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

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[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

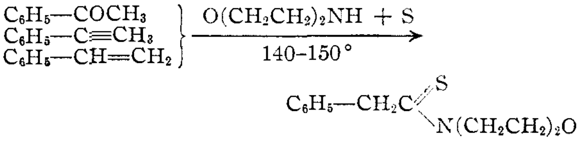
$$\left.\begin{array}{l} C_6H_5—COCH_3 \\ C_6H_5—C \equiv CH \\ C_6H_5—CH=CH_2 \end{array}\right\} \xrightarrow[(C_5H_5N)\ 160°]{NH_4OH + S} C_6H_5—CH_2CONH_2$$

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

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

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]



$$\left.\begin{array}{l} C_6H_5—COCH_3 \\ C_6H_5—C \equiv CH_3 \\ C_6H_5—CH=CH_2 \end{array}\right\} \xrightarrow[140–150°]{O(CH_2CH_2)_2NH + S} C_6H_5—CH_2C\begin{array}{l} \diagup\!\!\!\diagup S \\ \diagdown N(CH_2CH_2)_2O \end{array}$$

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.

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[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).

The yield of amide was quite low.[10] When a modified reagent consisting of concentrated aqueous ammonia, pyridine and sulfur[2] was used with isobutyl phenyl ketone the principal product isolated was phenylacetamide. Cleavage of a long chain alkyl phenyl ketone to form benzoic acid was reported by Willgerodt and Merk,[9] and recently Arnold, Schulz and Klug[14] obtained tetralincarboxylic acid from a Kindler reaction with propionyltetralin. So far as we are aware the isolation of phenylacetamide is the first example of a cleavage of the chain in a position not adjacent to the original carbonyl group. It is significant that cleavage occurred at the point of branching, an indication that the tertiary carbon atom presents a serious obstacle to the normal course of the reaction.

Consideration of the above data and the numerous examples published by Willgerodt and Kindler has led us to several general conclusions regarding this group of reactions. (1) The Willgerodt procedure, utilizing aqueous ammonia and sulfur or ammonium polysulfide, and the Kindler procedure, using primary or secondary amines and sulfur, are closely related in their fundamental chemistry. (2) The reactions of aldehydes, ketones, acetylenes, olefins and imines[15] are all fundamentally related and follow similar courses at some of the intermediate stages. (3) In all of the various modifications the normal process does not involve a rearrangement of the carbon skeleton of the starting compound. (4) Cleavage of the alkyl chain may occur, particularly when the alkyl chain is branched; the cleavage gives rise to carboxylic acid derivatives with fewer carbon atoms than are present in the starting compound. (5) The yields of amides obtained from straight chain ketones are usually very much better than those obtained under comparable conditions from analogous branched chain ketones having the same number of carbon atoms between the carbonyl group and the terminal methyl group.

The investigation of unsaturated hydrocarbons in the Willgerodt and Kindler reactions was prompted partly by stoichiometric considerations. The over-all process in every case represents a net oxidation. Acetylenes and ketones may be considered as being in the same state of oxidation, since they differ only by the elements of water. Olefins represent a lower state of oxidation and hence must undergo a greater degree of oxidation in being transformed into carboxylic acid derivatives. It was interesting and significant, therefore, that several carbinols (which bear the same relationship to olefins, with respect to the oxidation level, as carbonyl compounds to acetylenes) did not yield appreciable amounts of amides at 160° under the conditions which gave excellent yields of amides from the related carbonyl compounds and unsaturated hydrocarbons. This finding would appear to rule out the carbinols as important intermediates in the Willgerodt reactions of ketones and hydrocarbons at 160°.

