THE ACTION OF TERTIARY BUTYL HYPOCHLORITE
ON
SEVERAL ORGANIC COMPOUNDS

by

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TABLE OF CONTENTS

INTRODUCTION

It has long been known that the alkyl hypochlorites react with organic compounds, chlorinating them, saturating them, or oxidizing them, as the case may be. However, up to 1923, when Chattaway[1] discovered the stable tertiary hypochlorites, not much systematic research had been done on the subject, chiefly because of the great instability of the primary and secondary hypochlorites. With the discovery of the tertiary hypochlorites, and especially that of tertiary butyl hypochlorite, the organic chemist was presented with a new reagent which has shown great promise, more particularly so now that tertiary butyl alcohol is available in commercial quantities at low cost whereas it was formerly a laboratory curiosity, being made from acetone by the Grignard reaction.

The primary function of tertiary butyl hypochlorite is that of a chlorinating agent, being used in this respect as a substitute for free chlorine, and reacting apparently in simple metathesis. Its advantages over free chlorine for this purpose are obvious. It is easily and rapidly made in the pure state from the inexpensive materials tertiary butyl alcohol, sodium hypochlorite solution, and glacial acetic acid. It is a liquid and therefore easy to weigh or measure out and handle. Although it has an obnoxious odor, it is not necessary to work under the hood if the reagent is kept reasonably well covered. In running the reactions that are subsequently described it was contained in a graduated dropping funnel with the glass stopper fitted in loosely. Although it decomposes rapidly in bright sunlight, it is stable for months if kept in the dark. In the diffused daylight of the laboratory it is stable enough to carry out any ordinary reaction without taking precautions to protect it from the light.

Tertiary butyl hypochlorite reacts also as an oxidizing agent. With organic compounds this is particularly true with the primary and secondary alcohols, which can form intermediate primary and secondary hypochlorites, which in turn spontaneously lose hydrogen chloride, yielding respectively aldehydes and ketones. In general, with the aliphatic alcohols the reaction is so violent that no well characterized products can be isolated. In the course of this work, however, cyclohexanol was smoothly converted to cyclohexanone by this method. Inorganic compounds are easily oxidized by tertiary butyl hypochlorite, an example being the liberation of the halogens from the concentrated halogen acids.

Practically all the work done on tertiary butyl hypochlorite, with the exception of that of Chattaway's[2], has been performed in this laboratory under the direction of Professor Norris. This previous work will be mentioned under the review of the literature. The problem originated here when Professor Norris discovered that tertiary butyl hypochlorite could be made by the interaction of tertiary butyl alcohol, sodium hypochlorite solution, and glacial acetic acid. This method has the advantage over Chattaway's[3] in that it is not necessary to use free chlorine, and thus the chlorination of an organic compound can be carried out without the use of gaseous chlorine either in the preparation of the reagent or in the reaction itself.

The work accomplished in the present research may be divided into the following five departments.

1. Complete literature review of the alkyl hypochlorites.

2. Improvement of the method of preparation of tertiary butyl hypochlorite and the perfection of a method for its analysis.

3. An exact density determination of tertiary butyl hypochlorite.

4. A study of the stability of tertiary butyl hypochlorite alone and in various solvents under various conditions.

5. A study of the reactions of tertiary butyl hypochlorite with some organic compounds.

For the sake of brevity, tertiary butyl hypochlorite will hereinafter be referred to in this research simply as the "reagent".

REVIEW OF
THE LITERATURE

The first reference to organic compounds of hypochlorous acid is by Schmidt and Goldberg[4] in 1879 who observed that when bleaching powder reacts on absolute ethyl alcohol, and the mixture distilled, a greenish yellow oil comes over, which under the influence of light or heat decomposes explosively, giving off vapors of hydrochloric acid and hypochlorous acid. They did not succeed in isolating it, but said they thought it was the ethyl ester of hypochlorous acid, which was in all probability correct.

In 1881 Goldberg,[5] incidental with an attempt to improve the yield of chloroform in the reaction of bleaching powder on ethyl alcohol, studied the action of bleaching powder on methyl alcohol and on iso-amyl alcohol, and obtained products which were no doubt the corresponding hypochlorites, but he did not isolate or identify them. It is interesting in this connection to note that this investigator stated that in the reaction with methyl alcohol he obtained an unstable gas, because it was later found that methyl hypochlorite is a gas.

The credit for the discovery of the alkyl hypochlorites goes to Sandmeyer,[6] who in 1885 prepared, analyzed, and characterized ethyl hypochlorite. He prepared it by the reaction of hypochlorous acid on ethyl alcohol. Its physical properties are described completely. He reacted it with ammonia, and a few organic compounds such as phenol and aniline and stated that it chlorinates and oxidizes them almost explosively. He also found that it liberates the halogens from the halogen acids. He analyzed it by titrating with thiosulfate the iodine liberated by its action on acidified potassium iodide.

In 1886 Sandmeyer[7] prepared ethyl and methyl hypochlorites by passing chlorine into a cooled alkaline solution of the alcohol. He described the properties of the methyl compound, which is a gas, and is even more unstable than the ethyl compound. The latter was reacted with carbon dioxide, ethylene, amylene, acetylene, fumaric acid ethyl ester, and sulfur dioxide.

In 1895 Nef,[8] in his classic research on the divalency of the carbon atom in the isocyanides, reacted ethyl hypochlorite on potassium cyanide and on ethyl isocyanide and found that it added to the divalent carbon atom, itself splitting at the chlorine atom.

Willcox[9] in 1904 states that ethyl hypochlorite chlorinates sodium phenolate and sodium aceto-acetic ester, and that it reacts with diethylamine and trimethylethylene to form chorodiethylamine and chloroisoamylene respectively.

Gutmann[10] in 1917 oxidized sodium arsenite to sodium arsenate with ethyl hypochlorite and also brought about the following reaction:

$$\mathrm{EtOCl + KCN + KSH \rightarrow KCNS + KCl + EtOH}$$

In 1923 Chattaway and Backeberg[11] prepared normal propyl, isopropyl, primary, secondary, and tertiary butyl, and tertiary amyl hypochlorites. The secondary and tertiary hypochlorites were new compounds. He attempted also to prepare benzyl hypochlorite, but it decomposed into benzaldehyde and hydrogen chloride as fast as it was formed. He completely describes the physical and chemical properties of these compounds. The tertiary compounds he found were much more stable than either the primary or secondary, but the secondary are even more unstable than the primary. He studied their decomposition products and found that they decompose according to the following reactions:

1. $R{-}CH_2{-}OCl \longrightarrow R{-}CHO + HCl$
2. $R_2{=}CH{-}OCl \longrightarrow R_2{=}C{=}O + HCl$
3. $R_3{\equiv}C{-}OCl \longrightarrow R_2{=}C{=}O + RCl$

where R is an alkyl radical which may be the same or different in a compound containing more than one of them. These hypochorites were prepared by Sandmeyer's method. The tertiary butyl hypochlorite he describes as follows. It is a pale yellow, mobile liquid with a characteristic odor, and violently attacks the eyes and mucous membranes. It is very stable, and if protected from bright light may be kept for months at ordinary temperature with little or no decomposition. It boils at 79.6° and has the density .9585 at 18°/4°. When exposed to bright sunlight it decomposes quietly but with consideralbe evolution of heat, methyl chloride and acetone being the chief primary decomposition products.

Chattaway and Backeberg in 1924 identified ethyl hypochlorite as the first intermediate product in the classic reaction of chlorine on ethyl alcohol, and by means of a complex series of reactions explain the ultimate formation of chloral alcoholate.

Taylor, Mac Mullin, and Gammal[13] in 1925 used the reaction of lime on ethyl hypochlorite to prepare pure calcium hypochlorite, and incidentally during their research studied other hypochlorites. They prepared normal propyl, isopropyl, isobutyl, secondary butyl, tertiary butyl, isoamyl, secondary amyl, and tertiary amyl hypochlorites. They stated that a solution of ethyl hypochlorite in carbon tetrachloride reacts with phenol, aniline, methylaniline, sodium picrate, and similar easily oxidized substances. The stability of the esters was studied by allowing their carbon tetrachloride solutions to stand at ordinary temperature in diffused daylight and analyzing for available chlorine from time to time.

In 1925 also Goldschmidt, Endres, and Dirsch[14] studied the action of ethyl hypochlorite in solution on various organic compounds. They state that the addition of ethyl hypochlorite to double bonds may take place directly, or may be preceded by a splitting of the ester into ethyl alcohol and hypochlorous acid, and the latter add. This last statement is is hard to understand, inasmuch as their reactions were carried out in an anhydrous medium. With amylene, cyclohexene, and indene they obtained the chlorhydrins. With phenyl acetylene they obtained only dichloromethylphenyl ketone. Toward aromatic unsaturations the ester is very sluggish. Benzene nor anisole would not react. With phenol and hydroquinone, however, they obtained ortho and para chlorophenol and 2,3 dichlorohydroquinone respectively. With ethylamine, ethyl dichloramine was formed smoothly. From acetaldehyde the products were chloracetaldehyde and its acetals, and from acetone, monochloracetone. Benzaldehyde gave benzoyl chloride. They also ran stability tests on ethyl hypochlorite and identified the products of decomposition, namely, chlorine, hydrogen chloride, water, ethyl acetate, and acetaldehyde.

Durand and Naves[15] studied the action of ethyl hypochlorite in the two following reactions:

1. $\mathrm{MgX}\boxed{\mathrm{R} + \mathrm{Cl}}\mathrm{OEt} \longrightarrow \mathrm{MgXOEt} + \mathrm{RCl}$
2. $\mathrm{MgX}\boxed{\mathrm{R_2N} + \mathrm{Cl}}\mathrm{OEt} \longrightarrow \mathrm{R_2NCl} + \mathrm{MgXOEt}$

According to the first reaction, using phenyl magnesium bromide and the ester they obtained chlorobenzene in 85-90% yield. The ethoxy magnesium bromide was also identified. According to the second reaction, using magnesio bromaniline from the reaction of ethyl magnesium bromide and aniline, they obtained phenyl chloramine, which rearranged at once into ortho and para chloraniline. These authors also state that they prepared ethyl hypochlorite as a colorless liquid. This seems doubtful because all other literature references to it describe it as being yellow.

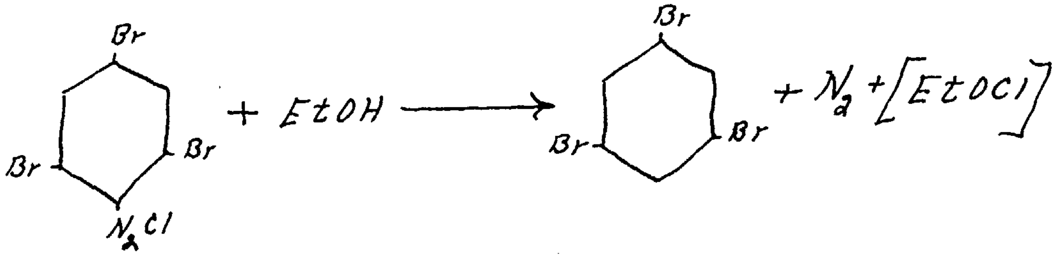
Durand and Naves[16] in a later article give considerable evidence in the form of reactions to show that the chlorine in hypochlorous acid and in ethyl hypochlorite is positive. He also studied the action of the ester with the halogen acids, and from these facts and others give a series of reactions accounting for all the decomposition products of it. The end products in this decomposition are similar to those obtained in the reaction of chlorine on ethyl alcohol.

Jackson[17] in 1926 added methyl hypochlorite and methyl hypobromite to unsaturated substances by forming the esters in a mixture of carbon tetrachloride and methyl alcohol, in which the unsaturated substances were dissolved. In this way he added the esters to cinammic acid, benzalacetophenone, and stilbene, obtaining in every case the halogen-methoxy compound.

Jackson and Pasuit[18] studied the addition of ethyl and tertiary butyl hypochlorites to certain unsaturated compounds. Working in alcohol solution they obtained α chloro βethoxy proprionic acid in 6% yield by the action of chlorine on cinammic acid. In tertiary butyl alcohol solution a 14% yield of α chloro β tertiary butoxy phenyl proprionic acid was obtained. The first reaction would not go in carbon tetrachloride solution. Tertiary butyl hypochlorite could not be added to benzalacetophenone in the above manner. The double bond was saturated instead with a molecule of chlorine. This article is interesting because it shows that in some cases at least, tertiary butyl hypochlorite can be added directly to unsaturated systems.

Bixby[19] attempted to make pure calcium hypochlorite from tertiary butyl hypochlorite and lime, but the attempt was not wholly successful.

In 1930 Hantzsch[20] postulated that in the decomposition of tribrombenzenediazonium chloride to tribrombenzene by means of alcohol ethyl hypochlorite is an intermediate product which is the source of the aldehyde obtained at the same time.

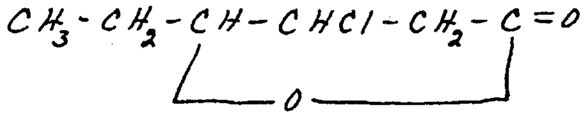


$$[EtOCl] \longrightarrow CH_3\text{-}CHO + HCl$$

Clark,[21] in 1931 studied the action of tertiary butyl hypochlorite on various classes of organic compounds. Reactions were carried out with phenols, amines, alcohols, aldehydes, esters, ethers, hydrocarbons, halogen derivatives, acids, and nitriles. He claims to have chlorinated or oxidized many of these in good yields.

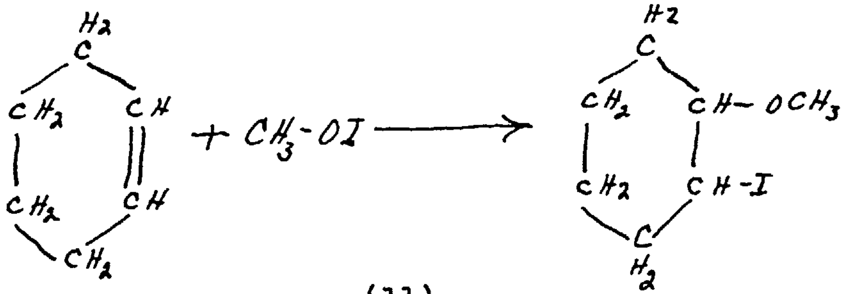
Bloomfield and Farmer[22] studied the influence of the carboxyl group on the addition of hypochlorous acid and of ethyl hypochlorite to unsaturated fatty acids. With crotonic acid and ethyl hypochlorite they obtained a mere trace of addition product. With sorbic acid they obtained a small yield of addition product. But with 2-hexenoic acid the following reaction took place with 92% yield of the lactone:

$$CH_3-CH_2-CH=CH-CH_2-COOH + EtOCl(\text{in } CCl_4) \longrightarrow$$

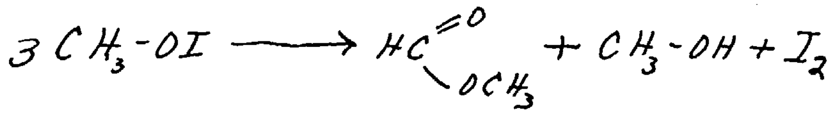


$$CH_3-CH_2-\underbrace{CH-CHCl-CH_2-C}_{O}=O$$

In 1932 also an article appeared by Birckenbach and Goubeau[23] in which was described for the first time the use of an alkyl hypoiodite as an iodinating agent, incidental to the main subject of the article. The reaction of silver perchlorate, iodine, and alcohols yields the esters of hypoiodous acid, which the authors state decompose at ordinary temperature with precipitation of iodine, but which are stable at -80. The existence of the esters was proved by carrying out their preparation at -80 in the presence of an unsaturated compound. Thus with cyclohexene the following reaction took place in 90% yield:



They explain the precipitation of iodine on warming up the solution of methyl hypoiodite to room temperature by a series of reactions which add up as follows:



$$3\,CH_3\text{-}OI \longrightarrow HC\begin{matrix}{}^{\diagup\!\!\diagup O}\\ {}_{\diagdown OCH_3}\end{matrix} + CH_3\text{-}OH + I_2$$

If the methyl hypoiodite could be prepared at low temperature by some method which does not include the use of silver perchlorate, it would seem to open up great possibilities of synthesis of iodinated compounds since ordinarily these have to be made by indirect methods.

