rate of saponification of an ester group in the para position is markedly reduced when the dimethylamino group is flanked by a methyl group on each side. This is unquestionably properly interpreted as the result of steric inhibition by the two ortho methyl groups of resonance donation of electrons to the ring.

It seemed of interest, however, to extend the investigation to ascertain the nature of the steric inhibition of resonance on the position meta to the dimethylamino group, since this position is not subject to any direct influence by a resonance effect. In order to accomplish this without having a substituent ortho to the reactive ester group, it was necessary to use only one hindering methyl group, even though this would decrease the effectiveness of the hindering.

If we compare the $\Delta \log k$ resulting from the introduction of the *p*-dimethylamino group in ethyl benzoate ($\Delta \log k = \log k_S/k_H = -1.53$[3]) and in ethyl 3,5-dimethylbenzoate ($\Delta \log k = -0.26$)[3] with that for its introduction into *m*-toluate ($\Delta \log k = -0.61$), it is evident that the single methyl group is effective but not as effective as two.

The over-all negative electrical effect of the *m*-dimethylamino group ($\sigma = -0.161$) cannot be ascribed directly to any of the four basic electrical effects between a substituent and an unsaturated system. The inductive, field and electrical polarization effects all predict small positive values for σ, the resonance effect cannot directly influence the meta position. However, the negative value may be a second-order field effect, arising from the negative charges placed on the adjoining ortho and para carbon atoms by resonance. One could also account for a resonance influence to the meta position as an inductive effect sharing with the intermediate meta atoms charge placed on the ortho and para carbon atoms by resonance.

An approximate comparison of the influence of the ortho-methyl group on the electrical effect of the dimethylamino group may be obtained by subtracting the σ-constant of the methyl group from the σ-constant for the doubly-substituted esters. If we subtract the σ-value for a meta-methyl group, $\sigma = -0.102$, from that for the 4-dimethylamino-3-methylbenzoate, $\sigma = -0.360$, the contribution of the *p*-dimethylamino group in the latter corresponds to $\sigma = -0.258$, much less than the unhindered value, $\sigma = -0.720$. For the hindered *m*-dimethylamino group, the contribution corresponds to $\sigma = -0.188 \ (-0.170) = -0.018$, considerably less than the unhindered value, $\sigma = -0.160$.

NOTRE DAME, INDIANA RECEIVED MARCH 22, 1950

[CONTRIBUTION FROM THE LABORATORY OF ORGANIC CHEMISTRY OF THE UNIVERSITY OF WISCONSIN]

The Diacylation of Amides by Acyl Chloride–Pyridine Compounds

BY QUENTIN E. THOMPSON

A novel acylation of amides has been reported in which amides of the type $RCONH_2$ react with two molecules of acyl chloride–pyridine addition compound at low temperatures to give the corresponding triacylated ammonias in good yields. Evidence is presented which indicates that this acylation is a true "diacylation" and does not involve the intermediate formation of a secondary amide. Some fourteen amides have been diacylated in this manner. Seventeen acid chlorides have been investigated to determine their relative ability to diacylate amides. Using acetamide as a standard amide, diacylation occurred with the following acid chlorides in order of increasing yield: cinnamoyl, anisoyl < *p*-toluyl, 3-methoxybenzoyl < 2-naphthoyl, 4-bromobenzoyl, benzoyl, diphenylacetyl, 4-chlorobenzoyl, 4-iodobenzoyl and 3-bromobenzoyl. Of the remaining six acid chlorides, 2-furoyl, propionyl and isocaproyl chlorides gave monoacylation while ortho-, meta- and para-nitrobenzoyl chlorides gave dehydration of the amide as the principal reaction.

A recent paper[1] from this Laboratory has described the preparation of anhydrides and diacyl sulfides by the diacylation of water and hydrogen sulfide by acyl chloride–pyridine compounds. The reaction unexpectedly appeared to be a one-step acylation without the intermediate formation of the acid. Minnuni,[2] who discovered the diacylation reaction with water, suggested without supporting evidence, a mechanism which was in effect termolecular. In the present paper, the extension of the diacylation reaction to some compounds of the ammonia system is reported and evidence supporting the premise of a one-step diacylation mechanism is presented.

Certain acyl chloride–pyridine compounds were found to diacylate primary amides (*i.e.* $RCONH_2$) very readily to give good yields of the corresponding tertiary amides. In all, the reactions between

$$RCONH_2 + 2R'COCl\cdot C_5H_5N \longrightarrow RCO(COR')_2 + 2C_5H_5N\cdot HCl$$

seventeen acid chlorides and some twenty-three amides have been investigated. Generally, it was found that any or all of the following reactions could occur: (a) diacylation (b) monoacylation, and (c) dehydration of the amide to a nitrile. The factors determining the reaction or reactions occurring were the experimental conditions, the effect of substituents on the acyl–chlorine bond and to a lesser extent, the structure of the amide being acylated.

A striking characteristic of these diacylation reactions was the remarkable facility with which they occurred at low temperatures. For example, optimum conditions for the preparation of tribenzamide involved the reaction of essentially equivalent quantities of benzoyl chloride and pyridine with one equivalent (one-half mole) of benzamide in a chloroform solution at temperatures around −60°. The diacylation of acetamide by such powerful diacylating agents as diphenylacetyl chloride, 3-bromobenzoyl chloride or 4-bromobenzoyl chloride occurred most readily in more dilute solutions and at even lower temperatures. Low tempera-

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[1] H. Adkins and Q. E. Thompson, THIS JOURNAL, **71**, 2242 (1949).

