

Action upon Hydrazobenzene in Chloroform Solution.—For these experiments a solution of 2–5 g. of hydrazobenzene in 50 ml. of chloroform was immersed in an ice-bath and a solution of an equivalent amount of the halogen compound in cold chloroform added slowly with stirring. In each case the color of the solution changed from yellow to red and a precipitate collected at the surface of the chloroform. These precipitates were filtered off, washed with chloroform, dried and dissolved in water. The resulting solutions were neutralized with potassium hydroxide and the brown precipitate resulting recrystallized from hot water. The filtrates were evaporated to dryness and the residues washed with ligroin to remove azobenzene.

Substance	Benzidine		Azobenzene		N-Compd.	
	M. p., °C.	Mixed m. p., °C.	M. p., °C.	Mixed m. p., °C.	M. p., °C.	Mixed m. p., °C.
Phenyl iodide dichloride	Insufficient		68	68
Dichloramine-T	115	121–124	62–66	63–67	120–123	131–133
N-Chloroacetanilide	101	115–120	64–67	66–68	113	113–114
N-Chlorosuccinimide	Insufficient		58–65	64–67	114–119	121–124

Summary

1. Phenyl iodide dichloride and iodine chloride may be used as nitridizing agents in liquid ammonia but the N-chloro acid amides so far investigated are valueless in this connection.

2. Phenyl iodide dichloride reacts with ammonia, either liquid or gaseous, to give nitrogen, phenyl iodide and ammonium chloride.

3. The N-chloro acid amides react with ammonia to give the parent amides, ammonium chloride, nitrogen and under certain conditions, tarry decomposition products.

4. In chloroform solution, phenyl iodide dichloride, dichloramine-T, N-chloroacetanilide, and N-chlorosuccinimide convert hydrazobenzene into a mixture of azobenzene and benzidine hydrochloride.

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ESTERIFICATION WITH THIOACETIC ACID

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The relative reactivity of primary, secondary and tertiary alcohols with acid chlorides, hydrochloric acid, and in acetal formation has received considerable attention in the past few years. As early as 1879 N. Menshutkin¹ observed a similar marked influence of the structure of alcohols upon their rates of esterification. He measured the rates with which fourteen widely different alcohols react with acetic acid at 154° in the absence of catalyst, and observed that with the exception of methyl alcohol, primary and secondary alcohols show only slight variation among themselves, while the tertiary alcohols show greater differences but invariably esterify one-tenth to one-twentieth as rapidly as do the

¹ Menshutkin, *Ann.*, 195, 334 (1879); 197, 193 (1879).

secondary alcohols. Arthur Michael² has studied the reaction rates of these same alcohols with trichloroacetic acid at 25°. Here there is a marked difference between the esterification rates of primary and secondary alcohols with the reactivity of the tertiary alcohols slightly greater than that of the latter. Recently an attempt has been made by Petrenko-Kritchenko, Bogatsky and Lubman³ to reconcile these results. As these data are of considerable interest to the present paper they are given in part in Tables I and II. The marked difference in the behavior of secondary and tertiary alcohols observed by Menshutkin is absent in the later results. The constants for trichloroacetic acid on the other hand agree well with those of Michael. In the case of the constants for hydrochloric acid the order is entirely reversed from that of acetic acid, with trichloroacetic acid occupying an intermediate position. The phenyl substituted alcohols bring out these effects even more clearly.

TABLE I

Alcohol	CH ₃ COOH ^a	CCl ₃ COOH ^b
Methyl	100	0.0370
Ethyl	70.3	.0068
Dimethylcarbinol	26.5	.00098
Trimethylcarbinol	1.4	.00118

^a From Menshutkin. Percentage esterified at end of one hour, methyl alcohol taken as the standard. ^b From Michael. First order reaction constants.

TABLE II

Alcohol	CH ₃ COOH	CCl ₃ COOH	HCl
Ethyl	0.00417	0.02550	0.0348
Dimethylcarbinol	.00237	.00644	.0477
Trimethylcarbinol	.00212	.00692	.2670
Benzyl	.00244	.00815	.0372
Benzhydrol	.00141	.00127	.6060
Triphenylcarbinol	.00040	.00197	2.8480

In an outstanding contribution to the knowledge of the mechanism of esterification, Reid and his collaborators⁴ found that thiolbenzoic acid and a primary alcohol gave hydrogen sulfide and a normal ester, whereas benzoic acid and a primary mercaptan gave water and a thiol ester. Using Henry's hypothesis that an intermediate product is formed, this would suggest that the mercaptan adds H- and C₂H₅S- rather than HS- and C₂H₅-. From analogy it is therefore commonly stated that in esterification the hydroxyl used in the formation of water is furnished by the acid and not by the alcohol. This is undoubtedly true for the cases investigated, but the question at once arises whether this is invariably so, especially

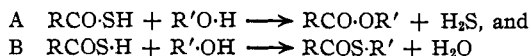
² Michael, *Ber.*, **42**, 3157 (1909); **43**, 464 (1910).

