# THE
# OXIDATION OF ORGANIC COMPOUNDS

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By

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## Introduction

Since an alkaline solution of iodine was first used by Lieben (1) as an oxidizing agent the reaction has been called the Lieben reaction. It is extremely sensitive in some cases, but it is by no means specific for any one substance. Generally, all those organic compounds containing the grouping $R-\underset{R}{\underset{|}{C}}$ combined to oxygen will react either with or without the formation of iodoform.

In the course of experiments dealing with the action of hydrogen peroxide on organic substances it was found necessary to employ iodometric methods of estimation whereever possible. In certain cases, however, there was such lack of agreement as required a complete investigation of the causes of the differences obtained. Preliminary tests made in connection with recently published results (2) showed the desirability of a thorough investigation of the conditions necessary for strictly quantitative results in well-known iodometric titrations. The first substance chosen for study was acetone because of its historical interest in this connection; other organic compounds succeeded this, but at this point it is merely necessary to state that the controlling factors seemed to be 1. order of addition of reactants and 2. concentration of the alkali employed.

# Part I

## Acetone

### Historical

The various methods for the quantitative determination of acetone are based upon the following reactions:-

(1) The formation of an addition compound with sodium bisulphite.

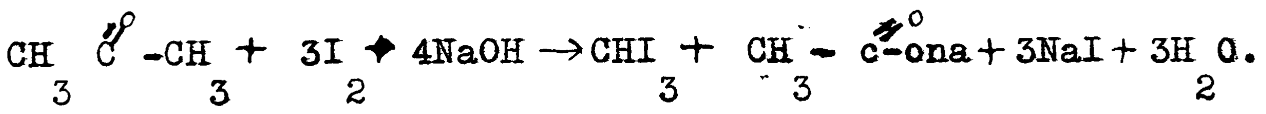
(2) The formation of osazones with phenyl hydrazine and its derivatives.

(3) The formation of complex insoluble mercury compounds.

(4) The formation of iodoform with an alkaline solution of iodine.

Lieben in his work on "The Formation of Iodoform and the Use of this Reaction in Chemical Analysis", showed that acetone in aqueous solution produces a precipitate of iodoform when treated with iodine and potassium hydroxide. He also showed that methyl alcohol does not belong to the class of compounds forming iodoform.

Kramer (3) worked out a quantitative gravimetric estimation of acetone on this basis. The acetone is treated with an alkaline solution of iodine, the iodoform thus precipitated is redissolved in ether, an aliquot of the ethereal solution is evaporated and the iodoform weighed. This method, according to Messenger (4), gives high results due to the slight solubility of potassium iodide in ether. To obviate this error Messenger suggested the first volumetric quantitative method of estimation based upon the reaction



$$CH_3\overset{O}{\overset{\|}{C}}-CH_3 + 3I_2 + 4NaOH \rightarrow CHI_3 + CH_3-\overset{O}{\overset{\|}{c}}-ona + 3NaI + 3H_2O.$$

In his original method 20.00C.C. of methyl alcohol of high acetone content were mixed with 30. C.C. of normal potassium hydroxide solution, a measured quantity (20-30 C.C.) of .2 normal iodine solution was added drop by drop, the mixture was shaken for $\frac{1}{4}$ - $\frac{1}{2}$ minute until it became clear and, after acidifying with hydrochloric acid (density 1.025), the excess iodine thus liberated was titrated with standard sodium thiosulphate using starch as an indicator. The accuracy of the results which he obtained speak well for the method. The results given in table I are, I in methyl alcohol solution, II in aqueous solution.

Table I

| | % of acetone as weighed | % of acetone as found | | | |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 |
| I | 1.95% | 1.93% | 1.95% | 1.92% | 1.93% |
| II | 2.05% | 2.04% | 2.03% | 2.04% | 2.03% |

The volumetric method described above is by far the most expeditious and therefore has been widely investigated. The same conditions under which it will give the most accurate results are not suggested by all investigators. As examples of conflicting results the following might be mentioned. Collischon (5) in his investigation found that, after the addition of the iodine solution to the sodium hydroxide and acetone mixture, the flask must be shaken for 4 to 5 minutes or else heated to a temperature of from 60° to 70° to complete the reaction. He also finds that, unless the mixture is shaken during the addition of the iodine, the results will be low due to the reaction, $3NaIO \rightarrow NaIO_3 + 2NaI$.