[2] G. Minunni, *Gazz. chim. ital.*, **22**, 213 (1892).

tures appeared to be a prerequisite to diacylation with acid chlorides which were the best diacylating agents since it was found that temperatures above 0° tended to inhibit the reaction and caused considerable dehydration and monoacylation of the amide. In the benzoylation of benzamide, for example, the yields of tribenzamide and dibenzamide, respectively, were 85 and 1.5% at −50°; 68 and 23% at 0°; 48 and 18% at 25°. In addition to these acylation products, both benzonitrile and benzoic anhydride were isolated in quantities which indicated that essentially all of the remaining benzamide had been dehydrated.

The presence of excess pyridine was observed to have a profound effect upon the course of the reaction between amides and acid chlorides. Titherley[3] has prepared dibenzamide in quantitative yield by the benzoylation of benzamide in pyridine solution. In the present investigation, benzoylation of benzamide in chloroform solution at 0° in the presence of a threefold excess of pyridine gave tribenzamide and dibenzamide in 8.5 and 69.6% yields, respectively, as compared with 68 and 23% for the same reaction without excess pyridine. Attempts by Titherley[3] and Freundler[4] to benzoylate acetamide in pyridine were unsuccessful and yielded dibenzamide instead of N-acetylbenzamide.

To some extent the structure of the amide influenced the course of the reaction. It was possible to diacylate some fourteen amides of various structures, but attempts to benzoylate 4-nitrobenzamide,[5] α-chloroacetamide and α,α-dichloroacetamide failed. Dehydration was the only observed reaction indicating that amides which are relatively acidic (compared to acetamide) are less amenable to acylation of any kind and probably more easily dehydrated. The constitution of the acid chloride appeared to be the primary factor determining the products of the acid chloride–primary amide reaction. Three groups of acid chlorides were found: those giving mainly diacylation, but also some dehydration or monoacylation; those effecting chiefly monoacylation with some dehydration; and negatively substituted acid chlorides functioning only as dehydrating agents.

A comparative study of the diacylation properties of acid chlorides was made using acetamide as a standard amide. In addition, the amide corresponding to the acid chloride was also investigated, and in all cases where acetamide could be diacylated, it was also possible to diacylate the related amide. The results of these and other reactions are summarized in Table I.

TABLE I

SUMMARY OF ACYLATION PROPERTIES OF ACID CHLORIDES TOWARD AMIDES AND THE RELATION OF ACYLATION BEHAVIOR TO ACIDITY CONSTANT OF PARENT ACID

Acid chloride RCOCl	K_1 of parent acid[a] $K_1 \times 10^5$	Yield in reaction of acid chloride with: CH_3CONH_2	Yield in reaction of acid chloride with: $RCONH_2$	Reaction occurring
2-Furoyl	0.7	..	80	
Propionyl	1.34	24	60	Monoacylation
Isocaproyl	1.53[b]	38	65	
Anisoyl	3.38	35	52	
Cinnamoyl	3.7	25	23	
p-Toluyl	4.24	76	54	
Benzoyl	6.3	86	89	
2-Naphthoyl	6.9	83	50	
3-Methoxybenzoyl	8.17	75	81	Diacylation
4-Chlorobenzoyl	10.4	88	67	
4-Bromobenzoyl	10.7	84	76	
Diphenylacetyl	11.2	87	79	
4-Iodobenzoyl	...	92	74	
3-Bromobenzoyl	15.4	93	82	
3-Nitrobenzoyl	32.1	..	84[c]	
4-Nitrobenzoyl	37.6	..	84[c]	Dehydration
2-Nitrobenzoyl	671.0	..	57[c]	

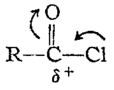
[a] N. A. Lange, "Handbook of Chemistry," Handbook Publishers, Inc., Sandusky, Ohio, 1946, p. 1377. [b] J. Bullitzer, *Monatsh.*, 20, 676 (1899). [c] These are yields of nitrile.

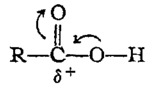
Under all conditions which were investigated, 2-furoyl, propionyl and isocaproyl chlorides were capable only of monoacylating and dehydrating amides. Di-2-furoamide, obtained in 80% yield from furoyl chloride and furoamide, could be converted to tri-2-furoamide in 89% yield by dissolving the secondary amide in pyridine and treating with another mole of furoyl chloride. Very little reaction occurred between furoyl chloride and acetamide under mild conditions, and dehydration took place when higher temperatures and greater pyridine concentrations were employed. Propionyl and isocaproyl chlorides readily monoacylated their own amides, but gave poor yields when acylating acetamide. The third category of acid chlorides was represented by ortho-, meta- and para-nitrobenzoyl chlorides. These were found to be incapable of acylating either acetamide or the related nitrobenzamide. Usually no reactions occurred at low temperatures in chloroform solution, but if more drastic conditions were employed, the amides were dehydrated according to the reaction

$$ArCOCl + ArCONH_2 \longrightarrow ArCN + ArCOOH$$
$$(Ar = o\text{-}, m\text{- or } p\text{-nitrophenyl})$$

Other nitrobenzoyl chlorides appear to give similar results, since Mitchell and Ashby[6] have employed 3,5-dinitrobenzoyl chloride in presence of pyridine for the quantitative dehydration and determination of primary amides.

The different reactions and reactivities of acid chlorides appear to have a rational basis if one considers the extent to which the acyl carbon of each is electron deficient. Acid chlorides do not have a common denominator through which this property can be easily related but, in the cases involved here, the parent acids do. Thus the extent to which the carbonyl polarization in each acyl moiety is or is not neutralized by the respective R-groups is reflected,





qualitatively at least, in the ionization constant of

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(3) A. W. Titherley, *J. Chem. Soc.*, **85**, 1684 (1904).

(4) P. Freundler, *Compt. rend.*, **137**, 712 (1903).

