tration unit (moles/l.) are made. The slope actually obtained from Fig. 6 is 21,900. The ratio 24,660/21,900 is within 1% of the ratio 4.2/3.7 (Table I), which shows clearly that incomplete extraction alone is responsible for the difference in these two slopes.

That dithizone is acid in character and may consequently be expected to form salts was demonstrated by its discoverer,[1b] who isolated from acid solution a zinc dithizonate of the formula $ZnD_2 \cdot H_2O$. As Hellmut Fischer[2c] has pointed out, the reactions which dithizone undergoes as an analytical reagent can all, with the possible exception of its oxidation, be explained on the assumption that enolization to give an H—S—C=N linkage occurs. He has also given plausible structural formulas of the dithizonates, according to which D^- is present in the keto form in CuD_2, and in the enol form in PbD. The essential difference between the two structural formulas is that a divalent metal is bound to both nitrogen and sulfur in the latter but only to nitrogen in the former.

Summary

With the aid of a photoelectric recording spectrophotometer, the spectral transmission in the visible range of carbon tetrachloride solutions of dithizone, its oxidation product, and of copper dithizonate have been measured.

The dithizone analytical methods for copper and lead have been modified so as to make them more reliable for small amounts; 1γ of either element can now be determined with reasonable accuracy.

The two chief difficulties encountered in securing results of high precision with these small amounts were incomplete extraction by the reagent solution of the aqueous layer containing the metals, and the oxidation of the reagent, which appears to be catalyzed by copper ion.

Transmission measurements involving only a few γ of either metal gave the formulas PbD and CuD_2 for lead and copper dithizonates.

Our experience with dithizone as an analytical reagent indicates that satisfactory quantitative results on small samples can be obtained only through painstaking and somewhat tedious manipulation. For this reason, it often will be advisable to use other methods of analysis when these will achieve the desired result.

SCHENECTADY, N. Y. RECEIVED JULY 23, 1937

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, UNIVERSITY OF NOTRE DAME]

Ester Formation and Some Structural Relationships

BY S. GERALDINE TOOLE AND FRANK J. SOWA

Bergmann, Engel and Wolff[1] in their work on the dipole moments of substituted methane derivatives showed that the tetrahedral angle caused by a chloro substitution was about the same as that of a phenyl group; or, in other words, the chlorine atom and the phenyl group possess about the same spacial requirements.

This investigation was undertaken to study the relationship between spacial requirements and chemical reactivity as applied to the formation of esters.

The process of ester formation suggests itself to determine this relationship using compounds that contain phenyl and chloro substituents in the acids and amides, for example, phenyl-, chloro-, dichloro-, and trichloroacetic acids and acetamides. In the case of the acetamides a relationship not involving acidity was introduced. The same agent, boron fluoride, was used to transform both acids[2,3] and amides[4] with alcohol into esters in this study.

Experimental Part

Amides with Methyl Alcohol.—Into a one-liter flask was weighed 0.75 mole of an acetamide and 1.5 moles of absolute methyl alcohol. The flask was fitted with a two-holed stopper containing an inlet and outlet tube. Boron fluoride was passed into the solution until it had absorbed 0.75 mole of the gas. The flask was cooled in an ice-bath during the total absorption. The solution was then refluxed for forty-five minutes. During this period the solution became cloudy due to the separation of monoamminoboron fluoride. After distillation directly from the reaction flask the ester was purified in the usual manner and fractionated. With the exception of methyl formate,

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[1] Bergmann, Engel and Wolff, *Z. physik. Chem.*, **17B**, 81 (1931).

[2] Hinton and Nieuwland, THIS JOURNAL, **54**, 2017 (1932).

[3] Sowa and Nieuwland, *ibid.*, **58**, 271 (1936).

[4] *Idem*, **55**, 5052 (1933).

which was not refluxed, the esters recorded in Table I were all prepared by the procedure just described. The results are the average of two yields which checked well with each other.

TABLE I

ESTERS FROM AMIDES AND METHYL ALCOHOL

Name of amide	Amide m. p., °C.	Methyl ester b. p., °C.	Methyl ester yield, %
Formamide	3	31	34
Acetamide	80	57	70
Chloroacetamide	118	131	64
Dichloroacetamide	98	143	57
Trichloroacetamide	141	153	53
Phenylacetamide	102	220	50
Propionamide	77	79	80
Benzamide	126	199	15

Acids with Methyl Alcohol (BF_3).—Into a one-liter flask was weighed 0.75 mole of the acid, 1.5 mole of absolute methyl alcohol, and 7.0 g. of the compound ether-boron fluoride, $(C_2H_5)_2O \cdot BF_3$. The solution was refluxed carefully for forty-five minutes at a temperature of 64 ± 1°, cooled to room temperature and purified in the usual manner, care being taken to recover all of the ester. Table II records the yields of methyl esters prepared in several runs both with and without boron fluoride.