The longer the alkali and iodine are standing the less iodoform will be formed, and after three hours none is produced at all. Krause (6) finds that results are irregular unless the whole mixture stands for at least fifteen minutes. Hubbard (7) determined a 0.01% solution of acetone accurately by adding iodine, then alkali, shaking for ten minutes, and titrating. Hermans (8) finds that results vary with conditions, and the proper conditions must be found for every dilution; too large an excess of iodine and alkali results in incomplete iodination even after long standing. Ella Söderlundt (9) obtained good results if at least 100% excess of iodine was used, but if the mixture was allowed to stand in the sunlight for twenty-five minutes a 0.1% solution of acetone was shown to contain 1% of acetone. Hofmeister (10), after separating the acetone in urine from interfering substances, adds iodine, then sodium hydroxide, shakes for ¼ to ½ minute and titrates. Marriot (11), in testing the accuracy of the method, diluted 25.cc of a solution containing 1.2249 grams of acetone per litre to 500 cc, added the iodine, then the alkali, shook, and then titrated the excess iodine after standing for 5 to 10 minutes. He found 30.64 mgms. of acetone where he had 30.62 mgms. by weight, and 21.09 mgms where he had 20.95 mgms.

It must be noted that various authors employ different orders of addition; Messenger advocated the order acetone, - alkali, - iodine, whereas most of the others reverse the alkali and iodine order. Though excess of alkali has been stated as harmful to the reaction due to possible formation of iodate, and too great an excess of iodine must be avoided, the excess of iodine desirable was suggested as 100% over that required by the equation already given. No particular stress has been laid by anyone on the order in which the reactants are to be added, nor upon the excess of alkali which should be added. Although the time of reaction in most cases is no more than fifteen minutes, no definite time is suggested, but Collischon noted that the longer the time of reaction the smaller the amount of iodine used up. Considering that 100% excess of iodine over the theoretical would be sufficient, the effect of the elements of time and of alkali concentration along with dilution, upon this reaction were studied in the experimental work done on acetone.

## Experimental.

In order to ascertain any error which might result from loss of iodine on standing, quantities of iodine solution, with sufficient sodium hydroxide solution to decolorize it, were allowed to stand for various lengths of time, and after acidifying, the liberated iodine was titrated with sodium thiosulphate. The results are given in table II.

Table II

| Time of standing | C.C of thiosulphate used |
|---|---|
| 1½ hours | 34.35 |
| 3½ " | 34.40 |
| 17½ " | 34.30 |
| 22 " | 34.30 |

These results indicate that there is no loss of iodine on standing.

The addition of reactants with acetone, as well as the other substances investigated, was made in three different orders, viz.,

(a) Acetone - sodium hydroxide - iodine.

(b) Acetone - iodine - sodium hydroxide.

(c) Sodium hydroxide - iodine - acetone

and hereafter referred to as Series I, Series II and Series III respectively. In order that comparisons could be drawn throughout, a total volume of 200 c.c. (except where the effect of dilution was determined), a time of reaction of one hour, and room temperature were chosen as the standard conditions. In Series I the procedure was as follows:- an exact volume of an aqueous solution of acetone whose strength was known by weighing, was measured into a flask; a known quantity of sodium hydroxide corresponding to a definite excess over the theoretical amount required, was added with continuous shaking, then the measured quantity of iodine corresponding to approximately 100% in excess of the theoretical amount was also added with continuous shaking; the mixture was at once made up to a volume of 200 c.c with distilled water, tightly stoppered and allowed to stand for one hour at room temperature and out of direct sunlight. At the end of the hour enough standard sulphuric acid was added to make the solution slightly acid and the unused iodine liberated was titrated with standard sodium thiosulphate solution using starch solution as indicator. The procedure for Series II and III was the same except for the order of addition of reactants.