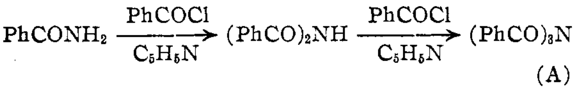
(5) From the Senior thesis of Charles S. Imig, presented at the University of Wisconsin in 1950. This work was done in coöperation with the author and the results are included here with the permission of Mr. Imig.

(6) J. Mitchell and C. E. Ashby, THIS JOURNAL, **67**, 161 (1945).

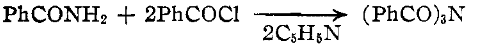
the parent acid. Examination of the data in Table I indicates that acyl halides derived from relatively weak acids give monoacylation, those from somewhat stronger acids are diacylating agents and those derived from relatively strong acids appear to function only as dehydrating agents. Undoubtedly, this is an oversimplification since steric effects are ignored as well as any limitations imposed by the presence of other reactive functional groups.

Unsuccessful attempts were made to diacylate other substituted ammonias by this apparent one-step process. The results with benzoyl chloride indicated that diacylation in the ammonia system was limited to primary amides. Ammonia, ethylamine, aniline, *p*-toluidine, and *p*-nitroaniline yielded only the corresponding substituted benzamides as the primary acylation product. Benzenesulfonamide gave an 81% yield of N-benzoylbenzenesulfonamide under diacylation conditions. Benzoylation in pyridine gave 93.4% monobenzoyl and 4.4% dibenzoylbenzenesulfonamide. Picramide gave no appreciable reaction with benzoyl chloride–pyridine under mild conditions, but reacted readily in pyridine to give a mixture of benzoyl picramide (66%) and dibenzoyl picramide (20%). Since benzoyl picramide could be benzoylated in 58% yield under the same conditions, it seemed unlikely that a one-step diacylation of picramide had occurred.

The distinction between diacylation, used in the present paper to represent a one-step replacement of two acylatable hydrogens as contrasted to their stepwise replacement by acyl groups, appears to be valid. Theoretically, the formation of tribenzamide from benzamide may occur either by route



$$\mathrm{PhCONH_2} \xrightarrow[\mathrm{C_5H_5N}]{\mathrm{PhCOCl}} \mathrm{(PhCO)_2NH} \xrightarrow[\mathrm{C_5H_5N}]{\mathrm{PhCOCl}} \mathrm{(PhCO)_3N} \qquad \text{(A)}$$



$$\mathrm{PhCONH_2} + \mathrm{2PhCOCl} \xrightarrow[\mathrm{2C_5H_5N}]{} \mathrm{(PhCO)_3N} \qquad \text{(B)}$$

(A) or (B). Titherley[3] has prepared tribenzamide by successively benzoylating benzamide in pyridine solution. The intermediate secondary amide was isolated in quantitative yield thus demonstrating that a distinct two-step acylation (route A) can occur. In the present investigation, no detectable benzoylation of dibenzamide occurred under conditions which were found to be optimum for the dibenzoylation of benzamide. Obviously had dibenzamide been formed as an intermediate in the latter reaction, high yields of tribenzamide (from dibenzamide) should have been obtained under the same conditions. Because of limited solubilities at low temperatures, these reactions were heterogeneous. By using more dilute chloroform solutions and higher temperatures, the dibenzoylation of benzamide and the benzoylation of dibenzamide were compared under homogeneous conditions. At 23°, with benzamide, benzoyl chloride and pyridine in the molecular ratio of 1:2:4, tribenzamide was obtained in 49% yield after 21.5 hours. The same reaction starting with dibenzamide and reactants in a 1:1:2 ratio, yielded only 18%. The experiments were repeated with the ratios of amide, halide, and pyridine 1:2:2.4. Benzamide at 23° for 21.5 hours gave tribenzamide in 47% yield compared to 44% for dibenzamide. At 0° for 16 hours, the yields were, respectively, 50 and 12% in spite of the fact that a molecular excess of acid chloride was present in the benzoylation of dibenzamide. Moreover, dehydration accounted for the loss of about 40% of the starting benzamide in each of these reactions whereas no dibenzamide was lost in side reactions. These results, which are summarized more fully in Table III, indicate strongly that the diacylation of amides (and presumably also of water and hydrogen sulfide) proceeds without the intermediate formation of the secondary amide and thus goes by route (B).

The question of the mechanism of diacylation requires not only a rationalization of how the reaction can occur, but why it is dependent upon extremely mild conditions, is limited to non-basic compounds (*viz.*, water, amides, etc.) and in the case of amides, at least, is further limited to acid chlorides derived from acids of intermediate acidity. Although there appear to be several possible explanations to account for these phenomena, perhaps the best is that diacylation occurs in two stages, the first of which is an attack on the amide by one mole of acylating agent to give a short-lived coördination complex of low thermal stability. Loss of hydrogen chloride in the form of pyridine hydrochloride would give the secondary amide. If, however, the complex was more susceptible to a second attack by the acylating agent than the secondary amide, and if its life was sufficiently prolonged (by mild experimental conditions) another acyl group could then be introduced giving rise eventually to a tertiary amide. Although it is possible to rationalize diacylation on this basis, there does not seem to be enough information presently available to allow a definite conclusion as to the mechanism involved.

Acknowledgment.—The author wishes to acknowledge his indebtedness to the late Professor Homer Adkins who supervised this work in its earliest stages. The interest and many helpful suggestions of Dr. Ben F. Aycock and Professor William S. Johnson are also very much appreciated.