³ Petrenko-Kritchenko, Bogatsky and Lubman, *Z. physik. Chem.*, **115**, 289 (1925).

⁴ Reid, *Am. Chem. J.*, **43**, 489 (1910); *THIS JOURNAL*, **37**, 1934 (1915); **38**, 2746, 2757 (1916); **39**, 1930 (1917).

in view of the great differences shown in the reactivity of primary, secondary and tertiary alcohols.

Purpose of Investigation.—The method used by Reid was of a qualitative rather than a quantitative nature. He reports that hydrogen sulfide was either present or absent. When present it was tentatively assumed that the reaction was entirely of one kind. Considering the following reactions



reaction A may take place to the exclusion of B. However, it is also possible that both may be taking place simultaneously. This can only be determined by following quantitatively the disappearance of the acid and the formation of hydrogen sulfide. Furthermore, if the reaction between thiolacetic acid and ethyl alcohol is found to take place in the proportion of 75% according to reaction A and 25% according to B, it does not necessarily follow that all alcohols will behave in the same way. It was with the hope of being able to determine the proportions of the two reactions A and B occurring in the esterification of a number of alcohols that this work was undertaken. It was also believed that such information might to some extent explain the apparent anomalies in the reaction rates of various alcohols with several different acids. The reactions selected were the esterification of methyl, ethyl, isopropyl and *tert.*-butyl alcohols and triphenylcarbinol with thiolacetic acid.

Experimental Method

The alcohols were purified by the usual methods, the removal of water being the primary object.

Thiolacetic acid at first offered some difficulty as commercial samples invariably contained considerable quantities of hydrogen sulfide. This is best removed by freezing the sample at about -40° , evacuating and allowing the acid to distil *in vacuo* into a trap surrounded by Dry-ice and ether at -70 to -80° . During this distillation the system was continually evacuated. In this way the hydrogen sulfide was entirely pumped off and the freshly distilled acid showed no test for the dissolved gas. This acid was used immediately as it was found that on prolonged standing unless protected from air and moisture hydrogen sulfide was regenerated.

The solvent used was benzene which had been purified by repeated shakings with concd. sulfuric acid, washed and dried.

2 *N* solutions of the alcohols and acid in benzene were made, equal quantities mixed and the reaction mixture titrated for the acid present; 10-cc. portions of this reaction mixture were introduced into several small hard glass bulbs by means of a capillary. These bulbs were so constructed as to be of uniform volume and have a maximum capacity of 12–13 cc. They were then frozen with liquid air, evacuated and sealed *in vacuo* by means of the capillary. They were then placed in a steel-jacketed vessel fitted with a reflux condenser into which there was a constant stream of carbon tetrachloride vapor. This ensured an even temperature of 76.7° . From time to time the bulbs were removed, frozen with liquid air, opened at the capillary and immediately connected with the hydrogen sulfide analysis train.

This train consisted of three traps, A, B and C, kept at -40 , -80 and -180° , respectively. Trap C was connected with an oil pump and the whole system continually evacuated. As the bulb approached room temperature the reaction mixture rapidly distilled into trap A where it again solidified. The sublimation from A to B required a much longer time, but the advantage of passing from one solid phase to another without liquefying permitted the absolute separation of the hydrogen sulfide from the reaction mixture. Trap B then contained the acid-alcohol-benzene mixture which after warming was pipetted out and titrated for the acid present. Trap C containing the solid hydrogen sulfide was then disconnected and attached to an absorption bulb containing an ammoniacal solution of cadmium chloride. As the temperature of C was gradually raised the hydrogen sulfide was evolved and precipitated in the absorption bulb as cadmium sulfide. The whole system was finally blown out with a stream of nitrogen and the cadmium sulfide titrated in acid solution with iodine. A number of blanks were run and the data in Table III show the method to be entirely satisfactory for the present purpose. Indeed it can be recommended for the analysis of hydrogen sulfide in the presence of any non-gaseous reducing agent.

TABLE III
ANALYTICAL DATA

The amounts are in terms of milliequivalents present in 10 cc. of benzene solution.