The flasks used were 500 cc erlenmeyers with tightly-fitting cork stoppers to avoid any loss of iodine in mixtures where alkali insufficient to decolourize the iodine was used. Pipettes, carefully standardized by weighing their volume of distilled water, were used in measuring the standard solutions wherever possible, and accurate burettes were used for the titrations.

Carbon dioxide-free solutions of sodium hydroxide were prepared from the clear saturated solution of Merk's alcohol-purified product, and standardized against either oxalic acid or hydrochloric acid which had been standardized against pure calcite. The sodium thiosulphate solutions were made from Schuchardt's anhydrous salt and, when used to standardize the iodine solutions, were allowed to stand at least thirty-six hours before being standardized against potassium dichromate. The iodine solution was made by dissolving the required amount of Schuchardt's resublimed product in a concentrated solution of potassium iodide containing about twice the weight of iodate-free potassium iodide, diluting to the desired volume, and standardizing against the thiosulphate solution. The strength of the solutions of iodine and sodium hydroxide ranged from .2N to .4N while the thiosulphate solution used was always more dilute than the iodine.

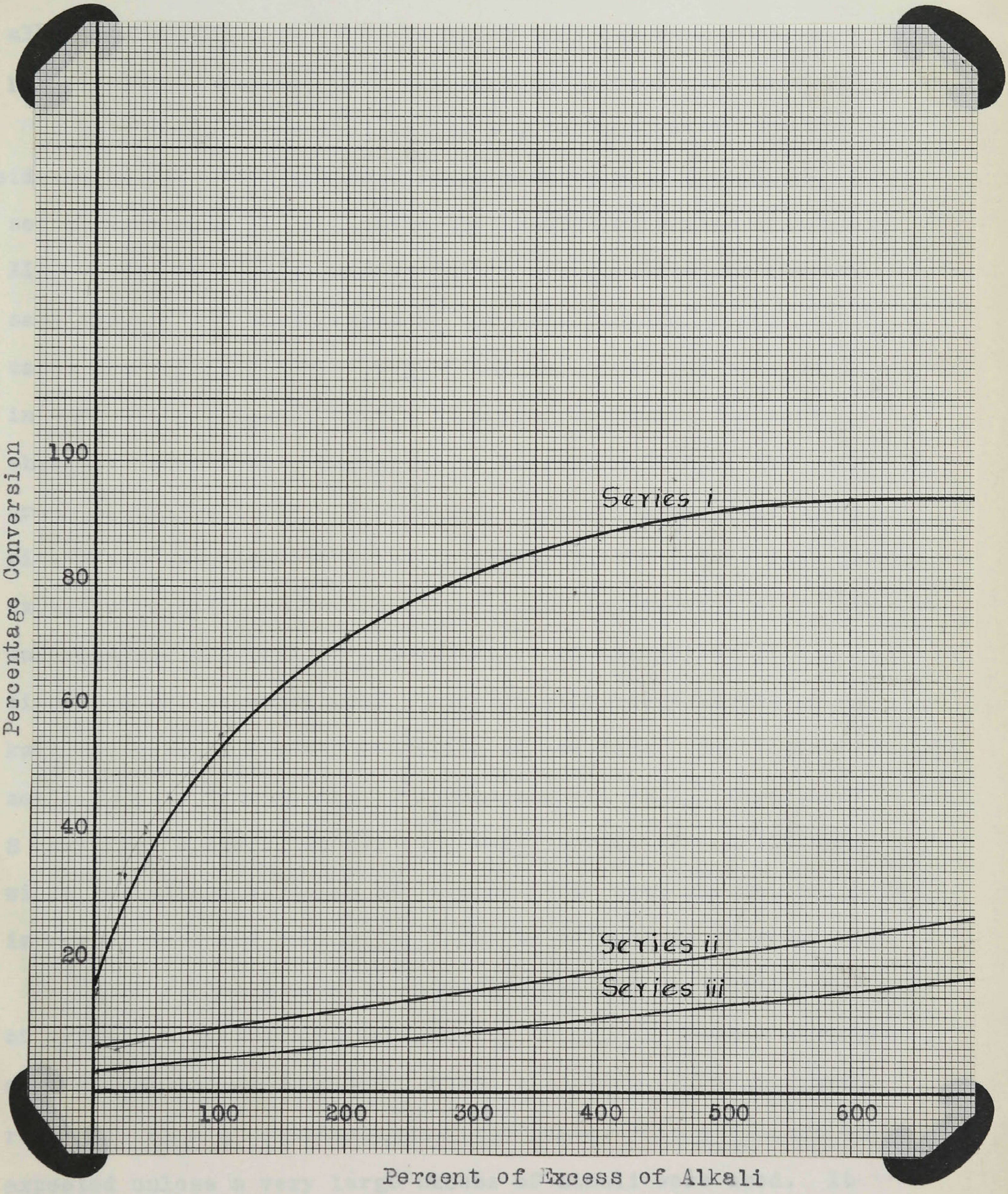
Since it was only relative results which were sought, it was not deemed necessary to purify the acetone with very great care. Accordingly, a quantity of Merk's acetone was distilled and the proportion boiling between 55.5° and 61.0° was collected, ten grams weighed out, made up to one litre, and stored in a tightly-fitting and greased glass-stoppered bottle. In the calculations 10.00 cc of this solution were considered as containing 0.1 grams of acetone.