Very early in the course of our investigation it seemed that the theories of Willgerodt,[16] of Kindler,[17] and of Kindler and Li[18] are inadequate to account for all of the experimental facts. It became increasingly evident, particularly in view of the results with isobutyl phenyl ketone, that a mechanism involving an assumed rearrangement of carbon atoms is improbable. The early suggestion of Willgerodt that the oxygen of the carbonyl group wanders to the end of the chain, while unsatisfactory in a literal sense, at least suggests a type of mechanism which seems capable of extension to include all of the modifications thus far developed.[19] All of the data which we have obtained are consistent with the postulate that the carbon skeleton remains fixed while a labile functional group moves along the chain and eventually undergoes irreversible oxidative conversion into a carboxylic acid derivative when it reaches the end of the chain.

In spite of the variety of starting materials which can be used for the synthesis of amides, no unequivocal evidence is available which establishes the chemical nature of the labile functional group capable of migrating along the chain; it is, in fact, possible that more than one type of group may be capable of migrating in this fashion.

The reactions of unsaturated hydrocarbons, exemplified by 1-phenylpropyne and 1-phenylpropene, may be explained by the assumption of an initial three-carbon tautomerization which would cause the unsaturated bond to move to a terminal position where it would be susceptible to an irreversible oxidation. The acetylenic bond in an unbranched aliphatic chain is known to possess a particularly high mobility in the presence of basic catalysts.[20] For example, di-*n*-amylacety-

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[10] Our yield of 1% of α-methyl-γ-phenylbutyramide was in fair agreement with the 1.8% obtained by Fieser and Kilmer (*cf.* ref. 5) but is much less than the 14–15% reported by Willgerodt and Merk (ref. 9). There is some question also as to the identity of the acid, m. p. 67.5°, which Willgerodt and Merk assumed to be α-methyl-γ-phenylbutyric acid. A specimen of α-methyl-γ-phenylbutyric acid was prepared by an unequivocal malonic ester synthesis and was found to be solid only at very low temperatures; this confirms the reports of various investigators that α-methyl-γ-phenylbutyric acid is a liquid at room temperature (refs. 11, 12 and 13).

[11] von Braun and Kirschbaum, *Ber.*, **47**, 264 (1914).

[12] Schroeter, Lichtenstadt and Ireneu, *ibid.*, **51**, 1587 (1918).

[13] Krollpfeifer and Schäfer, *ibid.*, **56**, 620 (1923).

[14] Arnold, Schultz and Klug, THIS JOURNAL, **66**, 1606 (1944).

[15] (a) Kindler, *Arch. Pharm.*, **265**, 389 (1927); (b) Kindler and Peschke, *ibid.*, **270**, 340 (1932); **272**, 236 (1934).

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

[17] Kindler, *Ann.*, **431**, 222 (1923).

[18] Kindler and Li, *Ber.*, **74B**, 321 (1941).

[19] Willgerodt did not elaborate upon his suggestion of a migrating carbonyl group. He may have visualized the original carbonyl group as forming a 1,2-epoxide, and that in turn an isomeric carbonyl compound, and so on until the oxygen appeared as an aldehyde upon the terminal carbon atom. Willgerodt demonstrated that aldehydes are converted into carbonamides under the conditions of the reaction.

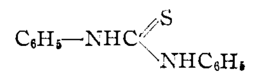
[20] (a) Bourguel, *Compt. rend.*, **179**, 686 (1925); **192**, 686 (1931); *Ann. chim.*, [10] **3**, 207 (1925); (b) Vaughn, THIS JOURNAL, **55**, 3455 (1933); (c) Nieuwland and Vogt, "The Chemistry of Acetylene," Reinhold Publishing Corp., New York, N. Y., 1945, pp. 79–81.

lene can be isomerized in one step to *n*-decylacetylene,[20b] although under conditions different from those obtaining in the Willgerodt reaction. Allylic shifts in olefinic systems are also known to be catalyzed by bases. Such tautomerizations may take place by the stepwise addition, elimination, and readdition of the elements of simple molecules such as ammonia, amines, sulfur, water and hydrogen sulfide,[21] or by the rearrangement of electrons in short-lived ionic or free-radical intermediates. The reactions of longer chain unsaturated molecules could occur similarly by a series of tautomeric shifts, terminating in the same type of final irreversible oxidation to an acid derivative. One would expect, in accordance with experimental observation, that the farther the original functional group is located from the end of the chain the more probable it will be that side reactions will intervene before the movement of the labile group to the end of the chain is complete.