Experimental[7]

Preparation of Tertiary Amides. General Procedure 1-a.—A solution of 0.025 mole of the desired acid chloride was prepared in 120 ml. of alcohol-free chloroform or if the reaction temperature was below −63°, in chloroform containing about 25% methylene chloride. (Exceptions, compounds 9 and 14 required 135 and 80 ml. of solvent, respectively.) This solution was cooled to the desired temperature, 5 ml. of pyridine was added to form the addition complex (exothermic), and then the finely powdered amide (0.03 mole if aliphatic or 0.0125 mole if aromatic). Only 0.0106 mole of amide was used for 14. Stirring was maintained throughout the reaction, and 5 ml. of ethanol was added and the mixture allowed to come to room temperature. Any solid not in solution at this point was collected by filtration and washed with 20 ml. of dilute hydrochloric acid. The chloroform solution was washed with two 60-ml. portions of cold 1 *N* hydrochloric acid (aqueous layers discarded) and once each with similar volumes of 0.5 *N* sodium hydroxide and distilled water. The alkaline extract was saturated with carbon dioxide in the case of compound 14 resulting in the precipitation of small amounts of the weakly acidic secondary amide 14a.

The organic layer was heated on a steam-bath under a

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[7] All melting points corrected for stem exposure.

TABLE II

TERTIARY AMIDES PREPARED BY DIACYLATION AND SECONDARY AMIDES OBTAINED AS BY-PRODUCTS

$2\,RCOCl + R^1CONH_2 \rightarrow (RCO)_2\,NCOR^1 + 2(HCl)$ where $R^1 = R, CH_3,$ or CH_3CH_2

Compd. no.	Amide	Procedure	Reacn.		Yield, %	M.p., °C. pure	Analyses, %					
			Time, hr.	Temp. (°C.)			Calcd. C	Calcd. H	Calcd. N	Found C	Found H	Found N
1	$(3\text{-}BrC_6H_4CO)_2NCOCH_3$	1-a	4	−75	93	129.4–130	45.20	2.67	3.30	45.21	2.80	3.40
2	$(3\text{-}BrC_6H_4CO)_3N$	1-c	20	−60	82	234–235 dec.[a]	44.55	2.14	2.47	44.70	2.17	2.45
3	$(4\text{-}IC_6H_4CO)_2NCOCH_3$	1-a	4	−70	92	186–187	37.02	2.14	2.70	27.00	2.13	2.77
4	$(4\text{-}IC_6H_4CO)_3N$	1-c	48	−25	74	283–284 dec.[a]	35.67	1.71	1.98	35.38	1.54	2.13
5	$(Ph_2CHCO)_2NCOCH_3$	1-a	4	−75	87	101–102	80.51	5.63	3.13	80.41	5.45	3.24
6	$(Ph_2CHCO)_3N$	1-c	26	−73	79	170–185 dec.[b]	84.10	5.54	2.34	84.15	5.34	2.40
7	$(4\text{-}ClC_6H_4CO)_2NCOCH_3$	1-a	4	−70	88	162–163	57.12	3.30	4.17	57.37	3.38	3.99
8	$(4\text{-}ClC_6H_4CO)_3N$	1-b	40	−60	67	259–260 dec.[a]	58.29	2.80	3.23	58.15	2.68	3.20
9	$(4\text{-}BrC_6H_4CO)_2NCOCH_3$	1-a	4	−70	84	176–177	45.20	2.61	3.30	45.50	2.85	3.43
10	$(4\text{-}BrC_6H_4CO)_3N$	1-a	30	−60	76	279–280 dec.[a]	44.55	2.14	2.47	44.70	1.91	2.52
11	$(2\text{-}NaphthylCO)_2NCOCH_3$	1-a	4	−70	83	143.5–144	78.45	4.66	3.81	78.29	4.63	3.68
12	$(2\text{-}NaphthylCO)_3N$	1-a	72	0	50	219–220	82.66	4.42	2.92	82.53	4.42	3.04
13	$(3\text{-}CH_3OC_6H_4CO)_2NCOCH_3$	1-a	4	−70	75	61–62	66.02	5.25	4.28	66.04	5.67	4.35
14	$(3\text{-}CH_3OC_6H_4CO)_3N$	1-a	20	−60	81	[c]	68.74	5.05	3.34	68.87	4.88	3.37
14a	$(3\text{-}CH_3OC_6H_4CO)_2NH$			—5		148–149	67.37	5.30	4.91	67.40	5.50	5.04
15	$(4\text{-}CH_3C_6H_4CO)_2NCOCH_3$	1-b	4	−65	76	156.1–156.8	73.04	5.80	4.74	73.20	5.76	4.47
16	$(4\text{-}CH_3C_6H_4CO)_3N$	1-c	24	−45	69	246 ± 2[a]	77.67	5.70	3.77	77.79	5.74	3.85
17	$(PhCH{=}CHCO)_2NCOCH_3$	1-b	2	15	25	154–155	75.20	5.37	4.38	75.40	5.45	4.11
17a	$PhCH{=}CHCONHCOCH_3$				22	131–132	69.83	5.86	7.73	69.78	5.76	7.40
18	$(PHCHOCHCO)_3N$	1-b	12	25	23	217–218 dec.[d]	79.58	5.05	3.44	79.51	5.19	3.42
18a	$(PhCH{=}CHCO)_2NH$				39	198.5–199	77.96	5.45	5.05	78.05	5.59	5.20
19	$(4\text{-}CH_3OC_6H_4CO)_2NCOCH_3$[e]	2-a	3	0	35	107.8–108.2	66.05	5.24	4.28	65.98	5.24	4.34
19a	$4\text{-}CH_3OC_6H_4CONHCOCH_3$				5	119–119.5	62.16	5.74	7.25	62.36	5.93	7.19
20	$(4\text{-}CH_3OC_6H_4CO)_3N$	2-b	12	25	52	197.5–198.0	68.74	5.05	3.34	69.08	4.99	3.27
21	$(C_6H_5CO)_2NCOCH_3$	1-b	4	−70	86	84.5–85.5	71.90	4.90	5.24	72.20	4.86	5.81
22	$(C_6H_5CO)_2NCOCH_2CH_3$[h]	1-b	4	−70	65	118.5–119.5			4.98			5.06
23	$(C_6H_5CO)_3N$	1-b	20	−60	89	211.5–212[f]			4.25			4.31
23a	$(C_6H_5CO)_2NH$				5	148–149[g]			6.22			6.36
24	$4\text{-}ClC_6H_4CON(COC_6H_5)_2$[h]	1-b	50	−60	70	188.5–189.5			3.86			3.84
	Secondary amides prepared by: $RCOCl + R'CONH_2 \rightarrow RCONHCOR' + (HCl)$, $R' = R$ or CH_3											
25	$(2\text{-}FurylCO)_2NH$	1-b	11	− 5	80	149–150	58.51	3.43	6.83	58.78	3.23	6.71
26	$CH_3CH_2CONHCOCH_3$	3-a	8	−60	24	86–87[i]			12.17			12.23
27	$(CH_3CH_2)_2NH$	3-a	4	−70	60	154.9–155.4[j]			10.84			10.78
28	$(CH_3)_2CH(CH_2)_2CONHCH_3$	3-a	7	−65	38	46–47	61.12	9.62	8.91	61.17	9.40	8.80
29	$[(CH_3)_2CH(CH_2)_2CO]_2NH$	3-a	4	−60	65	80.5–81	67.57	10.87	6.58	67.77	10.96	6.67