EXPERIMENTAL PART

A. SUMMARY AND CONCLUSIONS

The results of the experimental work done during the course of this research may be summed up and conclusions drawn from them as follows.

An improved method of preparation of the reagent has been developed which gives a 75% yield of the pure material. In a large number of preparations of the reagent this method gave consistent results, that is, the reagent so prepared was always pure.

A method of analysis of the reagent has been perfected after a great many attempts, and easily gives check results to within .2%. The method involves weighing out the sample in sealed wafer tubing, this being necessary on account of the great volatility of the reagent.

An accurate density determination of the pure reagent has been made, using a 15 c.c. pycnometer, and the result checks very closely that found in the literature.

A number of studies of the rate of decomposition of the reagent alone and in solvents have been carried out under various conditions of light and temperature. The general conclusions to be drawn from these studies are the following;

(1) The reagent itself is stable enough in diffused daylight so that any ordinary reaction can be carried out without the necessity of taking special precautions to protect it

from the light.

(2) The effect of artificial light, even when only one foot away from either the reagent itself or its carbon tetrachloride solution, is only slightly greater than that of diffused daylight, so that special precautions do not have to be observed against it in running ordinary reactions.

(3) Carbon tetrachloride, on account of its stabilizing effect on the reagent and the reagent's inertness toward it, is an excellent reaction medium, and this need not be the C.P. material, for the so-called technical "purified" is equally as satisfactory.

(4) Chloroform, especially the U.S.P. variety, is not suitable as a reaction medium because the reagent reacts first with the alcohol in it and then with the chloroform itself.

(5) Glacial acetic acid is a reaction medium in which the reagent is perfectly stable.

(6) The reagent itself, when kept in the dark was found to be 97.5% pure after standing two and a half months, and from this it was concluded that it can be kept pure indefinitely if completely excluded from the light. The decrease in purity in two and a half months was probably due to the fact that the reagent was exposed to the light for a few seconds every time a sample was removed for analysis.

(7) The rate of decomposition of the reagent in carbon tetrachloride is so rapid at the boiling point of the solution

that if a reaction is to be carried out in the solution at this temperature, it must be practically instantaneous, the reagent being added dropwise.

The summarized results of these decomposition studies may best be obtained from the plots, which follow in their proper place.

Lastly, a number of reactions of the reagent with various organic compounds have been run under various conditions of solvent, temperature, and proportion of reactants. This work comprises the main portion of the research, and the general conclusions to be drawn from it are as follows.

(1) The reagent is a good chlorinating agent for certain organic compounds, and those reactions which proceed with good yields are suitable for methods of preparation of the products.

(2) The reagent reacts as an oxidizing agent in at least one case, cyclohexanol being converted to cyclohexanone smoothly and with good yield.

(3) It was found that with alcohols, with which the reagent reacts to form an intermediate hypochlorite, which subsequently decomposes into an aldehyde or ketone and hydrogen chloride, it was necessary to use water as an acceptor for the latter.

(4) In one reaction at least, that with β-phenylethyl alcohol, it was found that the reaction medium definitely oriented the course of the reaction,in this case carbon tetrachloride or chloroform giving totally different products than

dilute acetic acid.

(5) Carbon tetrachloride is the best solvent to use as reaction medium in those reactions that proceed rapidly.

(6) Glacial acetic acid is the best solvent to use for those reactions which proceed sluggishly, because it exerts a marked catalytic effect.

(7) In at least one reaction, that with anthranilic acid, it was found that carrying out the reaction at very low temperature greatly increased the yield.

(8) In those reactions which are chlorinations pure and simple, the products obtained in all cases are the same as those that would result if free chlorine were used.

The summarized results from which these conclusions are drawn are best presented in the form of a table, which is immediately subjoined.

Reactant	Molal Ratio Reagent/Reactant	Temp.	Solvent	Product and Yield
(1) Anthracene	1:1	20°	$CHCl_3$	9,10 Dichloroanthracene, very small
(2) "	2:1	20°	CCl_4	9,10 Dichloroanthracene, 55%
(3) "	2:1	20°	HAc	9,10 Dichloroanthracene, 65%
(4) "	1:2	20°	HAc	9 Chloroanthracene, 12.8%

Note: In this last reaction 9,10 dichloroanthracene was also obtained, but it was not isolated.

(1) Anthranilic acid	1:1	20°	$CHCl_3$	5 Chloroanthranilic acid, 44.1% 3,5 Dichloroanthranilic acid, 10.5%
(2) "	2:1	20°	$CHCl_3$	3,5 Dichloroanthranilic acid, 49.2%
(3) "	1:1	-78°	$CHCl_3 + CCl_4$	5 Chloroanthranilic acid, 43.5%
(4) "	2:1	-78°	$CHCl_3 + CCl_4$	3,5 Dichloroanthranilic acid, 72.5%
(1) Benzaldehyde	1:1	20°	CCl_4	Benzoyl chloride, 60.5%
(2) "	1.25:1	20°	CCl_4	Benzoyl chloride, 57.5%
(3) "	1:1	20°	CCl_4	Benzoyl chloride, 67.5%
Cyclohexanol	1:1	20°	$CCl_4 + H_2O$	Cyclohexanone, 57.5%
Ethyl Acetate	1:1	Refluxing	Various	No definite products
Furane	1:1	Various	Various	No definite products

Reactant	Molal Ratio Reagent/Reactant	Temp.	Solvent	Product and Yield
(1)Heptane(pract).	1:1.2	Refluxing	CCl_4	Sec. Chloroheptanes, 16.1% 1 Chloroheptane, 3.6% Polychloroheptanes, large
(2)Heptane(C.P.)	1:2	Refluxing	CCl_4	Sec. Chloroheptanes, 25.4% 1 Chloroheptane, 9.1% Polychloroheptanes, medium
(1)Phenol	1:1	20°	$CHCl_3$	o-Chlorophenol, 46.1% p- " 36.4%
(2) "	1:1	20°	CCl_4	o- " 57.3% p- " 29.0%
(3) "	1:1	20°	$CHCl_3$	o- " 50.7% p- " 38.3%
(4) "	1:1	0°	$CHCl_3$	o- " 49.0% p- " 42.2%
(5) "	1:1	40°	$CHCl_3$	o- " 52.1% p- " 39.1%
(1)β-Phenylethyl alcohol	1:1	Various	$CHCl_3$	Tar and unchanged reactant
(2) "	1:1	10° to 23°	$CHCl_3$	β-Phenylethyl β-phenyl acetate, 37.8% Unchanged reactant
(3) "	1:1	Variable	None	β-Phenylethyl β-phenyl acetate, 19.2% Unchanged reactant
(4) "	1:1	Various	Various	β-Phenylethyl β-phenyl acetate, 49.8% Unchanged reactant, 72.5%

Note: the yields in this last reaction are the average of five separate runs.

Reactant	Molal Ratio Reagent/Reactant	Temp.	Solvent	Product and Yield
(5)β-Phenylethyl alcohol	1:1	20°	Dil. HAc	β,(p-Chlorophenyl) ethyl alcohol, 39.3%
Salicylic acid	1:1	20°	$CHCl_3$	5-Chlorosalicylic acid, 68.2%

B. METHOD OF PREPARATION OF THE REAGENT

For the benefit of future workers, a few remarks concerning the sodium hypochlorite solution will first be inserted here.

Since the sodium hypochlorite solution used varies in percentage available chlorine from about 7% down to zero, it must first be analyzed. This solution when first bought, will analyze about 7% chlorine as sodium hypochlorite, which corresponds to about 15% "available chlorine" by the commercial definition. The pure reagent can be prepared from sodium hypochlorite solution of chlorine strength varying from 7% to 2%, but it is impractical to use solution weaker than 2% because of the inconvenience of the large amount of water present. In the preparation of tertiary butyl hypochlorite subsequently described a considerable excess of acetic acid is used in order to neutralize the alkali in the sodium hypochlorite. The method of analysis of the latter is as follows.

15 c.c. of distilled water is placed in a 150 c.c.glass stoppered Erlenmeyer flask and weighed accurately. About 2 c.c. of the sodium hypochlorite solution are quickly pipetted into it, the stopper replaced, and the flask weighed again. To the flask are added 10 c.c. of a KI solution containing 3 grams of KI per 10 c.c., and 10 c.c. of glacial acetic acid, in that order. The liberated iodine is at once titrated with .1 normal thiosulfate, using starch as an indicator. 5 c.c. of concentrated hydrochloric acid may be substituted for the acetic acid if desired. The equivalent weight of chlorine here is $\frac{35.46}{2}$.

It should be noted here that this method of analysis gives results that are slightly high due to the chlorate in the sodium hypochlorite. For a very exact determination of hypochlorite chlorine the sodium arsenite method should be used. However, in this research the iodometric method was found to be satisfactory.

After considerable experimenting the method of preparation of tertiary butyl hypochlorite which was finally adopted is as follows.

A certain amount, say 500 grams, of sodium hypochlorite solution of previously determined chlorine strength is weighed out in a beaker and cooled in an ice bath. In another beaker are weighed out together the theoretical amount of tertiary butyl alcohol and the theoretical amount of glacial acetic acid plus a 50% excess. Both beakers are cooled to below 10°. Then they are poured into a separatory funnel and shaken gently. The crude reagent rises to the top as an oil. The water layer is drawn off and the crude reagent is shaken three times with an equal volume of a sodium bicarbonate solution of concentration 10 grams to 300 c.c. of water. The reagent is then dried over anhydrous potassium carbonate, filtered through a previously dried Gooch crucible, and stored in the dark in a glass stoppered flask until ready for use.

The preparation is carried out in diffused light under the hood and gives about 75% yield of product analyzing over 99% pure.

C. METHOD OF ANALYSIS OF THE REAGENT

After many futile attempts to get good check results, the following method of analysis of the reagent was adopted.

A piece of clean wafer tubing about 6 inches long sealed at one end is weighed accurately. By means of a thin pipette about .3 gram of sample is dropped in, care being taken not to get any on the sides of the tube. The lower end is cooled in ice water and the upper end sealed off quickly in a small flame. The two parts are then weighed again and the weight of sample obtained by difference. The sealed tube is carefully placed in a 250 c.c. glass stoppered Erlenmeyer flask containing 15 c.c. of glacial acetic acid and 15 c.c. of KI solution of concentration 3 grams KI per 10 c.c. The stopper is replaced in the flask and the latter shaken to break the wafer tubing. The hypochlorite immediately liberates iodine from the iodide, and is titrated with .1n thiosulfate, using starch as an indicator.

This method in many analyses gave results which checked easily within .2%.

D. DETERMINATION OF DENSITY OF THE REAGENT AT 18°/4°

A determination of density was made on a sample of pure tertiary butyl hypochorite made by the method above, to compare with the result obtained by Chattaway and Backeberg[24] and thus serve also as a check on the method of analysis outlined above. A pycnometer of about 15 c.c. capacity was used. The data and calculations follow.

	#1 at 26°	#2 at 23.5°
Wgt. pycnometer empty	24.8015 grams	24.8017 grams
" " plus water	39.3967 "	39.4086 "
" " " tertiary butyl hypochlorite	38.6400 "	38.7030 "
Wgt. water	14.5952 "	14.6069 "
" tertiary butyl hypochlorite	13.8385 "	13.9013 "
Density of water (from tables)	.9968	.9974

$\frac{13.9013-13.8385}{2.5} = .0251$ grams, change of wgt. of tertiary butyl hypochlorite per degree.

Calculations for determination at 26°

$13.8385+[.0251\times(26-18)]=14.0393$, wgt. of tertiary butyl hypochlorite at 18°

$\frac{14.5952}{.9968}=14.64$, wgt. of water at 4°

$\therefore \frac{14.0393}{14.64}=.9585$, density of tertiary butyl hypochlorite at 18°/4°

Calculation for determination at 23.5°

$13.9013+[.0251\times(23.5-18)]=14.0394$, wgt. of tertiary butyl hypochlorite at 18°

$\frac{14.6069}{.9974}=14.64$, wgt. of water at 4°

$\therefore \frac{14.0394}{14.64}=.9585$, density of tertiary butyl hypochlorite at 18°/4°

The density reported by Chattaway and Backeberg was .9583 at 18°/4°.

The two results obtained here are necessarily dependent one on the other, but the density was determined from each set of data separately simply as a check on the calculations.

E. STUDY OF THE RATE OF DECOMPOSITION OF THE REAGENT ALONE AND IN VARIOUS SOLVENTS

These studies were undertaken to find out the most suitable solvents to use as reaction media; to find out whether it was necessary to protect the reagent from the light during its preparation and while running reactions; to ascertain the stability of the reagent at elevated temperatures because it was necessary to carry out some reactions above room temperature; and in general to gather information which would enable us to handle the reagent more intelligently.

The tests on the reagent itself were carried out simply by allowing it to stand in a glass stoppered flask under the specified conditions, and analyzing a sample from time to time.

The tests on the reagent in the various solutions were carried out by allowing them to stand in glass stoppered bottles under the specified conditions, pipetting out a 25 c.c. sample from time to time into a mixture of 15 c.c. of glacial acetic acid and 15 c.c. of the KI solution, and titrating the liberated iodine with .1n thiosulfate. The solutions were of approximately 1% strength.

The tests with both the reagent alone at its boiling point and its solutions at their boiling points were done in an apparatus of the following description. A round bottomed flask of 1 liter capacity was fitted to a special removable neck about

6 inches long by means of a ground joint. Sealed into the side of this neck was a tube leading almost to the bottom of the flask, and which protruded horizontally from the neck about 4 inches, being closed off by a stopcock. To this neck was attached a long reflux condenser by means of another ground joint. An atomizer bulb was attached to the top of the condenser through a calcium chloride tube. With this apparatus a sample could be removed for analysis without disturbing the course of the decomposition, by simply pressing the atomizer bulb and opening the stopcock.

In the tests 12 inches away from a 40 watt lamp this lamp was the only source of illumination since they were done in a cupboard otherwise dark. The temperature at no time exceeded 30°, so the decomposition was due to the light and not the heat.

The tests run in diffused daylight were kept in the dark overnight to stop the decomposition. The time plotted was the actual time exposed to diffused daylight. This procedure was justified by the fact that smooth curves were obtained and by experiment. By analysis it was found that either the reagent or its solutions partly decomposed were stable in the dark. This is true of course only for those long time tests that had to be run over a period of days.

The alcohol-free chloroform used in some of these tests was prepared from U.S.P. chloroform by extracting with three separate portions of water, drying over calcium chloride, and distilling through a column.

The results of all these tests have been plotted. The plots of the tests using the reagent alone have time as abscissae and percentage chlorine as ordinates. The plots of the tests of the reagent in solution have time as abscissae and grams of chlorine per liter as ordinates.