TABLE II

ESTERS FROM ACIDS AND METHYL ALCOHOL

Acid used	$(C_2H_5)_2O \cdot BF_3$, g.	Ester yield, %
Acetic	7.0	56
Chloroacetic	0.0	43
Chloroacetic	7.0	65
Dichloroacetic	0.0	47
Dichloroacetic	7.0	70
Trichloroacetic	0.0	50
Trichloroacetic	7.0	73
Phenylacetic	0.0	0
Phenylacetic	7.0	86
Propionic	7.0	44
Benzoic	7.0	37

Acids with Methyl Alcohol (HCl).—Three pressure bottles were marked, mono-, di- and trichloroacetic acid. Into each was weighed 0.5 mole of the corresponding acid and one mole of methyl alcohol containing no hydrogen chloride. The bottles were sealed and placed in a constant temperature bath. The bath was equipped with a thermostat, heaters and a mechanical stirrer. The temperature was kept at 50 ± 1°. A series of reactions were run in which the only variable was time. The ester was purified in the usual manner immediately after the reaction was over.

A second series of reactions were run using 1.97 g. of hydrogen chloride in which the only variable was time. The maximum yields with the optimum time are given in Table III.

TABLE III

ESTERS FROM ACIDS AND METHYL ALCOHOL

Acid used	Time, min.	HCl used, g.	Ester yield, %
Chloroacetic	960	0.0	54.2
	240	1.97	68.5
Dichloroacetic	480	0.0	61.4
	240	1.97	72.0
Trichloroacetic	270	0.0	66.7
	240	1.97	74.6

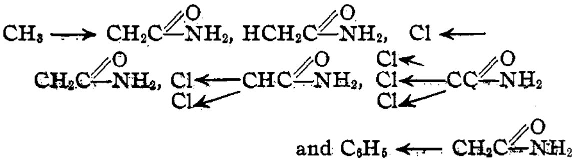
Acids with Methyl Alcohol (H_2SO_4).—A series of experiments was performed as described in the previous case except that 10 cc. of concentrated sulfuric acid was used in place of the hydrogen chloride. The temperature was maintained at 60 ± 1° for one hour. The yields of the methyl esters of chloroacetic, dichloroacetic, trichloroacetic and phenylacetic acids were 60.2, 71.3, 88.4 and 90.1%, respectively. By using dilute sulfuric acid the yields increased in the same order.

Acids with Ethyl Alcohol (HCl).—This reaction was performed exactly as described under "Acids with Methyl Alcohol (HCl)." By using 2 g. of hydrogen chloride and heating at 50° for five hours the yields of the ethyl ester of trichloroacetic, dichloroacetic, chloroacetic and phenylacetic acids were 53.1, 55.0, 72.5 and 80.5%, respectively.

Discussion of Experimental Results

The reaction of propionic, acetic, chloroacetic, dichloroacetic, trichloroacetic and phenylacetic acids with methyl alcohol in the presence of boron fluoride gave the corresponding methyl esters. The yield of the esters *increased* in the order named. Although ionization constants of the chloro substituted acetic acids increased in the same order, acetic, propionic, and phenylacetic acids all have a lower ionization constant than chloroacetic acid. This seems to indicate that there is at least no direct relationship between the acidity and the quantity of ester formed. The yields of methyl esters increased in the same order when either sulfuric acid or hydrogen chloride was used as an esterification agent. The same order was noted for the chloroacetic acids when no additional agent was used. Propionamide, acetamide, chloroacetamide, dichloroacetamide, trichloroacetamide and phenylacetamide likewise were treated with methyl alcohol and boron fluoride. The products were the same methyl esters as with the acids, along with monoamminoboron fluoride. It is noteworthy that in this case the yield of esters *decreased* in the order named.