[a] Melting point varies with rate of heating. Preheat bath to 30° below this temperature and heat sample at rate of eight degrees per minute. [b] No definite m.p., decomposes over range. [c] This compound when crystallized from organic solvents melts unsharply in the range 130–140° and contains solvent of crystallization which can be removed only by fusing the crystals under reduced pressure. Rapid cooling of the melt gives a modification m.p. 104–105°, slow cooling gives a form m.p. 114–115°. [d] On rapid heating of sample, but melts around 209° on slow heating. [e] Isolated from crude reaction material in the form of a loose addition compound, m.p. 82–84°, with anisic anhydride. Calcd. for $C_{34}H_{31}O_{10}N$: C, 66.56; H, 5.09; N, 2.28. Found: C, 66.81; H, 4.98; N, 2.30. [f] Reported 207–208°; Blacher, *Ber.*, 28, 435 (1898). [g] Reported, 148°; see reference 3. [h] Reference 5. [i] Reported, 86°, C. E. Colby and F. D. Dodge, *Am. Chem. J.*, 13, 4 (1891). [j] Reported, 152–153°, R. Otto and J. Troger, *Ber.*, 22, 1455 (1889).

stream of air until the volatile solvent was removed. The remaining oil was cooled, allowed to crystallize and combined with any product previously collected. This crude material was usually very nearly pure tertiary amide but was sometimes contaminated with anhydride or ester. In cases where acetamide was diacylated, the nitrogen content of the crude material was determined, and if lower than theory by more than 0.25 percentage points, the proper correction was applied in calculating the yield.

Procedure 1-b.—This procedure was essentially the same as 1-a, except that 0.05 mole of acid chloride was used and 0.05 mole (if aliphatic) or 0.025 mole of amide (aromatic) was added. The volumes of solvents for each of the compounds were as follows: 55 ml. (23), 65 ml. (15, 21, 22, 24, 25), 100 ml. (8, 17, 18). With the exception of 8 (7 ml.) and 15 (16 ml.), 5 ml. of pyridine was used in each preparation. Isolation of products was effected in the same manner as 1-a. In the case of compounds 17 and 18, it was not possible to remove the corresponding secondary amides from the reaction mixture by extraction with sodium hydroxide; thus this operation was omitted. Compound 17 could be separated from the secondary amide 17a by recrystallizing from methanol, the secondary amide remaining in the mother liquor. In the preparation of 18 and 18a, the tertiary amide separated from the chloroform reaction mixture as it was formed leaving 18a in solution. Three 5-ml. portions of 0.5 *N* sodium hydroxide were used to extract the secondary amide 25 from the chloroform. Treatment with carbon dioxide caused separation of the solid amide.

Procedure 1-c.—This procedure was similar to 1-a except that for compounds 2 and 4, 0.0125 mole of acid chloride, 100 ml. of solvent, 4 ml. of pyridine and 0.0063 mole of amide were used. Compound 6 was prepared using 0.0173 mole of acid chloride, 120 ml. of solvent, 1.7 ml. of pyridine and 0.0086 mole of amide. Compound 16 required 0.044 mole of acid chloride to 50 ml. of-solvent, 10 ml. of pyridine and 0.022 mole of amide.

Procedure 2-a.—A solution of 0.05 mole of anisoyl chloride in 50 ml. of pyridine was treated with 0.05 mole of acetamide. When the reaction was complete, 5 ml. of ethanol was added and the mixture poured into 35 ml. of cold 3 *N* hydrochloric acid. The solid was separated by filtration and stirred with two 50-ml. portions of 0.5 *N* sodium hydroxide. The aqueous alkali, when saturated with carbon dioxide, yielded small amounts of 19a. The remaining solid consisted of approximately equal quantities of 19 and anisic anhydride. The pure tertiary amide was isolated by dissolving 1 g. of the crude mixture in 14 ml. of methanol and adding 0.25 g. of glycine and 10 drops of pyridine. After boiling for 20 min. the solution was poured into 75 ml. of cold 0.5 *N* sodium hydroxide. The insoluble tertiary amide was extracted with ether and crystallized.