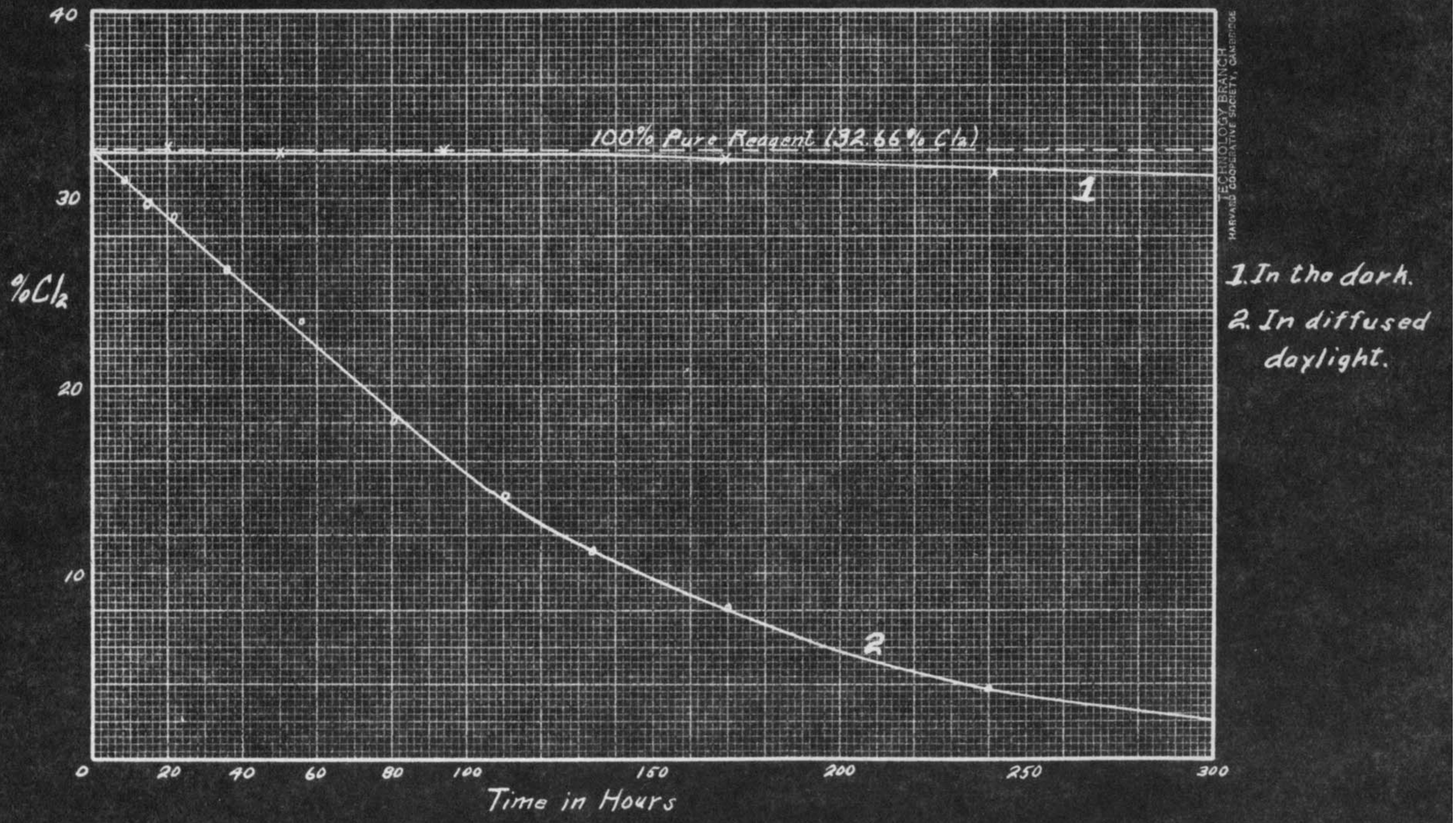
In the tabulated data following, all chlorine analyses of the reagent itself are the means of two check determinations, each of which was within .2% of the other practically without exception.

In the analyses of the solutions check determinations were not made in each case because it was found not to be necessary, the samples being taken with a 25 c.c. pipette.

The tabulated data and the plots immediately follow.

Rate of Decomposition of Reagent alone, at Room Temperature

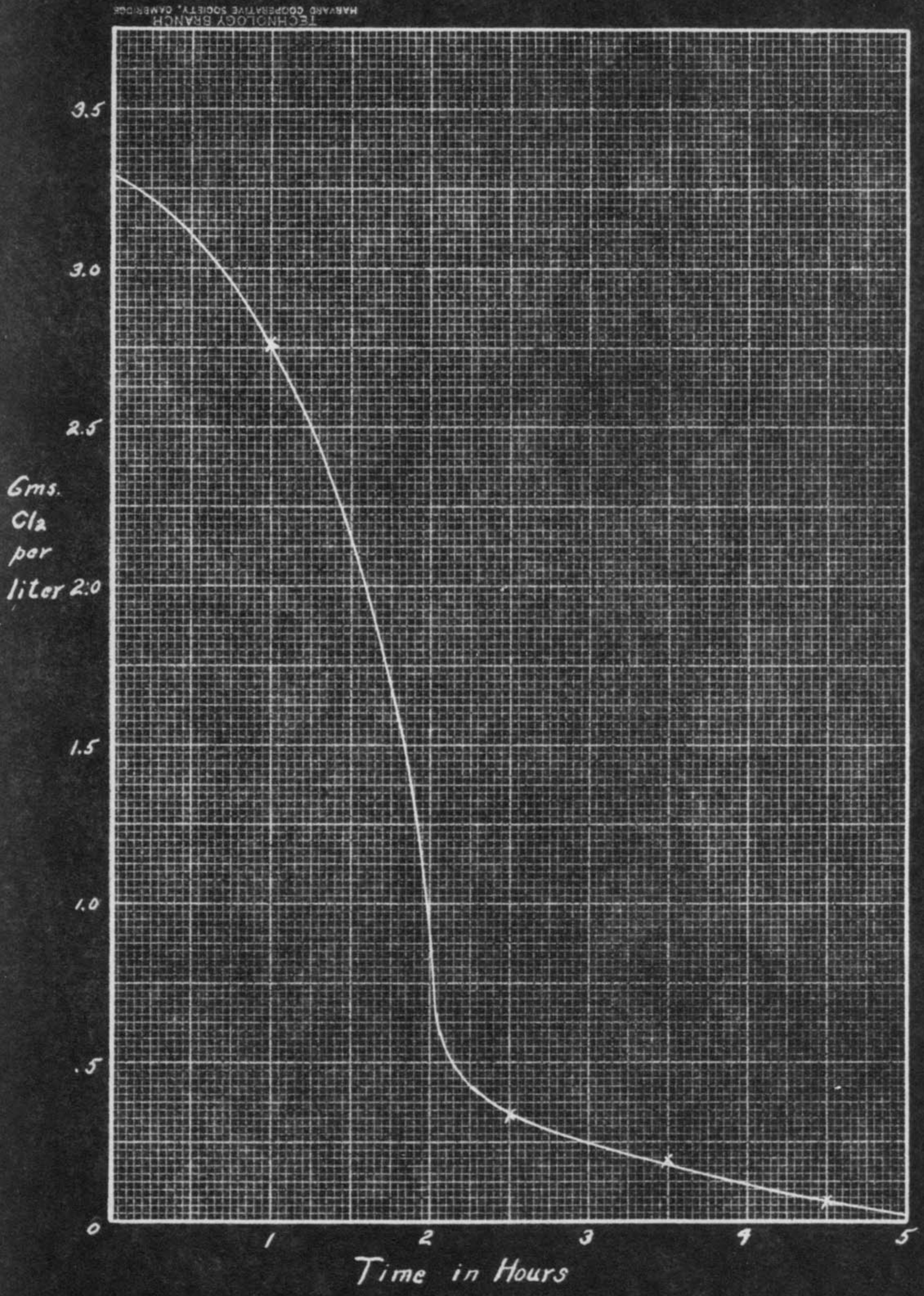
In the dark		In diffused daylight	
Time in hours	%Cl_2	Time in Hours	%Cl_2
0	32.57	0	32.57
20	32.82	1.5	32.37
50	32.49	8.5	31.11
94	32.64	14.5	29.88
169	32.12	21.5	29.07
241	31.34	35.5	26.28
310	31.19	55.5	23.58
380	31.23	80.5	18.18
		110.5	14.24
		134	11.32
		170	8.25
		240	3.913
		320	1.650



Rate of Decomposition of Reagent alone, at Room Temperature

Rate of Decomposition of Reagent in U.S.P. Chloroform, at Room Temperature, in the Dark

Time in hours	Grms.Cl_2 per liter
0	3.326
1	2.755
2.5	.3445
3.5	.1739
4.5	.06113
5.5	0

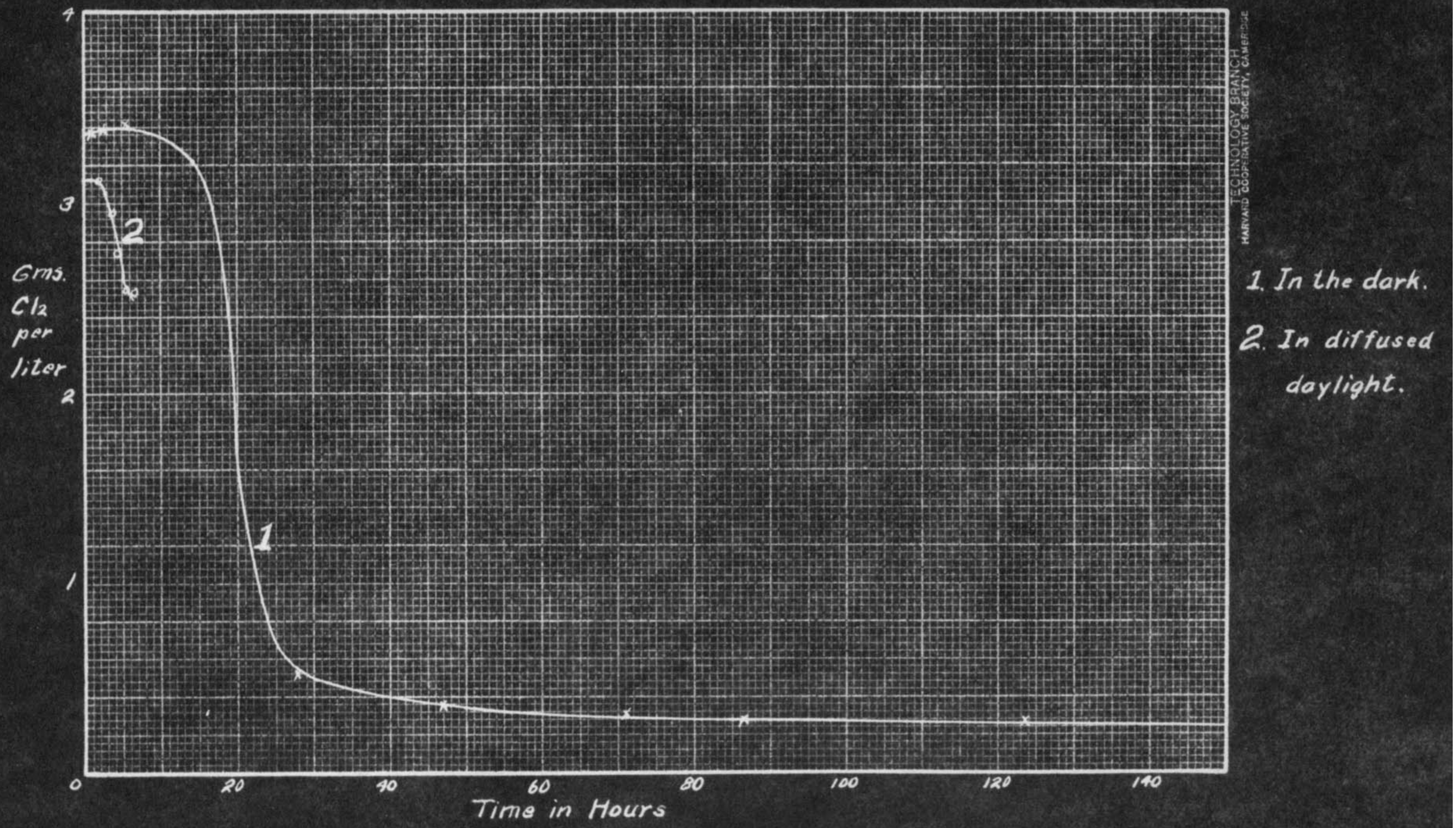


Rate of Decomposition of Reagent in
U.S.P. Chloroform, at Room Temperature, in the dark

Rate of Decomposition of Reagent in Alcohol-free Chloroform, at Room Temperature

In the dark		In diffused daylight	
Time in hours	Gms.Cl$_2$ per liter	Time in hours	Gms.Cl$_2$ per liter
0	3.380	0	3.123
1	3.388	2	3.147
2.5	3.389	3.5	2.956
5.5	3.415	4.5	2.747
28	.5333	5.5	2.542
47	.3724	6.5	2.520
71	.3288		
96.5	.2986		
123.5	.2821		
194	.2219		

When sample was then left overnight in the dark the value had fallen to 1.150



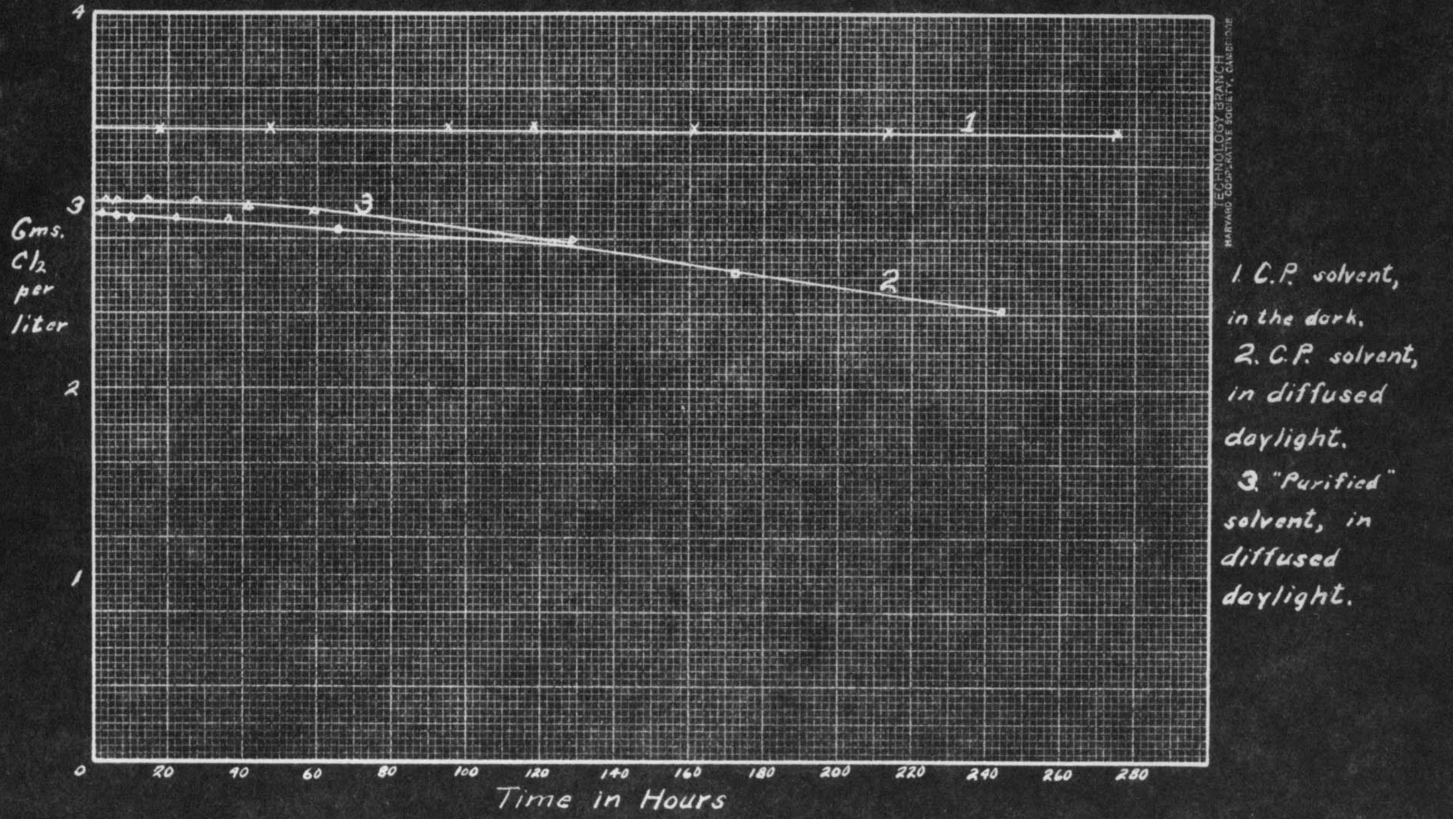
Rate of Decomposition of Reagent in Alcohol-free Chloroform, at Room Temperature

Rate of Decomposition of Reagent in Carbon Tetrachloride, at Room Temperature

C.P. CCl_4 in the dark		C.P. CCl_4 in diffused daylight	
Time in hours	Gms. Cl_2 per liter	Time in hours	Gms. Cl_2 per liter
0	3.392	0	2.944
19	3.394	2	2.939
47	3.398	5.5	2.935
95	3.394	10	2.927
118	3.393	22	2.919
137	3.319(?)	36	2.901
161	3.380	65	2.873
213.5	3.385	172	2.629
274.5	3.383	243.5	2.424