The close parallelism in the reactions of ketones, acetylenes, and olefins suggests that the unsaturated hydrocarbons may be intermediates in the reactions of carbonyl compounds. This possibility is under investigation and will be reported upon at a later time. It is important to note that an acetylenic group would not be able to pass a branch in the carbon chain without the elimination of one or more groups at the point of branching. The olefinic group may be capable of passing a tertiary carbon atom, but not a quaternary carbon atom, without the elimination of a group. The isolation of α-methyl-γ-phenylbutyramide in low yield from the reaction of isobutyl phenyl ketone proves that a mechanism exists by which the branched chain compounds can react without loss of carbon, but the poor yields from this and other branched chain compounds, the occurrence of cleavage reactions at points of branching, and the very markedly higher yields obtained with straight chain starting compounds may be interpreted as pointing to the existence of at least two different mechanisms, one of which can operate effectively only in unbranched alkyl chains (or which operates in branched chains with attendant degradation of the chain).[22]

The reaction of phenylacetylene, morpholine, and sulfur to produce phenylacetothiomorpholide was chosen for a more detailed study of the nature of the terminal oxidative process because of its apparently simple stoichiometry. Four possible reaction sequences were considered, as follows: (1) phenylacetylene and sulfur combine to form a reactive intermediate capable, with morpholine, of producing a thiomorpholide[23]; (2) morpholine adds to phenylacetylene to produce a vinylamine, which then combines with the sulfur; (3) a reaction product of morpholine and sulfur adds to the phenylacetylene; or, less probable, (4) the three reactants combine simultaneously.

Weith's[24] synthesis of thiocarbanilides from isonitriles provides an isosteric analogy for the first reaction sequence



$$C_6H_5{-}N\overset{\rightarrow}{\equiv}C + S \longrightarrow C_6H_5{-}N{=}C{=}S \xrightarrow{C_6H_5NH_2} C_6H_5{-}NHC\begin{matrix}\diagup\!\!\diagup S\\ \diagdown NHC_6H_5\end{matrix}$$

Similarly, acetylene is reported[25] to react at elevated temperatures with low concentrations of oxygen to form small amounts of ketene.

Attempts were made to prepare a reactive compound by warming phenylacetylene with sulfur. The solids which were isolated after the exothermic reaction, however, appeared to consist of mixtures of diphenylthiophenes similar to those obtained as by-products in the Willgerodt reaction with acetophenone.[2,9] The intermediates, whatever their nature, are apparently too reactive to be isolated by means of the usual preparative methods. Further studies of the reaction of phenylacetylene and sulfur, using methods better suited for the detection of short-lived intermediates, are planned.

The second reaction sequence is suggested by the experiments of Kindler[15] on the conversion of methylimines (tautomers of vinylamines) of aldehydes and ketones into substituted thioamides by heating with sulfur.

The reactions of amines with sulfur are apparently very complex. It is not possible to decide from present evidence whether a preliminary combination of morpholine and sulfur is an essential step in the formation of thiomorpholides.

The relationship between the Willgerodt and Kindler reactions has been obscured by the fact that the first modification yields carbonamides while the other yields N-substituted thioamides. That a thioamide of the type $RCSNH_2$ is first formed in the Willgerodt reaction seems probable. The thioamide is not isolated, however, because

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(21) A mechanism for ketones involving addition and elimination of hydrogen sulfide was proposed by King and McMillan (*cf.* footnotes 1 and 22).