Some light is thrown on this reaction by considering the electron displacements in the amides used. On the basis of the inductive effect of the substituent only, the structure of the amides may be written as follows



$$CH_3 \longrightarrow CH_2C\overset{O}{\underset{}{\lessdot}}NH_2,\ HCH_2C(=O)NH_2,\ Cl \longleftarrow CH_2C(=O)NH_2,\ \begin{matrix} Cl \longleftarrow \\ Cl \swarrow \end{matrix} CHC(=O)NH_2,\ \begin{matrix} Cl \nwarrow \\ Cl \longleftarrow \\ Cl \swarrow \end{matrix} CC(=O)NH_2 \text{ and } C_6H_5 \longleftarrow CH_2C(=O)NH_2$$

The electron density at the carbon to nitrogen bond decreases in the order given and so does the yield of methyl esters decrease in the same order. In the formation of the methyl esters from the same acids the yields seem to increase with decrease in electron density.

Sudborough and Lloyd[5] performed a series of experiments (acid and alcohol) similar to the first series mentioned except that ethyl alcohol was used in place of methyl alcohol; they found the opposite order of yield of ester. By repeating a few similar experiments with ethyl alcohol we were able to confirm their work. They used their data to correlate steric hindrance. Their conclusion was that steric hindrance played the most important part in controlling the yield of ester. If steric hindrance plays such an important part then phenylacetic and monochloroacetic acids should give about the same yield of ester since they occupy about the same space. Likewise, phenylacetamide and chloroacetamide should give practically the same yield of ester. The results in the present study far from confirm this point of view; they differ by 13% in the latter case and 20% in the former case.

It might be stated that the quantity of ester formed is more or less independent of the degree of ionization of the acid. It might also be stated that steric hindrance apparently plays only a minor part in the esterification of the substituted acetic acid derivatives considered in this study. A more important factor, which might be considered a division of steric hindrance, is the inductive effects of the substituent or, in other words, the electron density at the carbonyl carbon atom.

The esterifying agent did not change the order of yields of esters of methyl alcohol, while ethyl alcohol gave the reverse order of yields of the esters studied.

Summary

A study was made of the reaction between acids and alcohols and between amides and alcohols using boron fluoride as the esterifying agent. The same esterifications were also carried out in the presence of hydrochloric acid and sulfuric acid and without an esterifying agent.

The order of increasing yields of methyl esters from acids was propionic, acetic, chloroacetic, dichloroacetic, trichloroacetic, and phenylacetic acids. This order was reversed when the corresponding amides were used and also when ethyl alcohol reacted with the acids. The esterifying agent did not change the order of yield of methyl esters.

There seems to be no direct relationship between the ionization constant and the quantity of ester formed.

The spacial requirement of a substituent in acetic acid is less important than the inductive effect of the substituent upon the yield of ester.

NOTRE DAME, INDIANA RECEIVED JUNE 9, 1937

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[5] Sudborough and Lloyd, *J. Chem. Soc.*, **75**, 467 (1899).

[CONTRIBUTION FROM THE CHEMICAL LABORATORY OF THE JOHNS HOPKINS UNIVERSITY]

Studies in the Pyrrole Series. III. The Relation of Tripyrrylmethane Cleavage to Methene Synthesis[1,2]

BY ALSOPH H. CORWIN AND JOHN S. ANDREWS[3]

Our previous studies of the mechanism of the aldehyde synthesis of dipyrrylmethenes[4] have shown that definite structures can no longer be assigned to methenes on the basis of the simple carbinol mechanism. The possibility of the presence of a tripyrrylmethane intermediate led to the prediction that mixtures of three methenes may result.

More recently Metzger and Fischer[5] have announced an aldehyde synthesis which gives the mixture of three methenes predicted by our tripyrrylmethane mechanism. They prefer to disregard the significance of our predictions, however, and to explain their results by returning to the old mechanism of Fischer and Ernst.[6a]

We are now extending our studies to the synthesis of an unsymmetrical dipyrrylmethene (IV, Chart I) which does not owe its lack of symmetry to the presence of an N-methyl group. This re-

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[1] The major portion of this paper is from the doctoral dissertation of John S. Andrews, The Johns Hopkins University, 1935.

[2] Presented at the Pittsburgh meeting of the American Chemical Society, September, 1936.

[3] Present address, Research Laboratories, General Mills, Inc., Minneapolis, Minn.

[4] Corwin and Andrews, THIS JOURNAL, **58**, 1087 (1936).

[5] Metzger and Fischer, *Ann.*, **527**, 1 (1936).

[6] Fischer and Ernst, (a) *ibid.*, **447**, 146 (1926); (b) *ibid.*, 139; (c) *ibid.*, 141.