [i] M. p. in an evacuated capillary. [j] Reported m. p. 161–162°, Lesser, German Patent, 658,114 (1938); *C. A.*, **33**, 4798 (1938). [k] Prepared by the procedure of Lüttringhaus and Kacer, U. S. Patent 1,766,433 (1930). [l] Cleavage to anthracene occurred (85% recovery).

Summary

A critical study was made of the effect of time, temperature, composition of the reagent, and the presence of organic solvents on the yield of phenylacetamide from acetophenone in the Willgerodt reaction. A modified procedure involving the use of concentrated ammonium hydroxide, sulfur and pyridine without hydrogen sulfide was developed which gave higher yields than the classical reagent, ammonium polysulfide.

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[10] Carmack and DeTar, This Journal, **68**, 2029 (1946).

The modified procedures were applied to the reactions of several straight-chain alkyl phenyl ketones and several acyl derivatives of polycyclic hydrocarbons.

9-Propionylanthracene was cleaved to give a high yield of anthracene under conditions of the Willgerodt reaction.

PHILADELPHIA, PENNSYLVANIA
RECEIVED SEPTEMBER 15, 1945

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY AND CHEMICAL ENGINEERING OF THE UNIVERSITY OF PENNSYLVANIA]

The Willgerodt and Kindler Reactions. III. Amides from Acetylenes and Olefins; Studies Relating to the Reaction Mechanisms[1,2,3]

BY MARVIN CARMACK AND DELOS F. DETAR[4]

In the course of our investigations of the Willgerodt[5] and Kindler[6] reactions we have found that acetylenes and olefins[7] behave similarly to ketones, forming carbonamides and thioamides in the two procedures, respectively. Thus, in analogy with the conversion of acetophenone to phenylacetamide,[2] phenylacetylene and styrene both give good yields of phenylacetamide

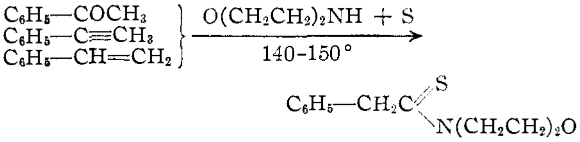
$$\left.\begin{matrix} C_6H_5—COCH_3 \\ C_6H_5—C\equiv CH \\ C_6H_5—CH=CH_2 \end{matrix}\right\} \xrightarrow[(C_5H_5N)\ 160°]{NH_4OH\ +\ S} C_6H_5—CH_2CONH_2$$

Paralleling the reaction of propiophenone, both 1-phenylpropyne and 1-phenylpropene yield β-phenylpropionamide

$$\left.\begin{matrix} C_6H_5COCH_2CH_3 \\ C_6H_5C\equiv CCH_3 \\ C_6H_5CH=CHCH_3 \end{matrix}\right\} \xrightarrow[(C_5H_5N)\ 160°]{NH_4OH\ +\ S} C_6H_5CH_2CH_2CONH_2$$

The unsaturated hydrocarbons thus share with the ketones the most remarkable feature of the Willgerodt reaction—the disappearance of an unsaturated group and the oxidation of a terminal methyl group. Under standard reaction conditions which had previously been found[2] to give optimum yields of amide from alkyl aryl ketones, the three types of compounds were found to produce amides in the following order of decreasing yields: ketones, acetylenes, olefins.

Phenylacetylene and styrene react with morpholine and sulfur to produce phenylacetothiomorpholide. The yield of *purified* product is about the same in each case as that obtained from acetophenone by the procedure of Schwenk and Bloch[6]



$$\left.\begin{matrix} C_6H_5—COCH_3 \\ C_6H_5—C\equiv CH_3 \\ C_6H_5—CH=CH_2 \end{matrix}\right\} \xrightarrow[140\text{-}150°]{O(CH_2CH_2)_2NH\ +\ S} C_6H_5—CH_2C\begin{matrix} {}^{\nearrow}S \\ {}_{\searrow}N(CH_2CH_2)_2O \end{matrix}$$

A marked evolution of hydrogen sulfides accompanies the reaction of styrene.

These reactions appear to be applicable to a wide variety of substituted acetylenes and olefins. We are exploring their scope and will report our findings in later publications.

Several further experiments carried out in this Laboratory are of interest in connection with the development of a general theory of the course of the Willgerodt reaction. Phenylacetaldehyde gives phenylacetamide under the same conditions as acetophenone, phenylacetylene and styrene. β-Phenylpropionaldehyde and phenylacetone[8] each give β-phenylpropionamide under the same conditions as propiophenone, 1-phenylpropyne, and 1-phenylpropene. However, methylphenylcarbinol,[8] β-phenylethyl alcohol,[8] β-phenylethyl acetate, and methylbenzylcarbinol fail to yield appreciable amounts of amide when heated with a typical Willgerodt reagent at 160°.

Using the ammonium polysulfide–dioxane reagent recommended by Fieser and Kilmer,[5] we were able to confirm the formation of α-methyl-γ-phenylbutyramide from isobutyl phenyl ketone, as reported originally by Willgerodt and Merk[9] and recently reinvestigated by Fieser and Kilmer.

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[1] EDITOR'S FOOTNOTE.—The original manuscript of this paper was received September 15, 1945. A manuscript by King and McMillan containing some closely related material and an interpretation of the mechanism of the Willgerodt reaction was received September 22, 1945. It was planned that both papers would appear in the same issue of THIS JOURNAL. As the result of a clerical error in the Editor's Office, however, the paper by King and McMillan was published (THIS JOURNAL, **68**, 632 (1946)) before the condensation and revision of the paper by Carmack and DeTar had been completed. In view of the prior publication of King and McMillan's paper, the article by Carmack and DeTar has been further revised to eliminate some historical material and to call attention to the results independently arrived at by King and McMillan.

[2] For the previous paper of this series see DeTar and Carmack, THIS JOURNAL, **68**, 2025 (1946).

[3] From the Ph.D. dissertation of DeLos F. DeTar, accepted by the Graduate School of the University of Pennsylvania, 1944.

[4] Present address: Department of Chemistry, Cornell University, Ithaca, N. Y.

[5] For a bibliography of references to the Willgerodt reaction consult Fieser and Kilmer, THIS JOURNAL, **62**, 1354 (1940), and ref. 2.

[6] For references to the Kindler reaction, consult Schwenk and Bloch, *ibid.*, **64**, 3051 (1942), and ref. 15.

[7] King and McMillan have observed independently that olefins yield carbonamides under conditions of the Willgerodt reaction; *cf.* footnote 1 and also *ibid.*, **68**, 525 (1946).

[8] Also investigated by King and McMillan (footnotes 1 and 7).

[9] Willgerodt and Merk, *J. prakt. Chem.*, [2] **80**, 192 (1909).