"Purified" CCl_4 in diffused daylight

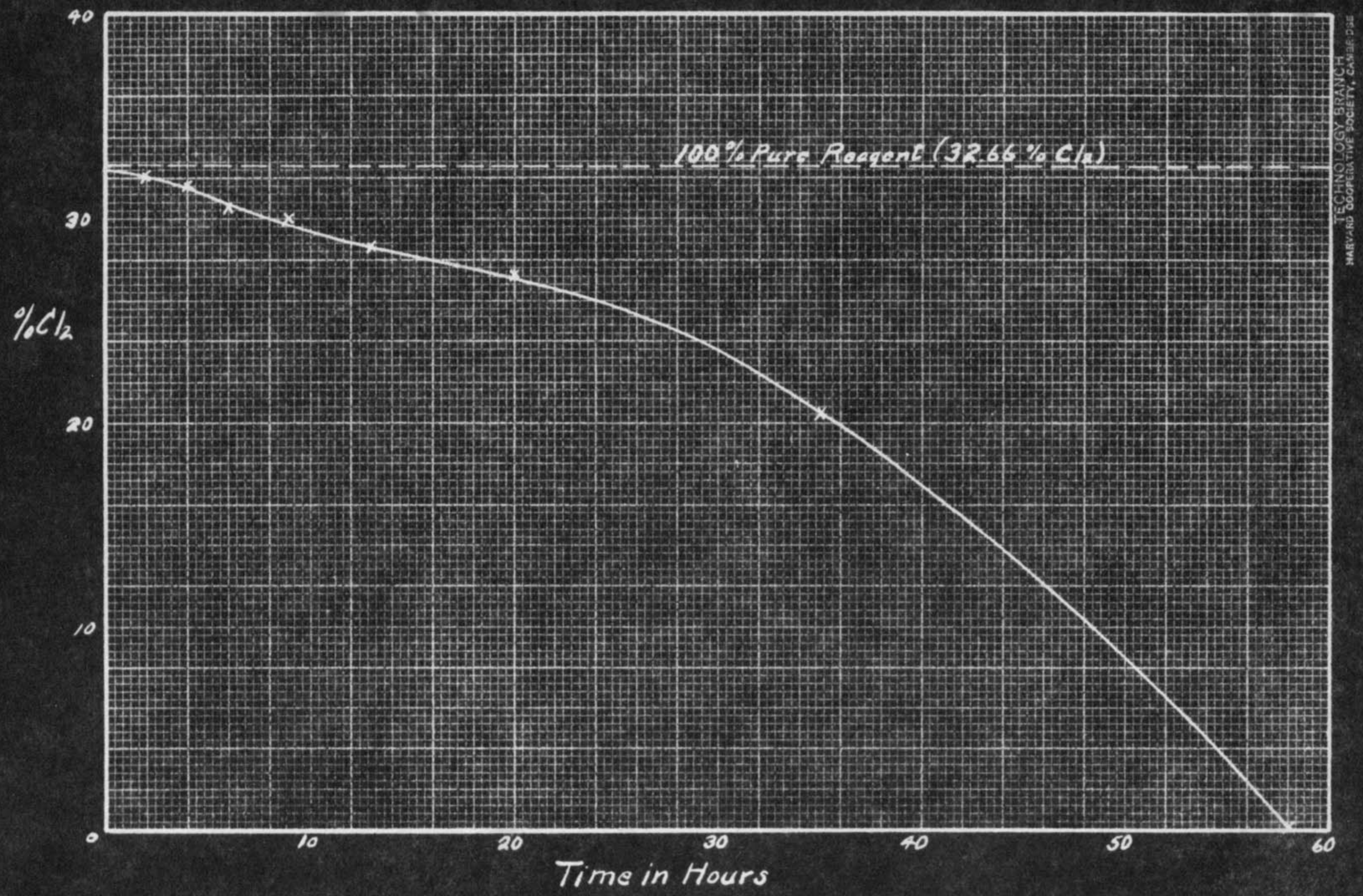
Time in hours	Gms. Cl_2 per liter
0	3.033
3	"
6	"
14	"
27	3.021
41	2.975
59	2.953
128	2.786



Rate of Decomposition of Reagent in Carbon Tetrachloride, at Room Temperature.

Rate of Decomposition of Reagent alone, 12 inches from a 40 watt Lamp, at Room Temperature

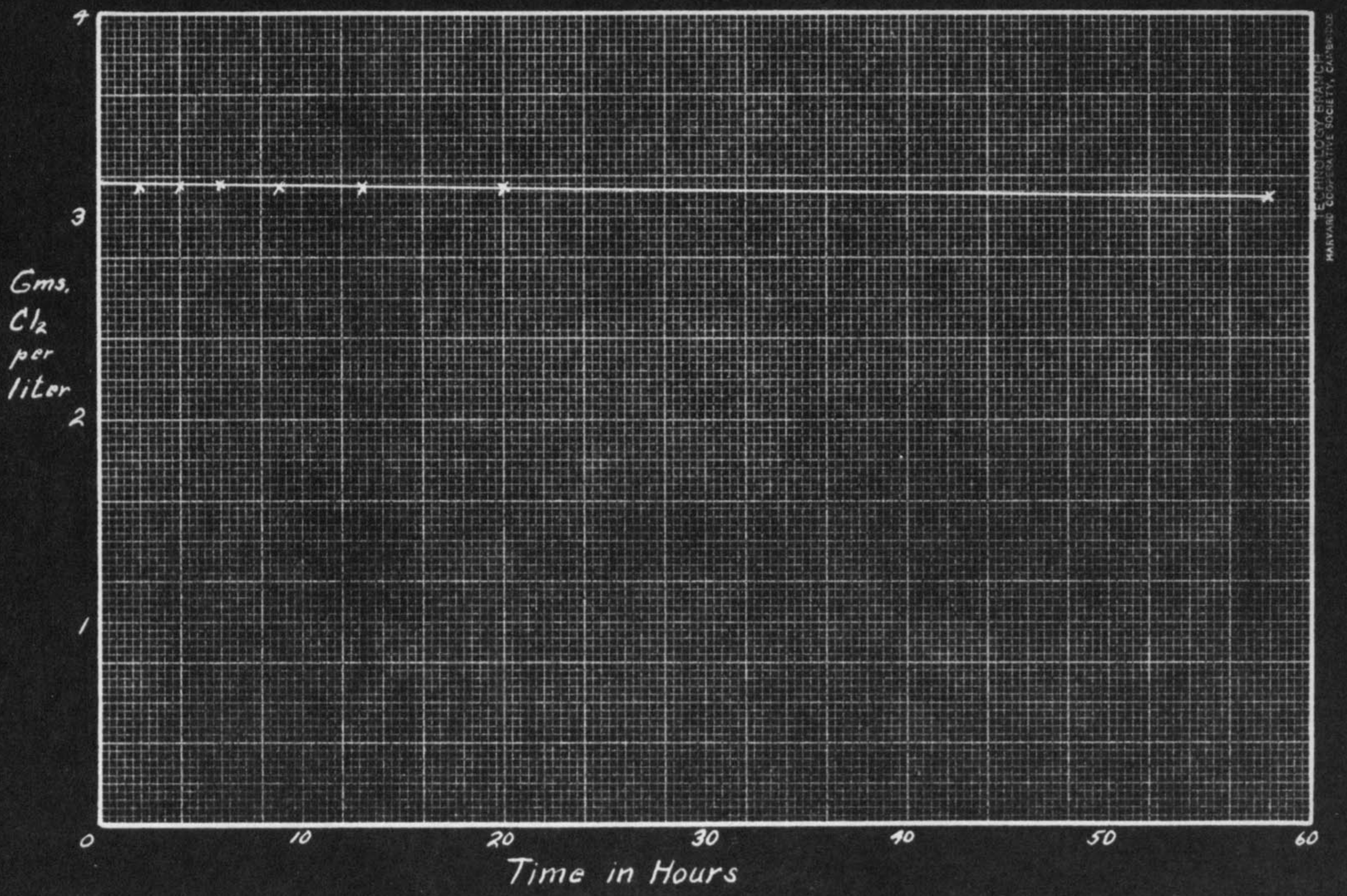
Time in hours	%Cl_2
0	32.42
2	32.04
4	31.67
6	30.58
9	29.97
13	28.73
20	27.26
35	20.49
58	0



Rate of Decomposition of Reagent alone, 12 inches from a 40 watt Lamp, at Room Temperature.

Rate of Decomposition of Reagent in "purified" Carbon Tetrachloride 12 inches from a 40 watt Lamp, at Room Temperature

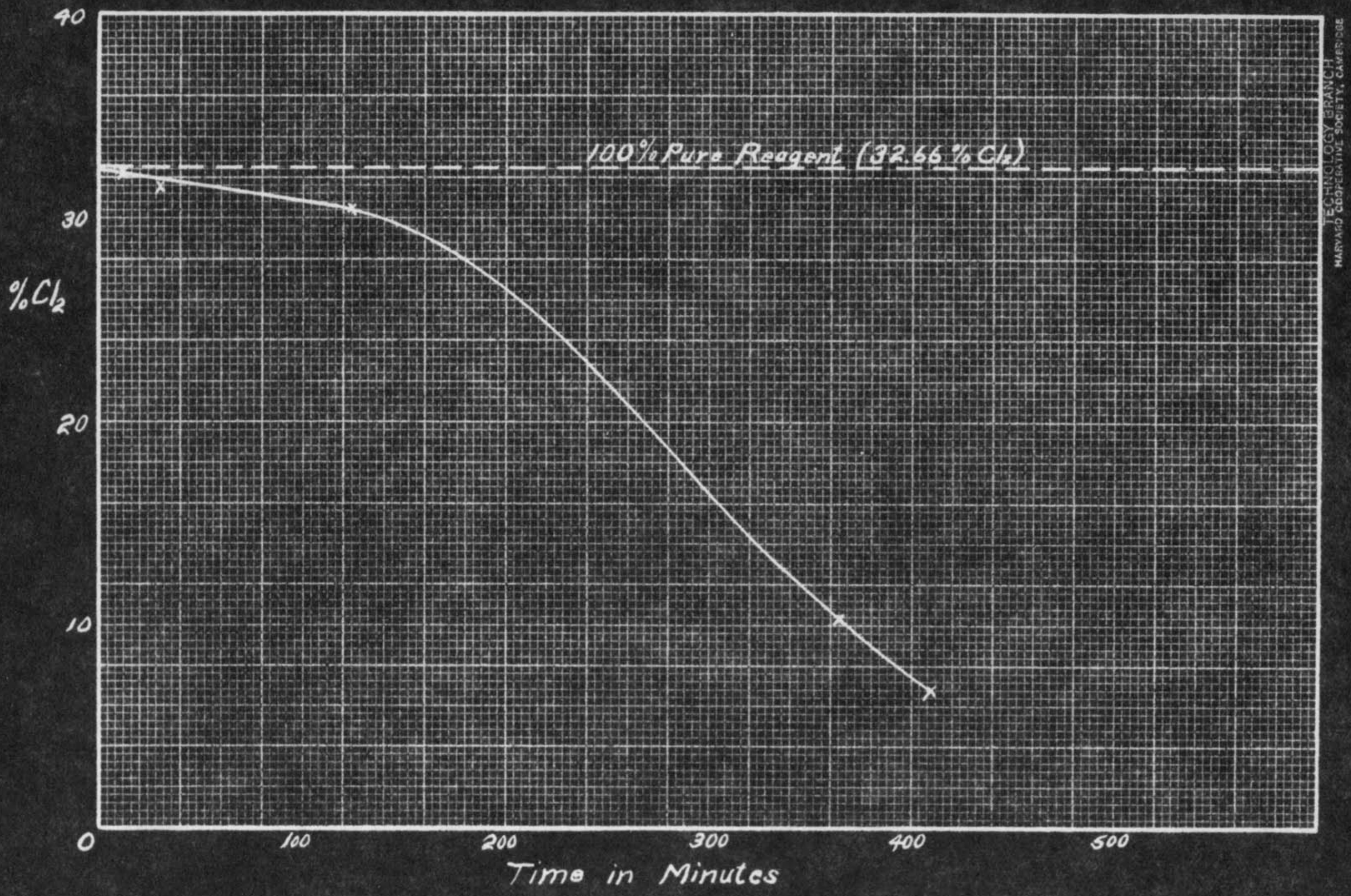
Time in hours	Gms.Cl_2 per liter
0	3.163
2	3.156
4	3.149
6	3.161
9	3.151
13	3.146
20	3.143
58	3.109
86.5	3.058
132	2.972



Rate of Decomposition of Reagent in "purified" Carbon Tetrachloride 12 inches from a 40 watt Lamp, at Room Temperature

Rate of Decomposition of Reagent alone at its Boiling Point, in Diffused Daylight

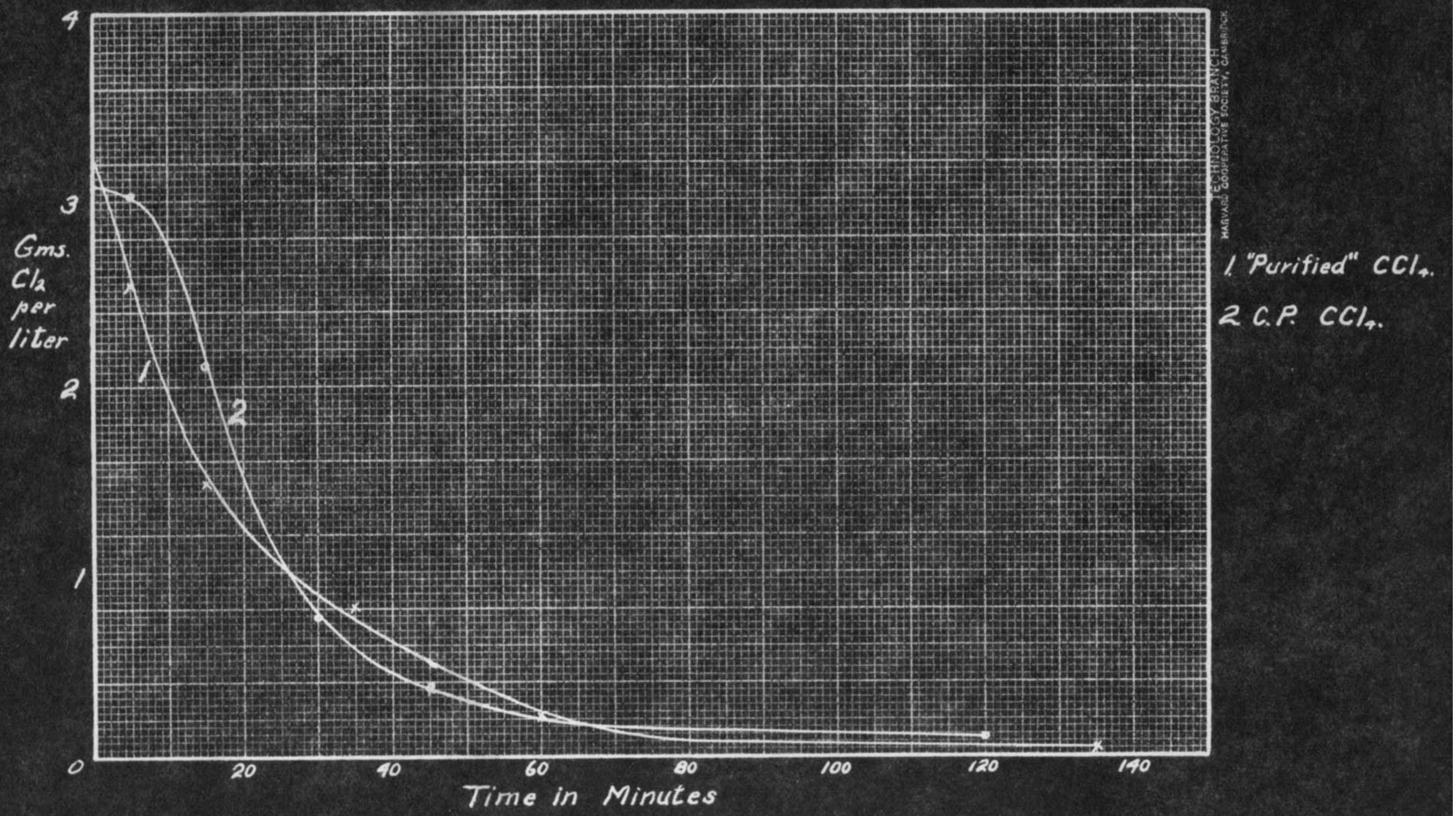
Time in minutes	%Cl_2
0	32.36
1	32.35
11	32.21
31	31.71
61	31.53
124	30.58
364	10.46
410	6.82