H ₂ S	Reagents		Recovered	
	CH ₃ COSH	CH ₃ COOH	H ₂ S	Acid
1.480			1.450	
1.320			1.319	
1.320			1.284	
	10.101 ^a		0.467	9.607
	10.267 ^a		.479	9.719
0.665		1.925	.640	1.895
.866		3.052	.842	3.000

^a Subsequent test proved hydrogen sulfide present in the original thiolacetic acid from which these samples were taken.

In the subsequent tables and drawings the course of the reaction is followed under the heading "Esterification" in terms of the millimoles of acid which reacted in the time t . For convenience the per cent. of esterification is given in the third column. If the reaction takes place entirely according to Equation A previously given, the millimoles of hydrogen sulfide produced should be equal to the millimoles of acid disappearing. The amount of hydrogen sulfide actually produced is given in column four of the tables and by the broken curves. If both reactions expressed by Equations A and B are taking place simultaneously, the millimoles of hydrogen sulfide produced will be less than the millimoles of acid disappearing and the fraction of the acid reacting according to Equation A is expressed in per cent. in the last column.

Discussion of Data

The data for methyl and ethyl alcohols presented in Tables IV and V (Figs. 1 and 2) would indicate that the percentage of hydrogen sulfide

TABLE IV

ESTERIFICATION OF ALCOHOLS WITH THIOLACETIC ACID IN BENZENE SOLUTION

Methyl alcohol, 1.00 *N*; thiolacetic acid, 0.957 *N*; temperature, 76°C.

Time, hrs.	Esterification		H ₂ S Produced	
	Millimoles	%	Millimoles	%
20	2.15	22.4	1.72	80.1
40	3.42	35.7	2.65	77.4
60	4.40	46.2	3.12	70.9
80	4.85	50.6	3.44	70.9
100	5.32	55.5	4.50	84.5
120	5.54	57.9	4.52	81.5
			Average	77.6

TABLE V

ESTERIFICATION OF ALCOHOLS

Ethyl alcohol, 1.00 *N*; thiolacetic acid, 0.965 *N*; temperature, 76°C.

Time, hrs.	Esterification		H ₂ S Produced	
	Millimoles	%	Millimoles	%
20	1.69	17.6	1.21	71.6
40	2.37	24.3	1.88	79.3
60	3.07	31.8	2.29	74.6
80	3.60	37.2	2.41	67.0
100	3.99	41.4	2.88	72.2
120	4.27	44.3	3.35	78.4
			Average	78.9

produced per mole of acid esterified is the same within experimental error. These results may also be interpreted as indicating that with primary alcohols about 78% of thiolacetic acid esterifies according to equation A and about 22% according to equation B.

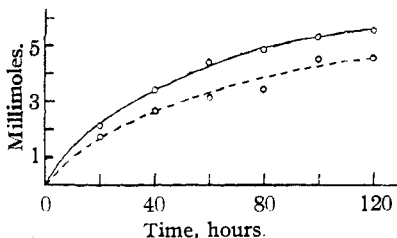


Fig. 1.—Methyl alcohol, 76°: —, esterification; ---, H₂S production.

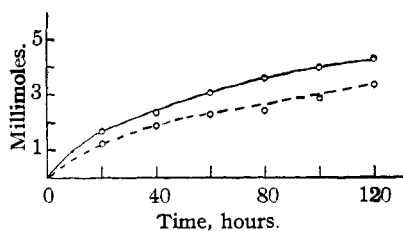


Fig. 2.—Ethyl alcohol, 76°: —, esterification; ---, H₂S production.

The behavior of a secondary alcohol, in this case isopropyl, is markedly different, since practically the theoretical quantity, 97.7%, of hydrogen sulfide is produced; Table VI and Fig. 3. It may therefore be assumed that with isopropyl alcohol thiolacetic acid esterifies entirely according to equation A.

As an example of a tertiary aliphatic alcohol the esterification of *tert*-butyl alcohol was attempted. This reaction is, however, exceedingly

TABLE VI
ESTERIFICATION DATA

Isopropyl alcohol, 1.00 *N*; thiolacetic acid, 0.952 *N*; temperature, 76°C.

Time, hrs.	Esterification		H ₂ S Produced	
	Millimoles	%	Millimoles	%
40	0.56	5.8	0.55	99.4
60	0.78	8.2	0.76	97.0
80	1.22	12.8	1.22	100.0
100	1.34	14.1	1.28	95.4
120	1.43	15.0	1.38	96.6

Average 97.7

slow and under prolonged heating was accompanied by decomposition of either the thiolacetic acid or its ester, so that from the data obtained it was impossible to follow the course of the reaction. However, the relative rates of esterification of the secondary and tertiary alcohols are in the same order as obtained by Menshutkin with acetic acid. If possible the velocity constants of the reactions with thiolacetic acid will be investigated.