(22) King and McMillan (*cf.* footnote 1) have proposed a mechanism for carbonyl compounds involving the following sequence of steps: ketone → thioketone → mercaptan → olefin → isomeric mercaptan → thioaldehyde → dithioacid → carboxylic acid → carbonamide. We believe that these authors are correct in assuming the probable occurrence of sulfur-containing intermediates, and consider a reaction course involving mercaptans as a plausible explanation for the formation of amide in some cases, particularly when there is branching of the chain. We consider it probable, however, that other more direct reaction paths exist which do not require the starting compound or some of the intermediates to be reduced to a lower level of oxidation before being oxidized to the final acid derivative. It seems to us improbable, for example, that the acetylenes are first reduced to olefins before being converted into amides or thioamides; it is an experimental fact that olefins, on the other hand, generate quantities of hydrogen sulfide when heated with sulfur alone or with sulfur and amines.

(23) Intermediates such as phenylthioketene ($C_6H_5{-}CH{=}C{=}S$) or phenylthiirene ($C_6H_5{-}\underset{\diagdown S \diagup}{C{=}CH}$) would be expected to react with amines; this possibility could not be tested directly since there are no known examples of these types of compounds.

(24) Weith, *Ber.*, **6**, 210 (1873).

(25) E. H. Ingold, *J. Chem. Soc.*, **125**, 1534 (1924).

of its instability in hot aqueous ammonia.[26] The product of hydrolysis of the thioamide, a carbonamide of the type $RCONH_2$, is relatively stable under the usual conditions of the Willgerodt reaction. A slow hydrolysis of the amide to the ammonium salt accounts for the formation of varying, and usually small, amounts of the latter.

Experimental

Phenylacetamide from Phenylacetylene.[27]—Phenylacetylene was prepared from styrene dibromide by the action of alcoholic potassium hydroxide. A mixture of 12.0 g. of phenylacetylene, 18.9 g. of powdered sulfur, 30 ml. of concentrated (15 *M*) ammonium hydroxide, and 18 ml. of pyridine was heated in a sealed glass tube at 160 ± 5° for four hours. Phenylacetamide was isolated as previously described for the preparative reaction with acetophenone[2]; the first crop of recrystallized product amounted to 7.90 g. of glistening, colorless plates, m. p. 157–158.5° cor. Additional crops brought the total yield to 11.24 g. (72%).

Phenylacetamide from Styrene.—A mixture of 21.7 g. of styrene,[28] 37.5 g. of powdered sulfur, 50 ml. of concentrated ammonium hydroxide and 30 ml. of pyridine was heated in a sealed glass tube at 165° for four hours. The mixture was worked up as previously described for the preparative reaction with acetophenone.[2] Two crops amounting to 16.1 g. of amide, m. p. 158.6–160.1°, were obtained and an additional 2.0 g. of a mixture of amide and phenylacetic acid brought the total yield to 64%.[29]

Other Amide Syntheses.—Table I summarizes the results of several experiments with different compounds under essentially the same conditions as those used in the preceding experiments. For each gram of starting compound approximately the following quantities of reagents were used: 5 ml. of concentrated ammonium hydroxide, 2.66 g. of sulfur and 2.5 ml. of pyridine. Temperatures were in the range 156–164°; time, approximately four hours; method of isolation, as previously described.[2]

TABLE I

SYNTHESIS OF AMIDES

Starting compound	Amide isolated	% Yield, amide	M. p., ° C. (cor.)
Phenylacetaldehyde	Phenylacetamide	48	157.4–158.8
Phenylacetone	β-Phenylpropionamide	72	99.3–100.0
β-Phenylpropionaldehyde	β-Phenylpropionamide	48	99.5–100.2
1-Phenylpropyne	β-Phenylpropionamide	90	99 –100
1-Phenylpropene	β-Phenylpropionamide	74	99 –100