Procedure 2-b.—To a solution of 0.025 mole of anisoyl chloride in 25 ml. of pyridine was added 0.0125 mole of anisamide. At the end of the reaction, 5 ml. of ethanol was added and the solution was poured into 250 ml. of cold 3 *N* hydrochloric acid. The solid tertiary amide, contaminated with anhydride, was collected, washed with 1 *N* sodium hydroxide and boiled with 75 ml. of ether to remove anhydride from the ether-insoluble tertiary amide.

Procedure 3-a.—A solution of 0.2 mole (for 28), 0.1 mole (for 26, 27) or 0.0348 mole (for 29) of acid chloride was prepared in 100 ml. (250 ml. for 28) of chloroform and cooled to the desired temperature. After the addition of 25 ml. (for 28), 10 ml. (for 26, 27) or 4 ml. of pyridine (29), acetamide, equal in moles to the acid chloride or one-half that amount of amide derived from the acid chloride was added as a saturated acetone solution. Compound 26 was isolated by removing chloroform and boiling the residual sirup with 200 ml. of petroleum ether (b.p. 60–68°). Concentration of the pet. ether layer yielded 26. Compounds 27 and 29 were obtained by washing out pyridine hydrochloride, removing the solvent and recrystallizing the residue. Compound 28 did not crystallize at this point and distillation was necessary. The fraction b.p. 118–122° (2 mm.) was collected.

Purification of Secondary and Tertiary Amides.—The following solvents or solvent pairs were found to be effective for recrystallization of the secondary and tertiary amides listed in Table II. Ether–petroleum ether (b.p. 60–68°), 1, 13a, 14a, 15, 19, 21, 22, 25, 27; chloroform, 2, 4[8], 8, 10, 16, 18; petroleum ether (b.p. 60–68°), 5, 19a, 26; petroleum ether (b.p. 90–100°), 9, 23a; acetone, 12, 18a, 20, 23; acetone and petroleum ether (b.p. 90–100°), 3[8], 6; carbon tetrachloride, 7, 11, 14; methanol and water, 17, 17a, 24, 29.

N-Formyldibenzamide Hydrate.—To a solution of 14 g. of benzoyl chloride and 9 ml. of pyridine in 100 ml. of chloroform at −60°, was added 2.25 g. of formamide dissolved in 10 ml. of dry acetone. After 2 hours at −60° with stirring, 5 ml. of ethanol was added and the temperature allowed to rise. Following a wash with two 60-ml. portions of 1 *N* hydrochloric acid, the solvent was removed and the solid N-formyldibenzamide hydrate remaining amounted to 9.9 g. (73%), m.p. 75–80°. Recrystallization from ether or benzene caused the hydrate to cleave smoothly to benzoic acid and N-formylbenzamide,[9] but recrystallization from methanol (30%) and water with temperatures below 60° gave small needles, m.p. 78–80°.

Anal. Calcd. for $C_{15}H_{13}O_4N$: C, 68.44; H, 4.83; N, 5.17. Found: C, 66.32; H, 4.73; N, 5.03.

Benzoylation of Benzamide and Dibenzamide (Homogeneous Conditions).—The specific details of these experiments are summarized in Table III. The amide being benzoylated was dissolved in 110 ml. of chloroform and cooled to the desired temperature. Benzoyl chloride and pyridine were added in that order. After the desired interval, 5 ml. of ethanol was added. The chloroform was washed with dilute acid (60 ml.) and dibenzamide was removed by extraction with two to five portions of cold 0.5 *N* sodium hydroxide. Crude tribenzamide, m.p. 206–208°, was obtained by removing the chloroform, and dibenzamide, m.p. 147–149° (crude), was recovered by saturating the alkaline extracts with carbon dioxide.

Benzoylation of Picramide (a) Dibenzoyl Picramide.—Benzoyl chloride (14 g.) in 50 ml. of pyridine was treated with 5.7 g. of picramide.[10] The temperature was held at 15° for 15 minutes and then allowed to rise to 25°. After stirring for 6 hours, 5 ml. of ethanol was added and the reaction mixture was poured into 250 ml. of cold 4 *N* hydrochloric acid. The solid was collected, washed with 40 ml. of petroleum ether and stirred for 5 minutes with two 75-ml. portions of 0.5 *N* sodium hydroxide to remove benzoyl picramide. The dibenzoyl picramide amounted to 2.2 g. (20%), m.p. 182–192° (crude), when collected, washed and dried. Recrystallization from acetone and petroleum ether yielded light yellow prisms, m.p. 204.5–205.5°.

Anal. Calcd. for $C_{20}H_{12}O_8N_4$: C, 55.05; H, 2.77; N, 12.81. Found: C, 55.21; H, 2.89; N, 12.59.

TABLE III

BENZOYLATION OF BENZAMIDE AND DIBENZAMIDE UNDER HOMOGENEOUS CONDITIONS

Part A. The dibenzoylation of benzamide

Expt. No.	Benzamide	Benzoyl chloride	Pyridine	Temp., °C	Time, hr.	Yield, % dibenzamide	Yield, % tribenzamide
1	0.025	0.05	0.10	23	21.5	11	49
2	.025	.05	.06	23	21.5	4	47
3	.025	.05	.06	0	16	4	50

Part B. The benzoylation of dibenzamide

	Dibenzamide, mole					Dibenzamide recovered, %	
1-a	0.025	0.025	0.05	23	21.5	74	18
2-a	.025	.05	.06	23	21.5	50	44
3-a	.025	.05	.06	0	16	85	12

(b) **Benzoyl Picramide.**—The alkaline liquors from (a) when saturated with carbon dioxide yielded 5.5 g. (66%) of benzoyl picramide. This solid, which was collected, washed with dilute acid and distilled water and dried, melted at 214–216° (crude) and 216.8–217.2° (pure), crystallizing in lemon colored needles from ethanol and acetone.