Rate of Decomposition of Reagent alone at its Boiling Point, in Diffused Daylight

Rate of Decomposition of Reagent in Carbon Tetrachloride, at the Boiling Point of the Solution, in Diffused Daylight

"Purified" CCl_4		C.P. CCl_4	
Time in minutes	Gms. Cl_2 per L	Time in minutes	Gms. Cl_2 per L
0	3.206	0	3.082
5	2.565	5	3.040
15	1.481	15	2.114
30	.8089	30	.7573
45	.3527	45	.3631
60	.2114	60	.2258
135	.04305	120	.1005

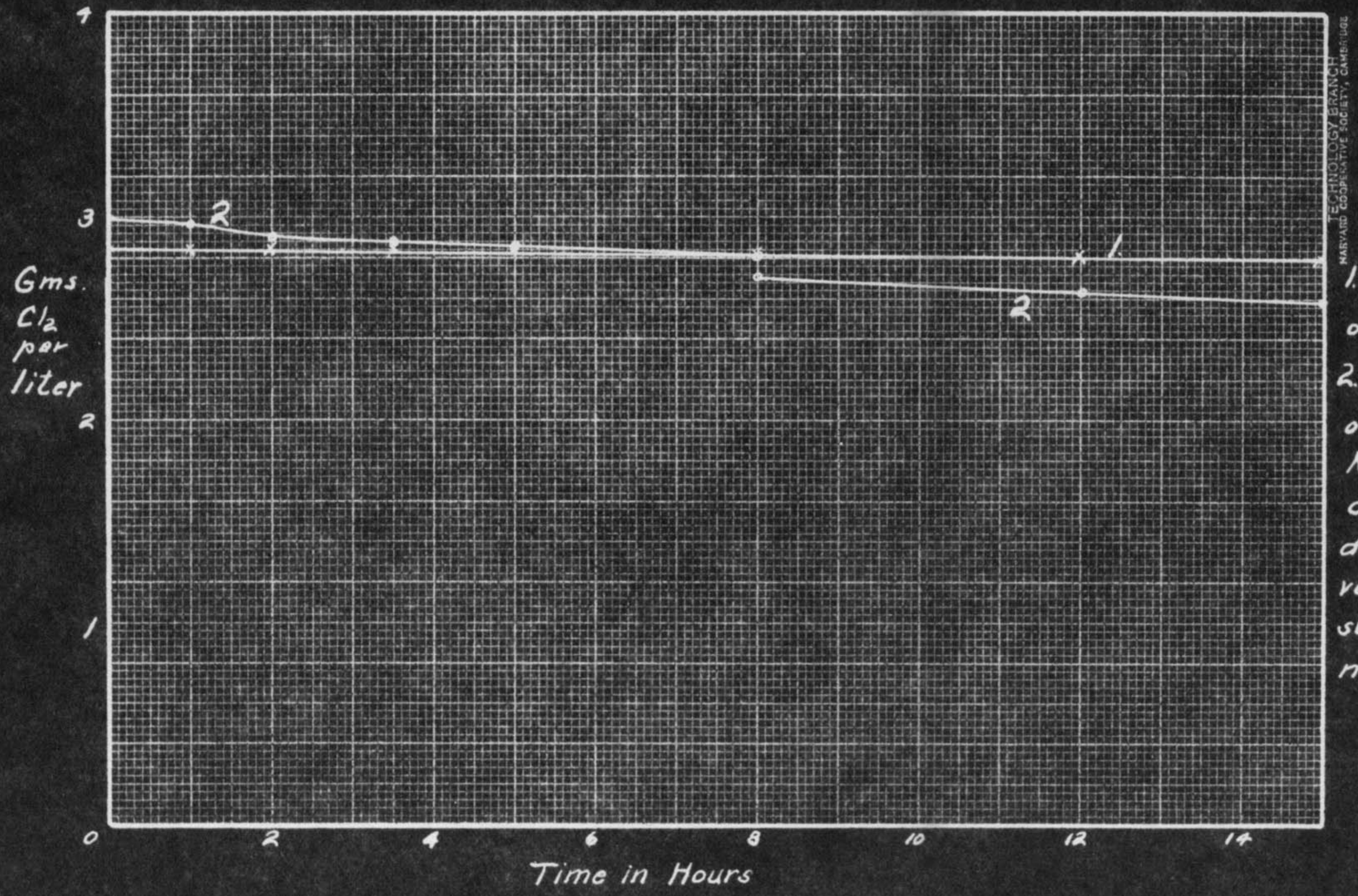


Rate of Decomposition of Reagent in Carbon Tetrachloride, at the Boiling Point of the Solution, in Diffused Daylight.

Rate of Decomposition of Reagent in C.P. Glacial Acetic Acid in Diffused Daylight at Room Temperature

With I_2		Without I_2	
Time in hours	Gms. Cl_2 per L	Time in hours	Gms. Cl_2 per L
0	2.990	0	2.849
1	2.968	1	2.849
2	2.905	2	2.856
3.5	2.882	3.5	2.846
5	2.849	5	2.847
8	2.803	8	2.836
8	2.730	8	2.833
12	2.661	12	2.808
15	2.598	15	2.796
15	2.362	15	2.789

Note: the difference between the two readings at 8 and at 15 hours represents the drop in chlorine value upon standing overnight in the dark.



1. In absence of I_2.

2. In presence of I_2.

Note: break in curve 2 due to drop in Cl_2 value upon standing overnight in dark.

Rate of Decomposition of Reagent in C.P. Glacial Acetic Acid in Diffused Daylight at Room Temperature.

F. REACTIONS OF THE REAGENT WITH VARIOUS ORGANIC COMPOUNDS

The reactions in general were run at 20° in a 1 liter 3-necked flask through the middle opening of which was a motor stirrer passing through a bearing made of a piece of glass tubing in a cork stopper. Through the second neck was a thermometer graduated in tenths of degrees, set in a cork, and through the third neck was a graduated dropping funnel of 60 c.c. capacity, set in a cork. Thus the flask was open to the atmosphere, no mercury seal being necessary. This apparatus will be hereinafter referred to simply as the "reaction flask". In running certain of the reactions special apparatus was used and their descriptions will be included under that of the reactions themselves.

In general the reactions were carried out by dissolving or suspending the reactant in the solvent in the reaction flask, and adding the reagent dropwise from the funnel, stirring all the time, and keeping the temperature constant by application of an ice bath if necessary.

No more introductory remarks will be made here because a complete description of experimental procedure, along with some discussion, will be found under the specific reactions, which immediately follow.

Reaction with Anthracene (1).

35.6 grams (1/5 mol) of Eastman "pure" anthracene, M. P. 210° uncorr. were suspended in 200 c.c. of U.S.P. chloroform, and 22.6 c.c. of reagent (1/5 mol) added 1 c.c. per minute, keeping the temperature at 20° and stirring continuously. There was no appreciable temperature rise until after all the reagent had been added, when there was a slight heat effect as the reaction got started. The material in the flask turned a deeper yellow as the reaction proceeded. At the end of 3 hours the reaction seemed to be over. A large part of the material had gone into solution. Stirring was stopped and the mixture allowed to stand overnight.

The next morning the reaction mixture was filtered on a Buchner funnel, whereupon 4.4 grams of a material M. P. 163°-202° was obtained. This was crystallized from chloroform and gave elongated, hexagonal, almost colorless, plate-like crystals M. P. 211°-212°. This was evidently anthracene, because both 9 chloroanthracene and 9-10 dichloroanthracene occur as yellow needles.

The deep orange colored chloroform filtrate was distilled to dryness on a water bath. Hydrogen chloride came over with the first portion of the distillate, as shown by its fuming in moist air. The residue obtained in this distillation melted at 83°-148°. It was extracted with hot alcohol to try to separate the 9 chloroanthracene from the 9,10 dichloroanthracene, since the latter is much more insoluble in alcohol than the former. The extract was allowed to cool whereupon a crystalline material separated out. This was filtered off and melted 82°-105°. Recrystallized from alcohol it melted 88°-100°. Recrystallized again it melted 99°-105°. Beilstein gives the melting point of the 9 chloro compound as 103°, and that of the 9,10 dichloro compound as 209°. Apparently there was present here a small amount of the 9,10 dichloro compound mixed with a large amount of the 9-chloro compound, and since the former is more insoluble than the latter in all the common solvents they are very difficult to separate.

The material left over from the extraction with hot alcohol was recrystallized several times from hot chloroform, whereupon a small amount, .1 gram, of yellow crystalline material in fine needles was obtained, M. P. 209°-210°, which was taken to be 9,10 dichloroanthracene.

Reaction with Anthracene (2).

The pure anthracene used in this and the following reactions was made from the crude 85% material, M.P.204°-207°, by crystallizing twice from furfural. The residual furfural was washed out of the anthracene with carbon tetrachloride by heating it to boiling with an insufficient amount to dissolve it, then filtering when cool, and washing again with carbon tetrachloride on the filter. The anthracene so prepared was colored light yellow and melted at 212°-213°.

17.8 grams (.1 mol) of this purified anthracene were suspended in 200 c.c. of "purified" carbon tetrachloride in the reaction flask and a few crystals of iodine added as a catalyst. The iodine dissolved in the solution, imparting to it a red color. The flask was cooled to 0°. With constant stirring 11.3 c.c. (.1 mol) of the reagent were added during the course of an hour. No reaction seemed to be taking place at 0° even after 3 hours. The solution was still colored red by the iodine. The flask was allowed to come to room temperature and a few iron filings added to see if the reaction would start. After stirring for another hour at room temperature there was still no change. The flask was put in an ice bath and allowed to stand overnight. The next morning there were needle-like orange yellow crystals present and the solution was yellow instead of red. Some reagent was still present as shown by testing with iodo-starch paper. Since the reaction now seemed to be progressing it was decided to add another .1 mol of reagent with the object of getting all 9,10 dichloroanthracene. This was done in the course of ½ hour, keeping the temperature at 20°. The reaction was smooth and not very vigorous. There was some evolution of heat. As the reaction proceeded the suspended material increased in amount. At the end of a ½ hour from the time of adding the last of the reagent, iodo-starch paper gave no test for hypochlorite, and the solution again became red from the iodine.

The suspended material, fine yellow needles, was filtered off on a Buchner funnel and melted 197°-205°. It was crystallized from a mixture of 3 parts benzene and 2 parts acetic acid and gave 10 grams of fine yellow needles M.P. 208°-209.5°. The product, when on the filter, was washed with acetic acid, then with water. This causedthe filtrate to separate into 2 layers and precipitated some more product. This wasfiltered off and gave a second crop. The two layers of the filtrate were separated and the water layer extracted twice with carbon tetrachloride and added to the organic layer. This benzene solution was evaporated almost to dryness and the filtered off product crystallized from the benzene-acetic acid mixture, yielding a third crop.

The carbon tetrachloride filtrate from the original reaction mixture was evaporated to dryness and crystallized twice from the benzene-acetic acid mixture, giving a fourth crop, making a total yield of 13.6 grams of 9,10 dichloroanthracene, corresponding to 55% of theory.

Remarks. A small scale experiment showed that this reaction proceeds almost at once if the carbon tetrachloride is first saturated with dry hydrogen chloride, and using iodine alone as a catalyst. This is due to the iodine chloride, which is formed by the action of free chlorine and iodine, the free chlorine being first formed by the action of the reagent and the hydrogen chloride.

Another small scale reaction showed that the dichloro product alone is produced even at 0° when hydrogen chloride and iodine are used. Thus if the mono chloro product, 9 chloroanthracene, is wanted, the use of catalysts should be avoided. The iodine seems to have a definite catalytic effect on both the rate of the reaction and the products formed.

Reaction with Anthracene (3).

Small scale experiments showed that this reaction proceeds much more rapidly in glacial acetic acid than in either chloroform or carbon tetrachloride, and the reaction seemed to be fairly complete, so it was decided to run a regular reaction using acetic acid as the solvent.

4.45 grams (.025 mol) of anthracene were weighed out into a 100 c.c. graduate. 50 c.c. of glacial acetic acid were added, and the graduate placed in a 1-liter beaker full of water at 20°. The mixture was stirred by motor, and 5.6 c.c. (.05 mol) of reagent added slowly during the course of an hour from an offset separatory funnel, keeping the temperature of the water bath at20° by adding ice when necessary. The reaction started about 25 minutes after the first portion of reagent was added, and proceeded smoothly andwith development of little heat for 50 minutes, after which time there was no hypochlorite present in the mixture, as shown by testing with a potassium iodide-acetic acid solution. As the reaction proceeded, fine yellow needles came out, so that it was necessary to add more solvent to keep the mixture fluid enough to stir.

After standing overnight the mixture was filtered off. The fine yellow needles melted at 160°-192°. Crystallization from a mixture of equal parts of benzene and acetic acid yielded the first crop, 3.5 grams, of 9,10 dichloroanthracene. The mother liquor from this was evaporated almost to dryness, filtered, and the solid material crystallized twice from the benzene-acetic acid mixture, giving .5 gram more product, making a total yield of 9,10 dichloroanthracene of 65% of theory.

The original acetic acid filtrate was evaporated almost to dryness but gave only a very small amount of very impure product, which was discarded.

Remark. The object of running this reaction in a graduate was to make it easier to follow the course of the reaction by noting the volume of the undissolved material from time to time, but since the reaction started much more quickly than was expected, this was unnecessary.

Reaction with Anthracene (4).

In this reaction a 100% excess of anthracene was used in order to favor the formation of 9-chloroanthracene if possible.

44.5 grams ($\frac{1}{4}$ mol) of anthracene were weighed out into the reaction flask and 300 c.c. of glacial acetic acid added. The mixture was cooled to 20° and 14.2 c.c. (1/8 mol) of reagent added dropwise during the course of an hour, stirring continuously, and keeping the temperature constant by applying an ice bath from time to time. The reaction started after 25 minutes and was complete after 1$\frac{1}{4}$ hours from the start. It was smooth and developed little heat. The amount of suspended material increased as the reaction proceeded.

When the reaction was over the suspended material was filtered off, and the 9-chloroanthracene thrown out of the yellow acetic acid filtrate by adding about 2 volumes of water. This was heated to coagulate the product. After cooling it was filtered off and washed with water. The crude product was then extracted with about 15 c.c. of cold ether three times, the material insoluble in ether being removed by filtration. The ether extract was evaporated to dryness. Then the picrate was made by pouring together a hot saturated alcoholic solution of the product and a hot saturated alcoholic solution of an excess of picric acid. On cooling slowly, the picrate separated in brilliant red needles. These were filtered off and melted up to 136°-137°. They were decomposed by suspending in alcohol and passing ammonia gas through the solution. The mixture was then poured into about 3 volumes of water, this operation precipitating the product and dissolving the ammonium picrate. The product was filtered off and washed thoroughly with water. It was crystallized three times from alcohol and yielded the first crop of 9-chloroanthracene M.P. 102°-104° in glistening small light yellow needles.

The picrate mother liquor and that from the crystallizations were worked up by evaporating down and repurifying through the picrate when necessary.

In all a yield of 3.4 grams of 9-chloroanthracene was obtained, being 12.8% of the theoretical.

Remarks. A small sample of the 9-chloroanthracene highly purified melted sharply at 105°.

The crude product was converted to the picrate as a means of purification because this was the only method found of separating it from the small amount of relatively insoluble 9,10 dichloroanthracene.

An attempt was made to convert a small amount of the product to anthranol or anthrone by refluxing it for 3 hours with concentrated alcoholic caustic soda, but the 9-chloroanthracene was recovered absolutely unchanged. The chlorine atom in it seems therefore to be aromatic in character.

The other product of the reaction was 9,10 dichloroanthracene, but it was not isolated.

The picrate of 9-chloroanthracene cannot be crystallized from alcohol without decomposition, but can be crystallized satisfactorily from a picric acid solution of alcohol.