The experiments were carried out as already indicated under series I, the amount of the alkali added was gradually increased until there was no further increase in the percentage conversion in series I. Duplicates were run in each series and for each concentration of alkali. Table III is a summary of the results obtained.

## Table III

| | | Series I | | | Series II | | | Series III | | |
|---|---|---|---|---|---|---|---|---|---|---|
| No. of Expt. | Excess NaOH | C.C's a | Thio. b | % Conversion | CC's a | Thio. b | % Conversion | CC's a | Thio. b | % Conversion |
| 1 | 0 | 36.00 | 35.95 | 15.40 | 39.16 | 39.30 | 7.50 | 41.20 | 41.10 | 2.97 |
| 2 | 20 | 70.44 | 70.26 | 34.12 | 82.17 | 82.15 | 6.28 | 83.14 | 83.17 | 3.93 |
| 3 | 40 | 67.42 | 67.60 | 40.80 | 81.87 | 81.60 | 7.27 | 83.05 | 83.17 | 4.02 |
| 4 | 60 | 65.15 | 64.95 | 46.60 | 81.10 | 80.74 | 9.11 | 83.00 | 82.90 | 4.41 |
| 5 | 100 | 61.20 | 60.67 | 56.34 | 78.87 | 78.72 | 14.17 | | 82.30 | 5.94 |
| 6 | 380 | 68.40 | 68.50 | 79.04 | 100.25 | 97.70 | 24.97 | 108.20 | 108.35 | 8.54 |
| 7 | 460 | 63.65 | 63.15 | 87.75 | 98.00 | 99.20 | 25.63 | 104.90 | 105.20 | 14.32 |
| 8 | 500 | 60.35 | 61.55 | 92.24 | 99.30 | .00 | 23.76 | 107.00 | 105.00 | 12.60 |
| 9 | 600 | 59.70 | 60.05 | 94.48 | 97.65 | 97.20 | 28.23 | 103.00 | 104.30 | 17.32 |
| 10 | 800 | 59.60 | 60.15 | 94.48 | 88.25 | 87.70 | 44.99 | 104.55 | 104.95 | 15.41 |

Action of Alkali on Acetone



In experiment 1. only theoretical quantities of iodine and alkali were used. It is to be noted that the same thiosulphate solution was not used throughout.

This table shows that series I gives what might be considered quantitative and concordant results when the excess of sodium hydroxide is 600%,while the results of series II and III are not as regular and certainly not quantitative for the same excess. An examination of the accompanying graphs indicates the relative efficiency of the three series, this being in the order series I, series II and series III. The above observations are also borne out by an examination of the progress of the reaction. In small excesses of alkali the precipitate was seen to form first in series I, and later, with larger excess of alkali, in series II and III. In parallel with this was observed the rate of disappearance of the colour of the iodine from the solution when a sufficiently large excess of alkali was present for the formation of iodoform. Duplicates in series I vary from 0.02cc to 1.20cc and all except experiment 8 vary from 0.02c.c. to 0.55c.c. while series II and III show wider variation; but when it is considered that the thiosulphate is weaker than the iodine the error in percentage is reduced.