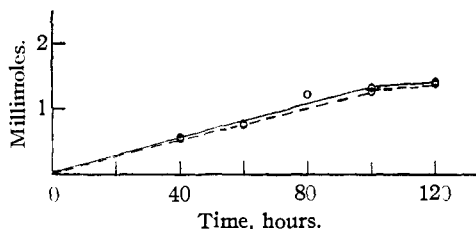


Fig. 3.—Isopropyl alcohol, 76°: ———, esterification; --- H₂S production.

Triphenylcarbinol, Table VII, and Fig. 4, offers an interesting contrast. Since the reaction was found to proceed too slowly at 76° it was carried out at 100°. As will be shown later at this temperature the acid slowly hydrolyzes to produce hydrogen sulfide. When the data in Table VII are corrected for this hydrolysis they show the entire absence of hydrogen sulfide. In this case,

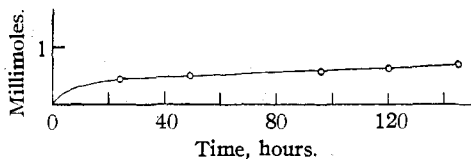


Fig. 4.—Triphenylcarbinol, 100°: ———, esterification; ---, H₂S production.

then, only water is produced and the course of the esterification may be satisfactorily represented by equation B.

TABLE VII
ESTERIFICATION DATA

Triphenylcarbinol, 0.50 *N*; thiolacetic acid, 0.506 *N*; temperature, 100°C.

Time, hrs.	Esterification		H ₂ S Produced	
	Millimoles	%	Millimoles	Corrected
24	0.44	8.7	0.18	0.01
49	.50	10.0	.22	— .03
96	.58	11.6	.35	— .07
120	.64	12.7	.42	— .10

As a control, bulbs containing only thiolacetic acid and benzene were subjected to prolonged heating. At 76° little or no hydrogen sulfide was observed, but at 100° the quantity became appreciable. From the data in Table VIII, however, it seems that the reaction soon reaches completion, for after ninety-six hours there is neither production of hydrogen sulfide nor disappearance of acid. To determine whether the presence of small amounts of water were responsible for the production of the hydrogen sulfide, a blank was run with thiolacetic acid and benzene 1 *N* in water, Table IX. Hydrogen sulfide was evolved in larger

TABLE VIII

ESTERIFICATION DATA

Blank, 100°C.; thiolacetic acid, 0.966 *N*

Time, hrs.	Acid decrease, Millimoles	H ₂ S produced, Millimoles
25	0.04	0.17
48	(.45)	.25
72	.15	.33
96	.24	.43
120	.24	.43

TABLE IX

EXPERIMENTAL DATA

Water, 1.00 *N*; thiolacetic acid, 0.966 *N*; temperature, 76°C.

Time, hrs.	Acid decrease, Millimoles	H ₂ S produced, Millimoles
24	0.11	0.34
48	.16	0.70
72	.28	1.02

quantities and the acid disappeared more rapidly. If a decomposition of the acid were taking place we should expect that for a mole of hydrogen sulfide produced at least a mole of acid would disappear. If on the other hand the reaction were purely hydrolytic the total acid concentration would remain constant,

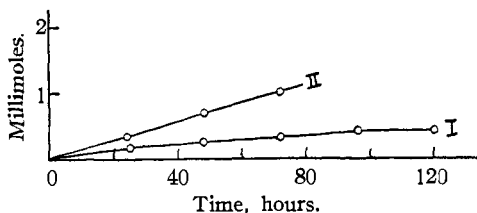


Fig. 5.—H₂S production: I, blank 100°; II, hydrolysis of thiolacetic acid by water.

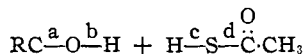
since for every mole of thiolacetic acid hydrolyzed a mole of acetic acid would be formed. It is interesting to note that in Tables VIII and IX the hydrogen sulfide cannot be quantitatively accounted for by the decrease in the acid concentration. That water is playing an important part, however, is shown by the fact that the acid disappears more rapidly in Table IX than in Table VIII. It is quite possible that both a thermal decomposition and hydrolysis are taking place, but for the purpose of correcting the data in Table VII it is sufficient to know the magnitude of the combined effect.