Phenylacetothiomorpholide from Phenylacetylene.—A mixture of 0.63 g. (0.02 mole) of flowers of sulfur and 7 ml. of morpholine was placed in a 50-ml. round-bottomed flask equipped with dropping funnel, condenser and stirrer. The mixture was heated in an oil-bath at 150 ± 5° while 2.1 g. (0.02 mole) of phenylacetylene was added dropwise, with stirring, during fifteen minutes. The last of the phenylacetylene was washed in with 3 ml. of morpholine and the mixture was cooled, taken up in ether, and washed with water. The dried ether solution yielded a partially crystalline mass which, upon recrystallization from petroleum ether (b. 90–120°), gave 2.62 g. (57.5%) of phenylacetothiomorpholide, m. p. 69–76°. When this material was recrystallized from aqueous methanol a small amount of high-melting material separated, then pure phenylacetothiomorpholide, m. p. 78–78.5° cor. A sample of the thiomorpholide for comparison was prepared from acetophenone.[6] The yield of *recrystallized* product was 55%.

Phenylacetothiomorpholide from Styrene.—A mixture of 2.1 g. of styrene, 1.28 g. of sulfur, and 10 ml. of morpholine was heated under reflux in an oil-bath at 140 ± 5° for six and one-half hours. Hydrogen sulfide was evolved. The yield of recrystallized phenylacetothiomorpholide was 2.29 g. (51%), m. p. 76–78°.

Behavior of Carbinols with the Willgerodt Reagent.—In a series of experiments each of the following compounds was studied in a Willgerodt procedure involving the use of 5 ml. of reagent (containing approximately 13 *M* ammonia and 0.7 *M* hydrogen sulfide), 5 ml. of dioxane and 0.5 g. of sulfur for each gram of compound at 160° for five hours: methylphenylcarbinol, β-phenylethyl alcohol, β-phenylethyl acetate, and methylbenzylcarbinol. The standard procedure of isolation was followed,[2] but in no case was an appreciable yield of amide obtained under these reaction conditions.

Reaction of Phenylacetylene with Sulfur.—(1) Phenylacetylene (5.0 g., 0.049 mole) and sulfur (1.5 g., 0.047 mole) were mixed in a flask and immersed in an oil-bath at 150°. A vigorous exothermic reaction set in but subsided after a few minutes. The mixture was then heated for one hour at 140–150°. The mass solidified upon cooling. In an effort to determine whether the mixture contained substances capable of reacting under mild conditions with morpholine, 2.5 g. of the reaction mixture was warmed with 5 ml. of morpholine for one hour on the water-bath; the resulting product was recrystallized from ether, giving yellow plates, m. p. 141–144°, which contained sulfur but no nitrogen. Fractional recrystallization of the solid, m. p. 141–144°, eventually gave three fractions of yellow plates melting as follows: 148.5–150° cor., 124–124.5° cor., and 108–110° cor.[30] A small amount of material melting above 200° was also obtained. The fraction melting at 124–124.5° was analyzed and found to have approximately the composition of diphenylthiophene.

Anal. Calcd. for $C_{16}H_{12}S$: C, 81.31; H, 5.12. Found: C, 80.16, 80.21; H, 5.30, 5.32.

(2) Phenylacetylene (2.5 g.) and sulfur (0.75 g.) were heated in a flask immersed in an oil-bath at 115–120°. The sulfur dissolved and a vigorous reaction took place. After five minutes, when the initial reaction had subsided, 5 ml. of morpholine was added and the solution allowed to stand for five minutes. The mixture was then diluted with water and extracted with ether. Fractional crystallization of the material in the ether extracts gave fractions similar to those obtained in the first experiment described above.

(3) A solution of 2.5 g. of phenylacetylene and 0.75 g. of sulfur in 5 ml. of carbon bisulfide was refluxed for eight hours. The reactants were recovered apparently unchanged.