Because of the great difficulty of purifying 9-chloroanthracene otherwise than by means of its picrate it was thought that perhaps it underwent disproportionation to anthracene and 9,10 dichloroanthracene. This was found not to be true because a small sample of the pure material after refluxing for 3 hours in alcohol solution was recovered unchanged.

Reaction with Anthranilic Acid (1)

34.3 grams, ($\frac{1}{4}$ mol) of anthranilic acid, M.P. 145°, were suspended in 250 c.c. of chloroform in the reaction flask and 28 c.c. ($\frac{1}{4}$ mol) of reagent were added dropwise with continuous stirring during the course of $\frac{1}{2}$ hour, the temperature being kept at 20° by applying an ice bath when necessary. The reaction was vigorous. The amount of suspended material increased as the reaction proceeded. It was necessary to add more solvent in order to keep the mixture fluid enough to stir efficiently. The solution was deep red at the end of the reaction. It was filtered on a Buchner funnel and the precipitate washed with chloroform. When dry the white cake was tinged with red and weighed 20.8 grams.

In previous experiments it was found that dilute hydrochloric acid (15 c.c. of concentrated hydrochloric acid to 85 c.c. of water) at the boiling temperature would completely dissolve 5 chloroanthranilic acid, and leave the 3,5 dichloro acid undissolved. Therefore this method of separation was used in the following.

The first crop was heated to boiling with 300 c.c. of the dilute hydrochloric acid, cooled to about 30°, and filtered on a Buchner funnel. The insoluble material was again heated with about 200 c.c. of the dilute acid, cooled to 30°, and filtered. It was crystallized from 50% alcohol, yielding .9 gram of fine brown needles, M.P. 225°-226°. This was the first crop of the dichlor acid.

The dilute hydrochloric acid filtrate was neutralized with strong sodium hydroxide solution, whereupon a voluminous precipitate of the 5 chloro acid came out. This was filtered off on a Buchner funnel, washed with water, and crystallized from 50% alcohol. 14.0 grams of light brown needles M.P. 206° were obtained. Partial evaporation of the mother liquor, filtration, and crystallization from 50% alcohol yielded 2.2 grams more 5 chloro acid.

The original chloroform filtrate was distilled to remove the solvent, and the dark red residue heated to boiling with 300 c.c. and again with 200 c.c. of the dilute hydrochloric acid. The insoluble material was crystallized twice from 50% alcohol, but did not show any purification as shown by its melting point, 170°-180°. It was again heated with an excess of dilute hydrochloric acid to make sure all the monochloro product had been removed, but when crystallized from 50% alcohol it still showed the same range of melting point. It now weighed 4.8 grams. It was sublimed in vacuum, giving 4.4 grams of nearly white sublimate, which on two crystallizations from 50% alcohol yielded 1.8 grams of fine white needles M.P. 224°-225°, making a total yield of 10.5% of dichloro acid.

The hydrochloric acid filtrate containing the hydrochloric acid soluble material from the residue left on distilling the original chloroform solution to dryness was neutralized with strong sodium hydroxide solution, and the precipitate crystallized twice from 50% alcohol. In this way 2.7 grams more of monochloro acid were obtained, making a total yield of 5 chloro-anthranilic acid of 18.9 grams, or 44.1% of theory.

The 5 chloro-anthranilic acid was identified by its melting point and by that of its methyl ester, which was prepared in the regular way using dry hydrogen chloride as a catalyst. The ester melted at 69°-70°.

The 3,5 dichloro-anthranilic acid was identified by its melting point and by that of the 3,5 dichloroacetyl anthranil prepared from it by the method of Elion,[25] which is as follows. A weighed amount of dichloro acid is heated for 15 minutes with five times its weight of acetic anhydride. It is cooled, filtered, and recrystallized from alcohol. That prepared melted at 149°-149.5°.

Reaction with Anthranilic Acid (2).

17.1 grams (1/8 mol) of anthranilic acid, M.P. 145°, were suspended in 250 c.c. of chloroform in the reaction flask, and 28 c.c. ($\frac{1}{4}$ mol) of reagent added dropwise during the course of 15 minutes, keeping temperature at 20°, and stirring continuously. At the end of the reaction the solid material in the flask was more voluminous than at the start, and solution was colored red.

The precipitate was filtered off and washed with chloroform. When dry it weighed 12.7 grams. This was crystallized from 50% alcohol, yielding 9.1 grams of nearly white fine needles, M.P. 224°-225°. The mother liquor from this was evaporated down until a precipitate began to form, then it was allowed to cool, and filtered. The filtered off material was washed twice with chloroform to remove the red dyestuff formed during the reaction. This was done by heating with chloroform, allowing to cool, and filtering. The nearly colorless material was crystallized twice from 50% alcohol, yielding .7 gram more product.

The chloroform filtrate from the original reaction mixture was distilled to dryness, whereupon a dark red material was obtained. This was washed twice with chloroform as described above, and crystallized twice from 50% alcohol, yielding 3.0 grams of fine grey needles, M.P. 225°-226°. Thus a total yield of 12.8 grams of 3,5 dichloroanthranilic acid was obtained, corresponding to 49.2% of the theoretical. It was identified by its melting point and by that of the 3,5 dichloroacetyl anthranil prepared from it by the method of Elion.[26] The derivative melted at 149°-150°.

Reaction with Anthranilic Acid (3).

These next two reactions with anthranilic acid were run at low temperature (-78°) to see if the yields of products could be increased.

The apparatus consisted of a large test tube to which were attached through a 3-holed cork stopper (1) an offset separatory funnel, (2) a calcium chloride tube, and (3) a mercury seal hand stirrer. The stirrer was a stiff piece of wire with a loop on the bottom and was worked up and down as in a molecular weight apparatus. During the reaction the test tube was set into a Dewar flask containing dry ice and ether.

2.75 grams (.02 mol) of anthranilic acid M.P. 145°, 5 c.c. of carbon tetrachloride, and 20 c.c. of chloroform were placed in the apparatus and the whole cooled down to -78°. 2.25 c.c. (.02 mol) of reagent were added dropwise during the course of 5 minutes. The reaction mixture was thoroughly stirred, and allowed to stand overnight at the low temperature. The next morning the reaction mixture was light reddish brown in color and the amount of insoluble material seemed to be greater than at the start.

The mixture was filtered off and washed with chloroform. The material on the filter when dry was light gray in color and melted at 199°-200°. Its weight corresponded to about 70% yield. It was crystallized twice from 50% alcohol, giving .7 gram of fine reddish brown needles, M.P. 204°-205°. The mother liquors were worked up and yielded .8 gram more product, the total yield of 5-chloroanthranilic acid corresponding to 43.5% of theory.

The original filtrate was evaporated to dryness and crystallized from 50% alcohol. This yielded an amorphous product. This was sublimed in vacuum at 4 m.m. and 150°. The white sublimate was crystallized three times from 50% alcohol, but gave no product of definite melting point.

Reaction with Anthranilic Acid (4).

Into the apparatus described in the previous reaction 2.75 grams (.02 mol) of anthranilic acid M.P. 145°, 5 c.c. of carbon tetrachloride, and 20 c.c. of chloroform were placed. The whole was cooled down to -78° and 4.5 c.c. (.04 mol) of reagent added dropwise with constant stirring. Stirring was continued for about an hour, and since no reaction seemed to be taking place the reaction mixture was allowed to stand overnight at the low temperature. The next morning the solution was colored red.

The crystalline suspended material was filtered off and washed with chloroform. The deep red filtrate was evaporated to about 1/3 its volume, and the precipitated material filtered off. This red material was washed with chloroform and added to the first crop. The total quantity of crude product was heated to boiling with 100 c.c. of dilute hydrochloric acid (15 parts of concentrated hydrochloric acid to 85 parts of water) and after cooling to 30° was filtered. The insoluble material was crystallized from 50% alcohol, giving a first crop of nearly white very fine needles, M.P. 226°. A small second crop was obtained by working up the mother liquor. The total yield of 3,5 dichloroanthranilic acid was 3.0 grams or 72.5% of theory.

The hydrochloric acid filtrate was neutralized with sodium hydroxide solution, but only a trace of precipitate came out, showing that practically no monochloro acid was present.

Reaction with Benzaldehyde (1).

53 grams ($\frac{1}{2}$ mol) of C.P. benzaldehyde were dissolved in 250 c.c. of carbon tetrachloride in the reaction flask, and cooled to 20°. 56 c.c. ($\frac{1}{2}$ mol) of reagent were added dropwise during the course of 3/4 hour, stirring continuously and keeping the temperature between 18° and 20°. The reaction was smooth, but developed considerable heat. After a total time of 2 hours there was still some reagent present, but the reaction seemed to be practically complete because at the end of this time there was no more heat given off.

The clear light yellow solution was transferred to a large separatory funnel and the theoretical amount of sodium hypochlorite solution and the theoretical amount of glacial acetic acid plus a 50% excess were added to reconvert the regenerated tertiary butyl alcohol to tertiary butyl hypochlorite. The water layer was separated and the carbon tetrachloride layer transferred to a distilling flask. The mixture was distilled until everything but the benzoyl chloride had come over. Then the crude product was transferred to a smaller distilling flask and the fraction 180°-215° taken off. This weighed 49.5 grams, corresponding to 70.5% crude yield of benzoyl chloride. It was redistilled and the fraction 190°-197° (practically all at 194°-195°) weighed 42.5 grams, corresponding to a yield of benzoyl chloride of 60.5% of theory.

Remark. The reconversion of the tertiary butyl alcohol to hypochlorite after the reaction was over was simply a means of removing the alcohol from the benzoyl chloride, with which it would react if heated to distillation temperature, to give benzoic acid and tertiary butyl chloride. The reagent itself reads not at all or only very slowly with benzoyl chloride, even at elevated temperature.

Reaction with Benzaldehyde (2).

In order to try to increase the yield of benzoyl chloride the reaction was repeated using a slight excess of reagent and making the refinements noted.

53 grams (½ mol) of benzaldehyde were dissolved in 250 c.c. of carbon tetrachloride in the reaction flask and cooled to 20°. 70 c.c. (5/8 mol) of reagent were added dropwise during the course of 3/4 hour, stirring continuously and keeping the temperature between 18° and 20°. After a total time of 2 hours the reaction seemed to be over because there was no longer any heat effect.

The clear light yellow solution was transferred to a large separatory funnel and the regenerated tertiary butyl alcohol reconverted into hypochlorite as in the previous reaction. The water layer was separated and extracted twice with carbon tetrachloride. The combined organic layers were dried over calcium chloride and transferred to a distilling flask. The mixture was distilled through a small column until everything but the benzoyl chloride had come over. The crude dark colored product was transferred to a smaller distilling flask and the fraction 180°-215° taken off. This weighed 49.8 grams. This was redistilled and the fraction 190°-197° (practically all at 194°-196°) weighed 40.4 grams, corresponding to a 57.5% yield of benzoyl chloride.

Remarks. No doubt better yields would have been obtained had the various distillations been carried out under vacuum because there was considerable residue left in the last two distillations.

This supposedly improved method did not prove to be as good as the original method without the refinements..

Reaction with Benzaldehyde (3)

This third reaction was run to test the suggestion of Professor Norris to the effect that the regenerated tertiary butyl alcohol might be removed from the final reaction mixture by simply extracting it with water, instead of reconverting to hypochlorite.

53 grams (½ mol) of benzaldehyde were dissolved in 250 c.c. of carbon tetrachloride in the reaction flask and cooled to 20°. 56 c.c. (½ mol) of reagent were added dropwise during the course of 3/4 hour, keeping the temperature at 20° and stirring continuously. The reaction was vigorous, but seemed to be over after 1½ hours because there was no longer any heat developed.

The solution was transferred to a separatory funnel and the regenerated tertiary butyl alcohol removed by extracting three times with about equal volumes of cold water. The reaction mixture was then transferred to a distilling flask and the distillation carried out until the temperature reached about 100°. The residue was again transferred to a smaller Claisen flask and the fraction 180°-220° taken off. There was a dark brown liquid residue boiling above 220° left, weighing 9.3 grams. The 180°-220° fraction weighed 50.9 grams. This was redistilled and the fraction 192°-196° taken as benzoyl chloride. Most of it boiled at 194°-195°. It weighed 47.4 grams, which corresponds to a 67.5% yield.

Remark. This method proved to be the best of the three from the standpoint both of improved yield and simplicity of operation.

Here again the yield might have been improved if the various distillations had been carried out under vacuum.

Reaction with Cyclohexanol

A number of preliminary experiments showed that cyclohexanol could not be reacted in the regular way with the reagent. When run in carbon tetrachloride solution the hydrogen chloride liberated reacted with the reagent, forming free chlorine which in turn reacted with the small amount of cyclohexanone formed and chlorinated it. When the reaction mixture was distilled under vacuum, the cyclohexanol was recovered in about 50% yield and the chlorinated cyclohexanones partially decomposed. Enough of the latter were obtained, however, to be identified, as shown by the formation of a bisulfite addition product after long shaking, and by the evolution of hydrogen chloride on distillation, even under a vacuum of 17 m.m.

It was thought, therefore, that if an acceptor for the hydrogen chloride were used, the cyclohexanone itself might be isolated. The first materials that suggested themselves were the tertiary amines. It was found, however, that both pyridine and dimethyl cyclohexylamine reacted very violently with the reagent, giving resinous products. The next material tried as an acceptor for the hydrogen chloride was water, and this gave promise of better results.

In the first experiment the reaction was run in acetic acid diluted with water so that all the materials were present in one phase. This reaction went very smoothly, but there was some evolution of chlorine, and difficulty was encountered in separating the products because on distillation the cyclohexanone steam distilled over, and in addition it is somewhat soluble in water. However, enough was isolated by salting out to identify it, so it seemed that the theory of the acceptor was correct.

In the next experiment the reaction was run in carbon tetrachloride in the presence of a water solution of sodium bicarbonate, the amount of the latter being in excess of that needed to neutralize the hydrogen chloride formed. But with 6 hours vigorous stirring there was absolutely no evidence of of a reaction taking place. Only when stirring was stopped and the two layers allowed to separate did the reaction start in the carbon tetrachloride layer. But when the stirring was started again the reaction stopped. It appeared that the reagent would not react in an alkaline medium.

The final experiment was run in carbon tetrachloride in the presence of a large amount of water, and this method proved successful. It is described in detail as follows.

50 grams ($\frac{1}{2}$ mol) of practical cyclohexanol were dissolved in 250 c.c. of carbon tetrachloride in the reaction flask and 500 c.c. of water added. This was cooled to 20°, and stirred vigorously while 56 c.c. ($\frac{1}{2}$ mol) of reagent were added dropwise during the course of 3/4 hour, maintaining the temperature at about 20°. The stirring was vigorous enough so that the

two layers were thoroughly mixed and had the appearance of an emulsion. The reaction started after 5 minutes, and developed considerable heat throughout. There was a very small amount of chlorine evolved, as detected by its odor. Stirring was continued for 15 minutes after the last addition of reagent.

When the reaction was over the carbon tetrachloride layer was separated. The water layer was partially saturated with ammonium sulfate and extracted with two separate portions of carbon tetrachloride. All the organic solutions were combined and dried over calcium chloride. This was distilled until the temperature had reached 90°. The yellow residue was then distilled under a pressure of 17 m.m. Three fractions were removed: (1) under 45°; (2) 45°-60°; and (3) 60°-65°. There was a brown liquid residue left whose weight was estimated to be about 10 grams. The second fraction was by far the largest. The boiling point of pure cyclohexanone at 17 m.m. waspreviously determined in a separate experiment to be 55°.

The three fractions were redistilled at atmospheric pressure and the fraction 152°-158° taken to be cyclohexanone. The boiling point of the pure material is recorded in the literature to be 155°. There was a yellow residue left estimated to weigh 5 grams.

The yield of cyclohexanone was 28.2 grams or 57.5% of the theoretical.

Reaction with Ethyl Acetate.