Since series I gave quantitative results at 600% excess of alkali, it was deemed unnecessary to try any larger excesses even though series II and III might also eventually give such results. From an examination of the curves this would not be expected unless a very large excess of alkali were used. It has been noticed in text-books and in journals that the directions for this reaction are that an excess of iodine be added and sufficient alkali just to decolorize the solution. Such an amount of alkali would not give a complete reaction in this case for the condition was met at about 300% excess of alkali, at which point quantitative results were not obtained.

In order to ascertain the effect of dilution upon percentage conversion a series of experiments on series I were carried out, the only departure from the previous method being in the final volume to which the mixture was diluted. An excess of alkali which had previously not given complete conversion was chosen so that the effect of dilution, if any, could be detected. The excess chosen was 460% and the results obtained are given in table IV.

Table IV

|  | CC's of thiosulphate |  |  |
|---|---|---|---|
| Volume | a | b | % Conversion |
| 200 c.c. | 63.15 | 63.65 | 87.75 |
| 400 c.c. | 60.85 | 60.90 | 93.99 |
| 600 c.c. | 60.35 | 60.95 | 94.34 |
| 800 c.c. | 60.10 | 59.60 | 95.75 |

From these results it can be seen that dilution is also a factor in the sensitiveness of the reaction, it being sensitive at a 0.012% concentration of acetone and at a smaller excess of alkali than when the concentration is 0.05%.

The element of time was investigated by two series of experiments, viz.,

(a) By noting the effect of the time of standing of the whole mixture

(b) By noting the effect of the time of standing of the alkali on the acetone before adding the iodine.

The excess of alkali used was 460% as in the experiment on dilution. Table V gives the results of (a) and table VI of (b).

Table V

| | CC's of Thiosulphate used | | |
|---|---|---|---|
| Time of standing | I | II | % Conversion |
| 10 minutes | 58.60 | 57.65 | 97.58 |
| 1 hour | 63.65 | 63.45 | 87.75 |
| 5 hours | 58.65 | 58.55 | 88.31 |
| 15.5 " | 61.70 | 63.90 | 89.35 |
| 24 " | 59.90 | 60.35 | 93.87 |
| 26 " | 69.62 | 69.35 | 94.38 |

The same thiosulphate solution was not used throughout.

Table VI

| Time of standing of alkali & acetone | CC of Thiosulphate | % Conversion |
|---|---|---|
| 6 minutes | 57.65 | 90.21 |
| 10 " | 57.80 | 89.91 |
| 27 " | 57.50 | 90.48 |
| 47 " | 57.80 | 89.91 |

The ten minute time of reaction as shown by table V, gives the highest percentage conversion, but the readings are not good checks as also in the 15.5 hour interval. Disregarding the first experiment the percentage conversion increases with the time of standing. This time element, however, can be overcome by using a larger excess of alkali.

The effect of the alkali, if there be such an effect, does not increase with time for the readings do not vary more than 0.30 cc.

## Part II

## Formaldehyde

### Historical

In addition to the colorimetric methods there are chemical methods for the quantitative determination of formaldehyde based upon first, its reducing powers, second, its powers of forming addition products. Of those based upon the former there are, with variations, two important methods, viz., (a) by oxidation to a formate with hydrogen peroxide in alkaline solution, (b) by oxidation to a formate with iodine in alkaline solution. As the latter method depends on the use of sodium hypoiodite as an oxidizing agent this reaction was studied quantitatively in the same manner as acetone, using the oxidation by hydrogen peroxide as a quantitative basis.