Theoretical

It seems that the reaction between various alcohols and thiolacetic acid is by no means simple. From the percentage esterification given in Tables IV, V and VI methyl alcohol appears to esterify somewhat more

rapidly than ethyl, but both are much more reactive than isopropyl alcohol. The data for triphenylcarbinol, Table VII, are at 100° so that no quantitative comparison can be made, but since the higher temperature was necessary to obtain accurate results, it is unquestionably less reactive than isopropyl alcohol. This is in good agreement with the data given by Petrenko-Kritchenko for these alcohols with acetic acid in Table II. The quantities of hydrogen sulfide evolved by these three reactions show, however, that we are dealing with three distinct processes. Triphenylcarbinol, although the most unreactive, yields only water, which means that only its hydroxyl group enters into the reaction. Methyl and ethyl alcohols while much more reactive can split off either hydroxyl or hydrogen. Isopropyl alcohol is but moderately reactive, yet only its hydrogen takes part in the reaction.

In dealing with esterification processes it is not sufficient to know the relative strengths of the bindings of the —OH and —H in the alcohols only, but one must also consider these bonds in the acids with which they react. For example, in the reaction



when R is $(C_6H_5)_3C-$ the bonds a and c split much more easily than the bonds b and d; therefore water is the only product obtained. When R is $(CH_3)_2CH-$ bonds b and d are much more easily broken than a and c; therefore only hydrogen sulfide is obtained. When, however, R is CH_3- or C_2H_5- the total energy necessary to break the bonds a and c cannot be very different from that required to break b and d, so that in this case both water and hydrogen sulfide are obtained. From the relative amounts of the two, however, it seems that b and d are the more easily split. Other alcohols will undoubtedly show great differences in the ease with which these two pairs of bonds are split and consequently yield varying proportions of water and hydrogen sulfide.

Since the rate and also the products formed depend not only upon the relative strength of binding in the alcohol but in the acid as well, the same alcohols may not react in the same manner with different acids. In the case of hydrogen chloride the —OH must be furnished by the alcohol so that the constants in Table II are probably a good indication of the relative strengths of binding of this group in the six alcohols studied. This is not the case, however, with trichloroacetic acid, whose —OH is probably more firmly bound than that in acetic acid. If we further assume that the —H is more labile in trichloroacetic than in acetic acid, then one can understand why the constants for the tertiary alcohols are higher than those for their secondary homologs when trichloroacetic acid is used but lower with acetic acid. Trichlorothioloacetic acid should yield water or hydrogen sulfide or both depending upon the structure of the alcohol,

but undoubtedly in proportions quite different from thiolacetic acid. These should be interesting in comparison with the data in Table II and it is our hope to consider them in a later communication.

Summary

The products of the reaction of thiolacetic acid with a number of alcohols have been studied quantitatively. Isopropyl alcohol yields only hydrogen sulfide and the normal ester; triphenylcarbinol only water and the thiol ester; methyl and ethyl alcohol give about 78% hydrogen sulfide and 22% water. The question of the mechanism of esterification in general is considered and an explanation of certain anomalies is attempted.

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[CONTRIBUTION FROM THE CHEMICAL LABORATORY OF KITASATO INSTITUTE]

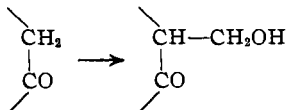
CONDENSATIONS BETWEEN FORMALDEHYDE AND MONOKETONES. I. CONDENSATION OF 5-ACETYL-8-HYDROXYQUINOLINE WITH ALDEHYDES

BY KONOMU MATSUMURA AND CHUSABURO SONE

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Many researches relating to the condensation between a methyl or methylene group adjacent to a ketone and aromatic or cyclic aldehyde have been published, whereas, as far as the authors are aware, except in the case of the pyrazolone series, there are only a few previous records of condensation with formaldehyde. K. Goto and his co-workers,¹ in the course of investigations of sinomenine, an alkaloid from *sinomenium acutum*, have found that on refluxing sinomenine, which contains a methylene group adjacent to a carbonyl in its molecule, with an excess of formaldehyde a condensation between them results in the formation of an hydroxy-methyl compound in accordance with the scheme



In the present investigation, on treating 5-acetyl-8-hydroxyquinoline with formaldehyde (40%) in a manner similar to that used for sinomenine, it is found that a condensation has taken place between them, but contrary to expectation, resulting in the formation of ω -methylene-bis-5-acetyl-8-hydroxyquinoline (I).

Furthermore, the reaction of 5-acetyl-8-benzoyloxyquinoline and formaline gives ω -methylene-bis-5-acetyl-8-benzoyloxyquinoline. It is evident in view of the latter fact that the presence of a free hydroxyl

¹ Goto, Shishido and Inaba, *Bull. Chem. Soc., Japan*, 5, 315 (1930).