This reaction was carried out at refluxing temperatures in chloroform, carbon tetrachloride, acetic acid, and with no solvent, both with and without the catalysts iodine and zinc chloride. In every case there was obtained a small amount of a clear colorless liquid boiling 115°-155°, unchanged ethyl acetate, and tar. The liquid when fractionated yielded three fractions about equal in amount: (1) 115°-130°; (2) 130°-140°; (3) 140°-155°. The first fraction seemed to be mostly α- chloro ethyl acetate but when decomposed with hot water gave hydrogen chloride and acetaldehyde, but no acetic acid as would be expected. The third fraction was saponified with potassium hydroxide but no definite products could be identified. The middle fraction was apparently a mixture of the other two.

No further work was done with this reaction because it was apparent that the reacted material was a complex mixture of ill-defined and unstable products.

Reaction with Furane.

It is well known that the reaction of free chlorine and furane yields no chlorofurane, but only resin, due to the action of the liberated hydrogen chloride on the furane. Since in the reaction of the reagent on furane no hydrogen chloride would be expected if a chlorofurane were formed by simple metathesis, it was thought that perhaps this method of chlorination might prove to be successful. Such, however, proved not to be the case, as is shown in the following.

The furane required for this work was made by a method suggested by Dr. Stevens of our Research Laboratory of Organic Chemistry. This method simply consisted of heating commercial furoic acid in a round bottom flask in a sand bath at about 200°. Connected to the neck of the flask through a cork stopper was a glass tube about 20 m.m. in diameter and 50 cm. long. A smaller tube (7 m.m.) was connected to the top of the larger one, and led into a suitable receiver kept at a low temperature by means of a dry ice and ether bath. The heating was so regulated that a steady stream of carbon dioxide and gaseous furane passed through the apparatus into the receiver, as was shown by the rate at which the carbon dioxide bubbled through the liquid furane in the receiver. About 1 bubble per second was a good rate. The wide tube leading from the reaction flask was tapped or shaken lightly from time to time to cause the sublimed furoic acid to fall back into the flask, to prevent stoppage of flow and possible accidents. The furane was dried over sodium and distilled. It all passed over at 31.5° giving a yield of over 50% of pure furane.

A set of small scale experiments was run using molal quantities of furane and the reagent (1c.c. and 1.6 c.c. respectively). The reactants were simply put together in a test tube, together with the solvent if any, and observed. The experiments are tabulated below.

1. No solvent, at 0°, in diffused sunlight.

2. 2.6 c.c. chloroform as solvent, 0°, diffused sunlight.

3. No solvent, 0°, diffused sunlight, in presence of anhydrous potassium carbonate.

4. 2.6 c.c. chloroform as solvent, 0°, diffused sunlight in presence of anhydrous potassium carbonate.

5. 2.6 c.c. chloroform as solvent, 25°, diffused sunlight in presence of anhydrous potassium carbonate.

6. No solvent, 25°, diffused sunlight in presence of anhydrous potassium carbonate.

7. No solvent, 25°, in the dark.

8. 2.6 c.c. chloroform as solvent, 25°, in the dark.

#5 and #8 became warm almost immediately andreached the boiling point in about 10 minutes. They were cooled down to room temperature. After 15 minutes they began to darken in color and after 20 minutes they were so dark as to be opaque.

#6 and #7 began to heat up after 15 minutes and soon became dark colored.

The tests run at 0° were left in an ice bath all night and the others were left at room temperature. Next morning they were all very dark colored. They were combined, extracted twice with water, and distilled. After the solvent came off the temperature rose rapidly to about 100°. No fraction 75°-85° was obtained.

At this point it might be well to give some of the properties of the chlorofuranes. 2-Chlorofurane is a liquid B. P. 77°. 3-Chlorofurane is a liquid B. P. 79°. They both slowly resinify on standing, have a peculiar chloroform-like odor, give a green color with strong aqueous hydrochloric acid, are slightly soluble in water, are purified by steam distillation, and are prepared in excellent yields by decarboxylation of the corresponding chlorofuroic acids.[27]

A second set of small scale experiments was run as follows:

1. No solvent, 0°, diffused daylight.
2. 2.6 c.c. chloroform as solvent, 0°, diffused daylight.
3. No solvent, 0°, dark.
4. 2.6 c.c. chloroform as solvent, 0°, dark.
5. No solvent, 0°, bright sunlight.
6. 2.6 c.c. chloroform as solvent, 0°, bright sunlight.

#1 after about 1½ hours suddenly boiled out of the test tube, even in the ice bath, and what was left was dark colored.
#2 started to darken after 1½ hours, and color continued to deepen until it was very dark brown.

#5 and #6 began to darken after 15 minutes and soon got so dark as to be opaque.

#3 and #4 stayed clear yellow for 3 hours. They were left in the dark in the ice bath over night, but the next morning they were both very dark colored.

All the tests from this second set of experiments were combined and distilled. The chloroform came off first. Then about 4-5 c.c. of liquid came over at 75°-85°. This was shaken with water to remove tertiary butyl alcohol, and about 1 c.c. of liquid was left. This was dried over calcium chloride, and a Siwoloboff boiling point taken. It started to boil at 65° and continued to 80°, with most vigorous boiling at 75°-80°. Above 80° boiling slowed down almost to a stop, and the liquid turned yellow and became viscous.

The 1 c.c. of liquid on which the boiling point was taken did not give a green color with hydrochloric acid, so it was concluded that it was not chlorofurane.

From these small scale experiments it was evident that the reagent had no advantage over free chlorine in the chlorination of furane.

Reaction with Practical Heptane (1).

Eastman practical heptane, B.P. 91°-96°, was used. It was first shaken with two separate portions of concentrated sulfuric acid to remove unsaturated compounds, washed with water, then dilute potassium carbonate solution, and dried over calcium chloride. The first sulfuric acid extract was colored distinctly yellow, and the heptane after this treatment smelled distinctly sweeter, showing that the practical heptane contained appreciable amounts of unsaturated compounds.

120 grams (1.2 mols) of the practical heptane treated as above were dissolved in 300 c.c. of carbon tetrachloride in the reaction flask, and 5 c.c. of reagent added at once. To the reaction flask were attached a reflux condenser and a dropping funnel. The third neck of the flask was closed with a cork. The mixture was heated over an open flame until it was refluxing gently. Within 10 minutes the yellow color of the reagent had disappeared, showing that the reaction had gotten under way. Keeping the mixture at a gentle reflux, the remainder of the reagent (107 c.c.) was added dropwise during the course of about an hour. Throughout this time the mixture remained colorless, showing that the reagent reacted immediately. A slight heat of reaction made itself evident.

When the reaction was over the clear solution was distilled at atmospheric pressure until a temperature of 90° had been reached. At this time the solution started to become colored greenish yellow.

The solution, smelling slightly of hydrogen chloride, was then removed and shaken with water to extract the acid, and dried over calcium chloride.

It was then distilled under a pressure of 29 m.m. and the following fractions taken off: (1) under 42°; (2) 42°-58°; (3) 58°-65°; (4) 65°-100°. There was a dark colored residue of about 2 grams. These were refractionated at the same pressure.

At this point a more thorough search of the literature revealed the fact that Sherrill[28] had prepared the four monochloro heptanes in the pure state and reported their boiling points as follows:

1-Chloroheptane, B.P. 61.4° @ 27 m.m.
2- " " 46.0° @ 19.5 "
3- " " 48.3° @ 21 "
4- " " 48.9° @ 21 "

From this information it was seen to be obviously impossible to separate the three secondary chloro heptanes by fractionation, so it was decided to separate the products into the following three divisions: (1) secondary chloroheptanes; (2) 1-chloroheptane; (3) polychloro heptanes.

Accordingly another fractionation was run on the products, yielding the following results under the conditions indicated.

(1) Secondary chloroheptanes, 44°-53° @ 20 m.m., 21.6 grams, or 16.1% of theory.

(2) 1-chloroheptane, 58°-65° @ 27 m.m., 4.9 grams, or 3.6%

of theory.

(3) Polychloro heptanes, above 65° @ 27 m.m., 33.9 grams.

There was a small fraction that came over under 44° @ 20 m.m. which did not appear to be heptane itself, but was probably a chlorination product of one of the lighter fractions in the practical heptane, presumably a hexane or a branched chain heptane.

Reaction with C.P. Heptane (2).

100 grams (1 mol) of C.P. n-heptane were dissolved in 300 c.c. of carbon tetrachloride in the reaction flask and 5 c.c.of reagent added at once. The solution was heated to gentle boiling under a reflux condenser. After about 10 minutes the solution was decolorized. Then the remainder of the reagent (51 c.c.) was added dropwise during the course of 1¼ hours, keeping the solution at a gentle reflux and regulating the rate of addition so that the solution was always colorless. There was a very slight heat of reaction.

At the end of the reaction the clear solution was removed to a flask and distilled at atmospheric pressure until the temperature had reached 95°.

The solution, still water-white, was then distilled under vacuum in an ordinary Claisen flask, the excess heptane taken off, and after the second fractionation gave the following fractions.

(1) 44°-55° @ 20 m.m., 12.3 grams.

(2) 59°-65° @ 27 m.m., 16.5 grams.

(3) Over 65° @ 27 m.m., 10.7 grams.

These were redistilled in a Claisen flask having a tall insulated side arm made into a Vigreux column, and yielded the following final fractions.

(1) Secondary chloroheptanes, 55°-58° @ 27 m.m., 17.1 grams, or 25.4% of theory.

(2) 1-Chloroheptane, 60°-63° @ 27 m.m., 6.1 grams, or 9.1%

of theory.

(3) Polychloro heptanes, over 63° @ 27 m.m., 12.0 grams. The first fraction was redistilled at 20 m.m. and all of it boiled at 48°-52°, thus checking the boiling points given in the literature for the secondary chloroheptanes.

Remarks. There was no evidence of hydrogen chloride being given off at any time during the various distillations, as was the case in the reaction with practical heptane.

All the products were sweet pleasant smelling clear water-white liquids.

Reaction with Phenol (1).

Several reactions were run altogether with phenol in an attempt to get a high yield of one monochloro product, but it was found in every case that a mixture of ortho and para chloro phenols was always formed, in about the same ratio as would be expected with free chlorine. Temperature apparently had little effect on the orientation.

47 grams (1/2 mol) of C.P. phenol were dissolved in 250 c.c. of chloroform in the reaction flask. The flask was cooled to 20° and the contents stirred while 56 c.c. (½ mol) of reagent were added 1 c.c. at a time during the course of an hour, keeping the temperature at 20°. The reaction was vigorous, considerable heat being evolved. When the reaction was over the light yellow solution was removed and the solvent distilled off. The deep yellow oily residue was then distilled through a fractionating column of suitable length, to which was attached an air condenser. Three fractions were obtained as follows.

(1) 170°-211° (mostly up to 185°), 29.6 grams, $N_{40}^{D}=1.5482$. This corresponds to 46.1% yield of ortho chlorophenol.

(2) 211°-217° (mostly at 215°-217°), 23.4 grams, $N_{40}^{D}=1.5585$. This corresponds to 36.4% yield of para chlorophenol.

(3) 3.3 grams of residue above 217°.

Remarks. The physical constants of the monochloro phenols are reported in the literature as follows.

Ortho chlorophenol, B.P. 175°-176°, $N_{40}^{D}=1.5473$.

Para chlorophenol, B.P. 217°, $N_{40}^{D}=1.5579$.

These constants were determined in this and the following reactions and used as a means of identification of the products.

Reaction with Phenol (2).

This reaction was run the same as the previous one, with the following differences. Carbon tetrachloride was the solvent. The total time of addition of the reagent was 40 minutes. Stirring was continued for 10 minutes after the addition of the last portion of reagent.

The solvent was removed from the light yellow solution as before, and the deep yellow residue distilled through the column, yielding the following fractions.

(1) 170°-211°, 36.8 grams, N_{40}^{D}= 1.5487, corresponding to 57.3% yield of ortho chlorophenol.

(2) 211°-217°, 18.6 grams, N_{40}^{D}= 1.5583, corresponding to 29.0% yield of para chlorophenol.

(3) Residue (small).

Reaction with Phenol (3).

This reaction was an exact repetition of reaction (1) and was run as a check on it. They checked very well, but better yields were obtained in this one.

The fractions were as follows.

(1) 170°-210°, 32.8 grams, $N_{40}^{D}=1.5492$, corresponding to 50.7% yield of ortho chlorophenol.

(2) 210°-217°, 24.8 grams, $N_{40}^{D}=1.5580$, corresponding to 38.3% yield of para chlorophenol.

((3) Residue (small).

Reaction with Phenol (4).

This reaction was run like the others, except that the temperature was kept at 0°, and the time of addition of the reagent was 75 minutes. The reaction mixture was stirred for 10 minutes after the last addition of reagent, and was colored light yellow. The solvent, chloroform, was removed, and the deep yellow residue distilled, giving the following fractions.

(1) 170°-205°, 31.7 grams, $N^{D}_{40} = 1.5480$, corresponding to a 49.0% yield of ortho chlorophenol.

(2) 205°-217°, 27.3 grams, $N^{D}_{40} = 1.5585$, corresponding to a 42.2% yield of para chlorophenol.

(3) Residue (small).

Reaction with Phenol (5).

This reaction was run like the others, except that the temperature was kept at 40°, and the time of addition of the reagent was 35 minutes. The solvent was chloroform. The solution was colored pink at the end of the reaction. The fractions were as follows.

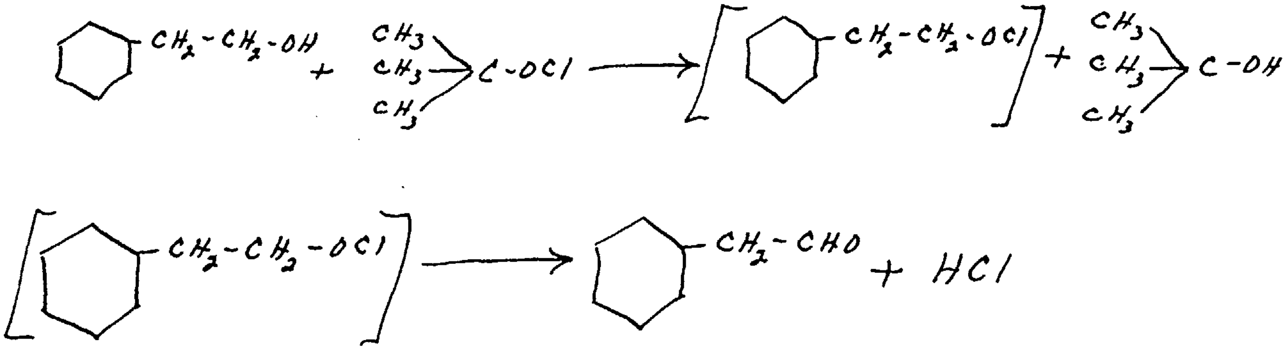
(1) 170°-205°, 33.7 grams, $N^{D}_{40} = 1.5477$, corresponding to a 52.1% yield of ortho chlorophenol.

(2) 205°-217°, 25.3 grams, $N^{D}_{40} = 1.5588$, corresponding to a 39.1% yield of para chlorophenol.

(3) Residue (small).

Reaction with β-Phenylethyl Alcohol.(1).

These various reactions with β-phenylethyl alcohol were carried out in an attempt to prepare phenyl acetaldehyde according to the equations



All attempts to isolate phenyl acetaldehyde, however, were unsuccessful, due probably to the polymerizing effect of the hydrogen chloride on it. Even in the pure state phenyl acetaldehyde is very prone to polymerization and on distillation in vacuum yields three fractions, one being the material itself and the other two being polymers.

In reaction (5), to be described later, even when water was used as an acceptor for the hydrogen chloride the aldehyde was not formed. In this case the reaction pursued a different course, the aromatic nucleus in the β-phenylethyl alcohol being chlorinated instead.

This and the ensuing numbered reactions of the reagent with β-phenylethyl alcohol are really collections of reactions, but they seem to fall logically under the headings indicated in the tabulated summary on page 18.