Anal. Calcd. for $C_{13}H_8O_7N_4$: C, 47.00; H, 2.42. Found: C, 47.26; H, 2.36.

N-Benzoylbenzenesulfonamide and N,N-Dibenzoylbenzenesulfonamide.—Benzenesulfonamide (3.9 g.) was treated at 0° for 24 hours with 7 g. of benzoyl chloride in 45 ml. of pyridine. The products were isolated in essentially the same manner as described for picramide except the crude mixture of benzoylated products was taken up in 300 ml. of chloroform after the reaction mixture had been poured into dilute acid. About 0.5 g. (4.4%) of dibenzoylbenzenesulfonamide remained in the chloroform after the alkali-soluble benzoylbenzenesulfonamide had been extracted with three 70-ml. portions of 0.5 *N* sodium hydroxide. Recrystallization and decolorization of the crude neutral material from ether and petroleum ether gave pure N,N-dibenzoylbenzenesulfonamide, m.p. 113–114.5° (pure), reported m.p. of an impure sample,[11] 100–105°.

Anal. Calcd. for $C_{20}H_{15}O_4NS$: N, 3.83. Found: N, 3.94.

The alkaline extracts containing benzoylbenzenesulfonamide were acidified with hydrochloric acid and yielded 6.1 g. (93.4%) of amide, m.p. 143–146° (crude) and 146–147° (pure) when recrystallized from dilute ethanol, corresponding to the reported[12] m.p. of 147°.

Tri-2-furoamide.—Difuroamide (2 g.), m.p. 149–150°, was treated with 2 g. of furoyl chloride in 20 ml. of pyridine for 12 hours at 23°. Isolation of products by pouring the reaction into dilute acid yielded 2.6 g. (89%) of trifuroamide, m.p. 158–161°. Recrystallization from ether and petroleum ether gave small colorless gritty crystals, m.p. 161–161.5°.

Anal. Calcd. for $C_{15}H_9O_6N$: C, 60.28; H, 3.03; N, 4.68. Found: C, 60.28; H, 3.11; N, 4.79.

Dehydration of Amides by the Mononitrobenzoyl Chlorides (a) 3-Nitrobenzonitrile.—To a solution of 45 ml. of pyridine and 4.63 g. of 3-nitrobenzoyl chloride, was added 4.15 g. of 3-nitrobenzamide. After 24 hours of stirring at room temperature, 5 ml. of ethanol was added and the reaction mixture poured into a separatory funnel containing 300 ml. of cold 3 *N* hydrochloric acid. Solid materials were taken up in three 60-ml. portions of chloroform. The aqueous layer was discarded and the chloroform layers were combined and extracted with two 50-ml. portions of 0.5 *N* sodium hydroxide. Alkaline extracts upon acidification yielded 3.5 g. (84.2%) of 3-nitrobenzoic acid, m.p. 130–140° (crude) and 140–141° (pure).

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[8] Principal impurity is 4-iodobenzoic anhydride, m.p. 240–241°. When this anhydride was first prepared in this Laboratory (*cf.* reference (1)) the m.p. was found to be 228–229°, corresponding closely to that previously reported by P. F. Franklin, S. R. Carter and E. B. Adams, *J. Chem. Soc.*, **101**, 2483 (1912). However, 4-iodobenzoic anhydride prepared in this Laboratory by the same method some two years later, melted 240–241°. A check of older samples which had originally melted at 228–229° showed that they now melted 240–241°. All subsequent preparations by any method have yielded the higher melting form, indicating that the lower melting material may have been a metastable crystalline modification.

[9] Q. E. Thompson, THIS JOURNAL, **73**, 5914 (1951).

[10] A. F. Holleman, *Rec. trav. chim.*, **49**, 112 (1930).

[11] Gerhardt and Chiozza, "Jahresbericht uber die Fortschritte der Chemie," p. 505, 1856.

[12] O. Wallach, *Ann.*, **214**, 211 (1882).

When the chloroform was removed, the remaining oil crystallized upon cooling and amounted to 3.1 g. (84%) of crude 3-nitrobenzonitrile, m.p. 90–105° and 117–118° after several recrystallizations from aqueous methanol. An authentic sample of nitrile was prepared by nitrating benzonitrile and, when purified, melted 117–118°, reported[13] 117–118°. Mixed melting points showed no depression.

(b) **2-Nitrobenzonitrile and 4-Nitrobenzonitrile.**—These procedures were exactly the same as described for 3-nitrobenzonitrile. Thus 2-nitrobenzoyl chloride and 2-nitrobenzamide yielded 2.1 g. (57%) of 2-nitrobenzonitrile, m.p. 95–105° (crude) and 109–110° (pure), reported[14] 110°; while 4-nitrobenzoyl chloride and 4-nitrobenzamide gave 3.1 g. (84%) of nitrile, m.p. 135–138° (crude) and 148–149° (pure), reported[15] 147.5–148.5°.

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(13) F. Beilstein and A. Kulhberg, *Ann.*, **146**, 336 (1868).

(14) A. Reissert, *Ber.*, **30**, 1039 (1897).

(15) M. T. Bogert and L. E. Wise, THIS JOURNAL, **32**, 1495 (1910).