The Willgerodt Reaction with Isobutyl Phenyl Ketone[31]

A. In Aqueous Pyridine Solution.—A mixture of 1.62 g. of isobutyl phenyl ketone, 3.2 g. of sulfur, 6 ml. of concentrated (15 *M*) ammonium hydroxide and 3 ml. of pyridine was heated in a sealed glass tube at 160° for four hours. The solution was evaporated to dryness on a water-bath and the dry residue was extracted with 20 ml. of hot water. Concentration of the aqueous extracts to small volume caused 0.16 g. of orange plates to separate.

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(26) Bernthsen has shown that phenylacetothioamide, for example, is converted into phenylacetamide by hot ammonium hydroxide; *Ann.*, **184**, 297 (1877).

(27) We are indebted to Mr. Dexter B. Pattison for carrying out the run described above. Runs made by one of us (D. F. D.) on approximately one-seventh this scale, using a higher proportion of sulfur, gave 80% of amide.

(28) The styrene was a gift from Mr. Mark Snyder of the United Gas Improvement Company, Philadelphia, Pa.; it was specially purified (99.5%) by low temperature crystallization, and contained traces of hydroquinone inhibitor.

(29) Runs on a much smaller scale, with a higher proportion of sulfur, gave as high as 89% yield.

(30) The melting points of some of the diphenylthiophenes are reported as follows: 2,4-, m. p. 119–120° (Baumann and Fromm, *Ber.*, **28**, 891 (1895)); 2,5-, m. p. 152–153° (Kapf and Paal, *ibid.*, **21**, 3058 (1888)); 3,4-, m. p. 114° (Hinscher, *ibid.*, **46**, 1613 (1913)).

(31) These experiments were carried out by Mr. Dexter B. Pattison.

Recrystallization of this material from chloroform-petroleum ether gave 0.05 g. of light-colored plates, m. p. 157–160°; the mixed melting point of these crystals with an authentic specimen of phenylacetamide was 158–160° cor. In order to prove that the product did not arise from impurities in the starting ketone, some of the isobutyl phenyl ketone was converted into the oxime in 98% yield, m. p. 72–73°; the oxime was reconverted into the ketone by hydrolysis with 6 N sulfuric acid. A repetition of the Willgerodt experiment with the recovered ketone gave the same results.

B. In Aqueous Dioxane Solution.[31]—A mixture of 2.4 g. of isobutyl phenyl ketone, 6.4 g. of sulfur, 12 ml. of ammonium sulfide solution (12 M in ammonia and 7.5 M in hydrogen sulfide by analysis[2]) and 6 ml. of dioxane was heated in a sealed glass tube for four hours at 190°. The mixture was evaporated to dryness, extracted with 10 ml. of hot water, and the extracts concentrated to small volume; upon cooling, 0.035 g. of brown plates separated, m. p. 100–105°. Recrystallization from water, then from ether and petroleum ether, gave a small amount of α-methyl-γ-phenylbutyramide, m. p. 118–120°. The residue from the original reaction mixture, consisting mostly of unreacted sulfur, was washed with 20 ml. of hot alcohol; 0.29 g. of oil separated from the alcohol upon cooling. The alcohol solution was separated from the oil and evaporated to dryness, leaving 0.39 g. of semisolid. The mass was spread on a porous plate, leaving 0.03 g. of nearly colorless solid; recrystallization of the latter from ether-petroleum ether gave 0.01 g. of practically colorless plates, m. p. 121–121.5° cor. A mixture of the final product with an authentic specimen of α-methyl-γ-phenylbutyramide, m. p. 121–122°, cor.; melted at 121–121.5°, cor.[32]

Summary

Acetylenes and olefins were found to give carbonamides under conditions of the Willgerodt reaction. Under conditions of the Kindler reaction acetylenes and olefins were found to produce thioamides.