The description of reactions (1) now follow directly.

a. 61 grams ($\frac{1}{2}$ mol) of β phenyl-ethyl alcohol B. P. 217°-218° were dissolved in 250 c.c. chloroform in the reaction flask and cooled to 10°. Keeping the temperature at 10°, 56 c.c. ($\frac{1}{2}$ mol) of reagent were added with continuous stirring 2 c.c. per minute until all had been added. There was no perceptible temperature rise during the addition, and the solution was yellow after it had all been added, as if the reagent simply dissolved without reaction. Stirring was continued for 3 hours, after which time hydrogen chloride began to come off. The flask was left in an ice bath overnight. The next morning the solution was colorless. It was stirred for $\frac{1}{2}$ hour, and, after the solvent had been evaporated off, was distilled. A liquid of wide range of boiling point was obtained, the last part boiling up to 220°. There was a considerable amount of tar left in the distillation flask.

b. This reaction was run like (a), with the following differences. At the end of 2 hours hydrogen chloride began to come off with rise in temperature. The temperature was kept between 25° and 32° for 1 hour until the solution became colorless. It was stirred for an hour longer. After removal of the solvent the liquid was distilled, but had no constant boiling point. Hydrogen chloride was given off during the distillation. Tar remained as a residue as before.

c. This reaction is similar to (a) and (b) except as follows. Hydrogen chloride began to come off after 1 hour and the temperature was allowed to rise from 10° to 35-40°. The solution was decolorized after hydrogen chloride had stopped coming off. Stirring was continued until the total time was 2½ hours. The solvent was removed and the liquid distilled as before, with the same result.

d. This reaction differed from (a), (b), and (c), only as follows. The reagent was added in 5 minutes. There was no temperature rise. The solution was stirred at 10° for 2 hours, when hydrogen chloride started to come off. Stirring was continued for 3 hours longer, when the reaction seemed to have stopped, but the solution was still yellow. The temperature was then allowed to rise to 22°, during which time hydrogen chloride came off slowly. When the temperature reached 22° the solution decolorized and the reaction seemed to be over. It was stirred ½ hour longer and let stand overnight. Upon removal of the solvent, and distillation, no constant boiling liquid was obtained, but a considerable fraction 215-220° came over, and was apparently unchanged β-phenylethyl alcohol. Tar was left in the flask.

Reaction with β-Phenylethyl Alcohol (2).

61 grams (½ mol) of β-phenylethyl alcohol (B. P. 217°-218°) were dissolved in 250 c.c. chloroform in the reaction flask and cooled to 10°. 56 c.c. (½ mol) of reagent were added in 5 minutes. There was no temperature rise. The solution was stirred for 2 hours at 10° until hydrogen chloride began to come off. Then the temperature was allowed to rise to 20°-23°, when more hydrogen chloride came off and the solution decolorized. It was stirred for ½ hour longer.

The solvent was distilled off on a water bath under slightly diminished pressure. The residual liquid was then distilled under vacuum and the following fractions obtained:

(1) 90° - 104° and 9 m.m. --- 23.8 grams
(2) 104° - 112° " 8 " --- 11.5 "
(3) 112° - 160° " 6 " --- 2.4 "
(4) 160° - 176° " 6 " --- 0.0 "
(5) 176° - 185° " 7 " --- 22.7 "
(6) Non volatile residue--- 4.7 "

Fractions (1) and (2) were combined and shaken for 5 minutes with saturated sodium bisulfite solution, but the non-aqueous part did not decrease in volume, and no addition product separated from the aqueous layer. The non-aqueous layer was separated and distilled at atmospheric pressure. Two fractions were obtained; (1) 205°-220°; and (2) 220°-230°. The second was about twice the amount of the first. There was also tar left in the flask. The second fraction was shown to be β-phenylethyl alcohol by the melting point of its 3.5 dinitrobenzoate, M. P. 106°-107°.

Fraction (5) from the original distillation seemed to be β-phenylethyl β-phenyl acetate, so it was refluxed for 2 hours with 1 N alcoholic sodium hydroxide to saponify it. The phenyl acetic acid was isolated and identified by its peculiar odor, and melting point (76°). The phenyl ethyl alcohol was isolated and identified by the melting point of the 3,5 dinitrobenzoate prepared from it.

These identifications accounted for practically all of the reaction products and showed that they are three in number; (1) unchanged β-phenylethyl alcohol, (2) β-phenylethyl β-phenyl acetate, and (3) tar.

Reaction with β-Phenylethyl Alcohol (3).

In this reaction no solvent was used. 9.0 grams of β-phenylethyl alcohol and 8.4 c.c. of reagent (molecular quantities) were placed in a 250 c.c. Erlenmeyer flask under a reflux condenser and let stand at room temperature. After about 5 minutes there was violent boiling due to the heat of reaction, and fumes of hydrogen chloride and reagent came out through the top of the condenser. When the reaction mixture cooled down it was removed, washed with water (to remove hydrogen chloride), and shaken with ether. The ether extract was dried with calcium chloride and the ether distilled off on the water bath. The faintly yellow colored residue was distilled under a pressure of 11-12 m.m. This yielded three fractions.

(1) 85°-105°--- 5.1 grams
(2) 105°-180°--- 1.0 "
(3) 180°-190°--- 1.7 "
(4) Residue--- .5 "

The fraction 85°-105° was redistilled at 12 m.m. and boiled over the same range. This was again redistilled at 9 m.m. and gave 3.9 grams of a fraction 90°-94°. This was β-phenylethyl alcohol because a sample of the pure alcohol boiled at 93 under the same conditions. Fraction (3) was apparently β-phenylethyl β-phenyl acetate.

Reaction with β-Phenylethyl Alcohol (4).

These experiments were undertaken because previous work had indicated that the reagent was decomposing before reacting, since large amounts of reactant were recovered in each case. It is known that the reagent decomposes immediately in bright sunlight, and slowly in diffused sunlight, so these experiments were carried out in the dark. Where a solvent was used, carbon tetrachloride was chosen instead of chloroform.

a. 4 grams of β-phenylethyl alcohol and 3.7 c.c. of reagent (molecular quantities) were dissolved separately in 16.5 c.c. and 20 c.c. of carbon tetrachloride respectively. The solutions were cooled and then put together in an Erlenmeyer flask. The flask was kept in an ice bath in the dark for 5 hours, then the ice bath was refilled and the flask left overnight. The next day the solution was still yellow and apparently no reaction had taken place. It was left in the ice bath all day, and over another night. The next morning the solution was colorless and smelled of hydrogen chloride. The solvent was removed under slight vacuum and the residue distilled at 10 m.m. The following fractions were obtained.

(1) 95°-125° (mostly 95°-105°) --- 3.1 grams

(2) 125°-187°(" 180°-187°)--- 2.1 "

(3) Small amount of brown resin.

b. 4 grams of β-phenylethyl alcohol and 3.7 c.c. of reagent were placed together in the Erlenmeyer flask (no solvent). In the dark the solution was decolorized at the end of an hour.

The fractions were obtained at 8-10 m.m.

(1) 95°-125° (mostly 95°-105°) --- 3.1 grams
(2) Above 125° 2.0 "

Fraction (1) was redistilled at 10 m.m. and boiled 95°-105°. This was redistilled again at atmospheric pressure, and boiled 215°-220°, indicating it to be β-phenylethyl alcohol. Therefore a recovery of 77.5% of reactant was obtained.

c. This was a repetition of experiment (a). After distillation at 9 m.m. the fractions were:

(1) 95°-125° (mostly 90°-105°) --- 2.5 grams
(2) 125°-187° (" 180°-187°) --- 2.6 "
(3) Resinous residue

d. 4 grams of β-phenylethyl alcohol and 7.4 c.c. of reagent were dissolved separately in 16.5 c.c. and 20 c.c. carbon tetrachloride respectively. These quantities correspond to 1 mol of the alcohol and 2 mols of the reagent. The two solutions were cooled and then put together in the Erlenmeyer flask in an ice bath at 2:30 P.M. At 5 P.M. the ice bath was repacked and left overnight. Next morning the solution smelled of hydrogen chloride, but was still yellow. It was allowed to stand at room temperature until 11 A.M., at which time it was colorless. The solvent was removed as usual, the residue distilled at 9-10 m.m. The fractions were as follows:

(1) 95°-125° (mostly 95°-105°) --- 3.0 grams
(2) 125°-187° (" 180°-187°) --- 1.4 "

(3) Resinous residue.

These figures indicate that the reagent decomposes more rapidly than it reacts.

e. 4 grams of β-phenylethyl alcohol in 16.5 c.c. of carbon tetrachloride and 3.7 c.c. of reagent in 20 c.c. of carbon tetrachloride were cooled separately and put together in an Erlenmeyer flask in a bath at 10°. It was let stand at 10° from 10 A.M. until 5 P.M. There was no apparent change. After standing overnight at room temperature the solution was colorless. The solvent was removed as usual and the residue distilled at 9 m.m. Fractions were as follows:

(1) 95°-125° (mostly 95°-105°) --- 2.8 grams
(2) 180°-182° 1.7 "
(3) Resinous residue

These five reactions of the fourth group were all carried out in the dark, and the average recovery of β-phenylethyl alcohol unchanged was 72.5% The average yield of β-phenylethyl β-phenyl acetate was 49.8%.

Reaction with β-Phenylethyl Alcohol (5).

Since all previous attempts to make phenyl acetaldehyde by this method had failed, it was decided to run the reaction again in the presence of water as an acceptor for the hydrogen chloride formed, this method having been successful in the case of cyclohexanol.

In the first run the reactant was dissolved in carbon tetrachloride and an excess of water added. This was stirred vigorously while the reagent was added dropwise. But whereas in the case of cyclohexanol this method gave excellent results, in this case there was absolutely no evidence of reaction even after 6 hours' stirring.

Then it was decided to try to run the reaction in dilute acetic acid solution. This time a reaction took place immediately and is described in detail below.

24.4 grams (1/5 mol) of pure β-phenylethyl alcohol, 100 c.c. of glacial acetic acid, and 200 c.c. of water were added to the reaction flask and cooled to 20°. The materials were all present in 1 phase. 22.4 c.c. (1/5 mol) of reagent were added dropwise during the course of ½ hour, keeping the temperature at 20°, and stirring vigorously. The clear solution became opaque as the reaction progressed. The heat effect was noticeable but slight. After all the reagent had been added the reaction was still going on, judging by the slight evolution of heat. The yellow opaque solution was stirred ½ hour longer, when the reaction seemed to be over.

The solution was then poured into about 500 c.c. of water, whereupon a yellow oil settled out. This was separated, dried over calcium chloride, and distilled at 16 m.m. A very small amount of liquid came over up to 133°, then at 133°-135° 12.3 grams of a clear water-white oil came over. This boiled at 243°-245° at atmospheric pressure with slight decomposition.

It was evident from this boiling point that the compound was neither β-phenylethyl alcohol nor phenyl acetaldehyde. Qualitative tests showed that it contained chlorine, was soluble in concentrated sulfuric acid, and reacted with sodium. Hot aqueous and alcoholic potassium hydroxide had no action on it, even after 2 hours boiling. It was saturated because it did not decolorize bromine in carbon tetrachloride solution. Nessler's reagent gave a negative test.

It was tentatively concluded that the material was β-(p-chlorophenyl) ethyl alcohol. This compound could not be found in the literature, so its structure was proved as follows.

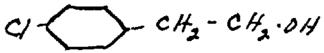
(1) Oxidation to p-chlorobenzoic acid.

(2) Chlorine analysis and molecular weight calculated therefrom.

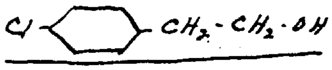
(3) Quantitative acetylation.

The oxidation to p-chlorobenzoic acid was carried out by heating about 2 grams of the material with an excess of nitric acid, specific gravity 1.2, for about an hour under reflux. The derivative was dissolved in sodium hydroxide solution, extracted with ether three times, and the sodium salt reconverted to the acid by adding a slight excess of dilute sulfuric acid. The precipitated organic acid was filtered off, washed with water, and crystallized twice from dilute alcohol. The fine white needles melted at 234°-234.5°. A mixed melting point with pure p-chlorobenzoic acid showed no depression. The pure acid is reported to melt at 235°-236°.

The chlorine analysis was carried out by the standard Carius method and gave the following results compared with the theoretical, after correcting the analysis for glass in the Gooch crucibles and chlorides in the distilled water.

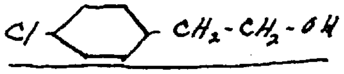
Found		Calculated for
1	2	
22.45%Cl_2	22.45%Cl_2	22.66% Cl2

The molecular weight calculated from the chlorine analysis was as follows.

Found		Calculated for
1	2	
157.8	157.8	156.53

The quantitative acetylation was carried out according to the method of Verley and Bölsing[29] and is as follows. A mixture of 120 grams of acetic anhydride and 880 grams of pyridine is made. A definite volume of this mixture (20 c.c. in this case) is pipetted into a flask, an equal volume of water added, and titrated with 1 normal sodium hydroxide using phenolphthalein as an indicator. The figures obtained in this blank titration are used in calculating the results of the acetylation itself, which is done as follows. Into a 200 c.c. flask is weighed 1-2 grams of the alcohol, 20 c.c. of the acetic anhydride-pyridine mixture is added from a pipette, and the solution heated on the water bath ¼ hour. It is cooled, 20 c.c. of water added, and titrated with 1 normal alhali. The difference between the amount of alkali needed for the blank (about 50 c.c.) and the amount needed for the sample after acetylation represents the weight of acetic anhydride reacted, and is specific for the alcohol used.

The calculated and theoretical amount of 1.225 normal alkali needed were as follows.

Found		Calculated for
1	2	
5.172 c.c.	5.171 c.c.	5.214

From all this evidence it was concluded that the unknown compound was β-(p-chlorophenyl) ethyl alcohol, which was obtained in 39.3% yield. This yield might have been considerably higher if an air leak had not been used in the vacuum distillation. The air seemed to have an oxidizing effect on the alcohol because there was a large amount of non-volatile solid material left in the flask after the distillation was over.

Reaction with Salicylic Acid.

34.5 grams (¼ mol) of salicylic acid, M.P. 158° were suspended in 250 c.c. of chloroform in the reaction flask, and cooled to 20°. Keeping the temperature at 20°, and constantly stirring, 28.3 c.c. (¼ mol) of reagent were added 1 c.c. per minute. There was no appreciable temperature rise until after two-thirds of the reagent had been added. Then there was noticed a slight rise (1 - 2) after each addition. As the reaction progressed more and more of the suspended material went into solution, and at the end of 1¼ hours from the start the solution was clear, and remained clear for about an hour, then crystals began to come out of solution. Stirring was continued until the total time was 4 hours, after which time no more crystals deposited.

The crystalline material was filtered off on a Buchner funnel and washed with a little chloroform. The filtrate was distilled down to about 50 c.c., cooled, and the deposited crystals again filtered off. The two crops of crystals were crystallized twice from 50% alcohol, yielding 16.3 grams of product M.P. 171°-172°.

The alcoholic mother liquors were evaporated down, the precipitate filtered off, and crystallized twice from 50% alcohol, yielding 9.6 grams more product, M. P. 171°-172°.

The 50 c.c. of chloroform filtrate were evaporated to dryness, and crystallized three times from 50% alcohol, giving 3.5 grams more product M. P. 171°-172°.

The total yield of 5-chlorosalicylic acid was 29.4 grams, or 68.2% of theoretical. It was identified by its melting point (Beilstein gives values of its melting point varying from 167.5° to 176°) and by that of its methyl ester. The value obtained for the ester was 47°-48°. Beilstein gives 48°. The ester was prepared in the regular way by refluxing some acid with methyl alcohol saturated with dry hydrogen chloride for about an hour, cooling, and crystallizing from alcohol. An acetyl derivative was also prepared, but although good crystals were obtained, they showed no constant melting point, softening at 130°, and being completely liquid at 148°. Three recrystallizations did not improve it. Apparently a rearrangement or decomposition takes place.

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BIOGRAPHICAL NOTE

The author was born in Cambridge, Massachusetts November 24, 1903. He was educated in the public schools of Cambridge, Somerville, and Quincy, all in Massachusetts. He was graduated from the Quincy High School in June, 1922. In the Fall of 1922 he entered the Massachusetts Institute of Technology and in June 1926 received the S.B. degree in Chemical Engineering. From 1926 until 1931 he was employed in industry, chiefly with the Hood Rubber Company of Watertown, Massachusetts as analytical, research, and development chemist, and technical aide. In the summer of 1931 he returned to the Institute to pursue studies leading to the Ph.D. degree in Organic Chemistry, which work he has been engaged in up to the present time.