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[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, DUKE UNIVERSITY]

Cleavage of Benzyl-, Diphenylmethyl- and Triphenylmethyltrimethylsilanes by Potassium Amide and Certain Other Bases[1]

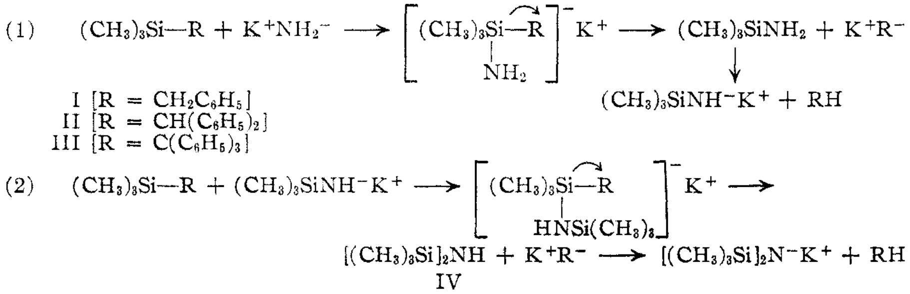
BY CHARLES R. HAUSER AND CHARLES R. HANCE

The benzyl, diphenylmethyl and triphenylmethyl groups in appropriately tetrasubstituted hydrocarbon silanes have been cleaved from silicon by potassium amide in liquid ammonia and by sodium ethoxide in refluxing ethanol. However, such cleavages were not effected by certain other basic reagents. The influence of the metallic cation and the medium was studied. Some new syntheses are described.

Although various silanols and siloxanes have been cleaved by bases to form hydrocarbons along with silicon derivatives,[2] allyltrimethylsilane has apparently been the only tetrasubstituted hydrocarbon silane cleaved previously by a base. This hydrocarbon silane was cleaved by long refluxing with methanolic potassium hydroxide to form propylene and trimethylmethoxysilane.[3] Indeed, Gilman and co-workers[2c] have shown that such hydrocarbon silanes as tetraphenylsilane and trimethylphenylsilane fail to undergo cleavage with butyl lithium in refluxing ether.

We have found that three hydrocarbon silanes, benzyltrimethylsilane (I), diphenylmethyltrimethylsilane (II) and triphenylmethyltrimethylsilane (III) are readily cleaved by potassium amide in liquid ammonia. None of the original silanes were recovered after one hour. Silane I gave toluene (77%) and silicon products which, on the basis of their physical properties, were hexamethyldisilazane (IV) (14%) and an azeotropic mixture (43%) of trimethylsilanol and hexamethyldisiloxane. The latter two compounds were formed presumably from IV during the working up process, such a hydrolysis having been reported previously.[4] Silanes II and III immediately produced red colored liquid ammonia solutions indicating the formation of the diphenylmethide and triphenylmethide ions.[5] On neutralization of the reaction mixtures with ammonium chloride, these silanes gave diphenylmethane (90%) and triphenylmethane (91%), respectively. No attempt was made to isolate the silicon products. In other experiments, the liquid ammonia was replaced by ether and Dry Ice added; silane II gave diphenylacetic acid (61%) and diphenylmethane (30%), and silane III gave triphenylacetic acid (20%) and triphenylmethane (72%).[6]

These cleavages appear to involve displacements on silicon (through the expansion of its octet) as represented by equations (1) and (2). In (1) the amide ion displaces the benzyl, diphenylmethyl or triphenylmethyl group (R) as an anion and, in (2), the anion of the trimethylaminosilane, which is formed in (1), displaces more of the hydrocarbon anion to form the disilazane (IV). The latter is probably converted by the alkyl anion (R^-) or by the amide ion to its anion. In the somewhat similar reaction of triethylsilane with potassium amide, Kraus and Nelson[7] obtained, in addition to hydrogen, the anion of hexaethyldisilazane (also called ditriethylsilicylamine).



$$(1)\quad (CH_3)_3Si{-}R + K^+NH_2^- \longrightarrow \left[\begin{array}{c}(CH_3)_3Si{-}R\\ |\\ NH_2\end{array}\right]^- K^+ \longrightarrow (CH_3)_3SiNH_2 + K^+R^-$$

$$\downarrow$$

$$(CH_3)_3SiNH^-K^+ + RH$$

$$\begin{array}{l}\text{I } [R = CH_2C_6H_5]\\ \text{II } [R = CH(C_6H_5)_2]\\ \text{III } [R = C(C_6H_5)_3]\end{array}$$

$$(2)\quad (CH_3)_3Si{-}R + (CH_3)_3SiNH^-K^+ \longrightarrow \left[\begin{array}{c}(CH_3)_3Si{-}R\\ |\\ HNSi(CH_3)_3\end{array}\right]^- K^+ \longrightarrow$$

$$\underset{\text{IV}}{[(CH_3)_3Si]_2NH} + K^+R^- \longrightarrow [(CH_3)_3Si]_2N^-K^+ + RH$$

In agreement with these equations, 11 mole per cent. of potassium amide gave with silane I twice this amount (22%) of toluene and 21% of the disilazane (IV) which was isolated as the azeotrope

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(1) The work was carried out under Contract N7onr-455 with the Office of Naval Research.

(2) See especially (a) G. Martin and F. S. Kipping, *J. Chem. Soc.*, **95**, 302 (1909); (b) R. H. Krieble and J. R. Elliot, THIS JOURNAL, **68**, 2291 (1946); and (c) H. Gilman, R. A. Benkeser and G. E. Dunn, *ibid.*, **72**, 1689 (1950).

(3) L. H. Sommer, L. J. Tyler and F. C. Whitmore, *ibid.*, **70**, 2872 (1948).

(4) R. O. Sauer and R. H. Hasek, *ibid.*, **68**, 241 (1946).

(5) Although silane II has a benzohydrilic hydrogen that might be ionized by the amide ion to produce a colored anion, silane III has no such active hydrogen and the color is undoubtedly due to the triphenylmethide ion formed on cleavage.

(6) This relatively low yield of triphenylacetic acid is rather surprising since the triphenylmethide ion has been carbonated in high yield under somewhat similar conditions. See R. Levine, E. Baumgarten and C. R. Hauser, THIS JOURNAL, **66**, 1230 (1944).

(7) C. A. Kraus and W. K. Nelson, *ibid.*, **56**, 195 (1934).