Several carbonyl compounds were investigated in the Willgerodt reaction. Isobutyl phenyl ketone, a typical branched chain compound, gave a small amount of α-methyl-γ-phenylbutyramide with one reagent, but formed phenylacetamide with another reagent.

Preliminary studies were made on the course of the Willgerodt and Kindler reactions.

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(32) The sample of α-methyl-γ-phenylbutyramide for comparison was prepared by Mr. Collis H. Davis from the corresponding acid. This acid, which was liquid at room temperature, was synthesized by the hydrolysis and decarboxylation of ethyl ethyl-β-phenethylmalonate.[11] The acid was also converted into the anilide, m. p. 142–143° cor. (reported m. p. 140°[13]).

PHILADELPHIA, PENNSYLVANIA

RECEIVED SEPTEMBER 15, 1945

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

The Willgerodt Reaction. IV. Acetylenes, Olefins, and Tertiary Carbinols[1,2]

BY DEXTER B. PATTISON[3] AND MARVIN CARMACK

In an extension of the previous studies of the Willgerodt reaction with acetylenes and olefins,[1] 1-heptyne and 1-heptene were both found to yield heptanamide. Undecylenic acid gave a mixture of amides containing some nonane-1,9-dicarbonamide; hydrolysis of the mixture yielded nonane-1,9-dicarboxylic acid, indicating that the primary reaction product of the Willgerodt reaction probably contained some of the ammonium salt of the monoamide as well as the diamide.

2-Vinylnaphthalene gave 2-naphthaleneacetamide. 2-Vinylpyridine produced 2-pyridineacetamide. The latter appears to be the first example of the use of a vinyl derivative of a heterocyclic nucleus in the Willgerodt type of amide synthesis; however, the conversion of 3-acetylpyridine to the isomeric 3-pyridineacetamide has been reported.[4]

The effect of branching of the chain in olefins was studied with 1,1-diphenylethylene, 2-phenylpropene, and 1,1-dineopentylethylene. Diphenylacetamide was the only product isolated from 1,1-diphenylethylene. Under a variety of reaction conditions 2-phenylpropene produced mixtures of α-phenylpropionamide and phenylacetamide. Total yields of as high as 56% of carbonamide were obtained. Although no satisfactory quantitative separation for the two homologous amides was found, it was possible to isolate each of the products in pure form.[5] 1,1-Dineopentylethylene was cleaved with the elimination of one neopentyl group: the only identifiable product was a small amount of neopentylacetamide.

Dimethylphenylcarbinol and methyldiphenylcarbinol reacted to form the same products as 2-phenylpropene and 1,1-diphenylethylene, respectively. The yields were lower with the tertiary carbinols than with the corresponding olefins. It seems reasonable to assume that de-

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(1) For the previous paper of this series, see Carmack and DeTar, THIS JOURNAL, **68**, 2029 (1946).

(2) From the Ph.D. Dissertation of Dexter B. Pattison, University of Pennsylvania, Philadelphia, Pennsylvania, 1946.

(3) Present address: J. E. Rhoads and Sons, Wilmington, Delaware.

(4) (a) Hartmann and Bosshard, *Helv. Chim. Acta*, **24**, 28E (1941); (b) British Patent, 558,774; *British C. A.*, BII, 102 (1944).

(5) King and McMillan, THIS JOURNAL, **68**, 632 (1946), have recently reported the isolation of a 3% yield of α-phenylpropionamide in the Willgerodt reaction of 2-phenylpropene with ammonium polysulfide reagent. These authors apparently did not observe the side reaction involving the elimination of a methyl group and formation of phenylacetamide. Willgerodt and Merk, *J. prakt. Chem.*, [2] **80**, 192 (1909), and Arnold, Schultz, and Klug, THIS JOURNAL, **66**, 1606 (1944), have noted cleavages of aryl alkyl ketones to form derivatives of aryl carboxylic acids, and we have previously noted (ref. 1) the formation of phenylacetamide from phenyl isobutyl ketone.