The oxidation of formaldehyde by hydrogen peroxide in alkaline solution was first suggested as a quantitative method by Blank and Finkenbeiner (12). 3 grams of formalin under investigation were weighed out and mixed with 25 cc. of normal sodium hydroxide, immediately and gradually 50 cc of 2.5-3.0% of hydrogen peroxide were added and after 2 - 3 minutes standing the excess alkali titrated with standard acid, using litmus as an indicator. The calculations being made according to the reaction:-

$$HCHO + H_2O_2 + NaOH \rightarrow HCOO\ Na + 2H_2O.$$

Klöss (13) , Schoorl (14), Robin (15), and Auerbach and Plüddermann (16) all used phenolphthalein as an indicator. Mack and Herrmann (17) believe that polymers of formaldehyde are not titrated with the peroxide oxidation, while Haywood and Smith (18) with Grünheit (19) found that the results are low if the alkali is allowed to stand with the formaldehyde before the addition of the hydrogen peroxide due to the following reaction:-

$$2HCHO + NaOH \rightarrow HCOONa + CH_3OH + H_2O$$

This effect can be overcome by adding the hydrogen peroxide to the alkali before mixing the formaldehyde and heating the mixture to hasten oxidation.

The iodometric method which is based upon the reaction,

$$3NaOH + I_2 + HCHO \rightarrow 2NaI + HCOONa + H_2O$$

was first introduced by Romijn (20), his method being the same as previously described here under series II. Borgstrom (21) was able to get quantitative results in the presence of methyl alcohol and, with Horsch (22) in the determination of formaldehyde in paraformaldehyde, he got substantial agreement with the results obtained in the Liebig combustion furnace, but not so with the hydrogen peroxide oxidation.

## Experimental

An aqueous solution containing approximately 16 grams of formaldehyde per litre was made by dissolving 42.cc. of Schuchhardt's 40% solution of formaldehyde in methyl alcohol in one litre of solution.

The quantity of formaldehyde present was determined by oxidation with hydrogen peroxide in alkaline solution. The formaldehyde was placed in a tightly stoppered erlenmeyer flask, the standard alkali added followed by a 3% hydrogen peroxide solution, whose acidity had been determined, the mixture was allowed to stand for 10-15 minutes, then boiled to complete the reaction, if necessary, and to decompose any excess of hydrogen peroxide. The solution was then cooled and the excess of alkali titrated with standard hydrochloric acid using phenolphthalein as indicator. The following results were obtained:-

Table VII

| C.C. of formalin solution | CC of NaOH | CC of H O added | NaOH actually used |
|---|---|---|---|
| 9.94 | 39.85 | 20 | 14.41 |
| 9.94 | 41.90 | 50 | 14.41 |
| 9.94 | 52.30 | 50 | 14.71 |
| 9.94 | 60.65 | 50 | 14.26 |
| | | average | 14.45 |

Unless the solution was boiled to decompose the excess of hydrogen peroxide it was difficult to obtain a sharp end-point. The alkali used was .3751N and calculating from this one litre of the solution contained 16.26 grams of formaldehyde.

The previously mentioned procedure for the iodometric method, viz., approximately 100% excess iodine, reacting time one hour, and the addition of the reactants made as in series I, II and III was employed. Calculating on the total formaldehyde content as found by oxidation with peroxide the following results were obtained:-

Table VIII

| % Excess of NaOH | % Conversion Series I | % Conversion Series II | % Conversion Series III |
|---|---|---|---|
| 20 | 98.43 | 91.49 | --- |
| 40 | 98.28 | 98.50 | 12.09 |

Since some of these results showed almost quantitative oxidation, and since series III gave such low results, this series of experiments was not further continued. The results, as in the case of acetone, indicate clearly that series I is the most efficient being closely followed by series II, while series III falls far below either series I or II. The excess of alkali necessary for complete oxidation is much smaller in series I than for acetone under similar conditions, also the excess necessary for series I is less than for series II. With the quantities used in 40% excess of alkali the iodine solution was not quite decolorized by the alkali.

The effect of time was also determined in a series of experiments whose results are given in table IX.

Table IX

| Time of standing | % Excess of NaOH | % Conversion | |
|---|---|---|---|
| | | Series I | Series II |
| 10 min. | 40 | 97.72 | |
| 1 hour | 40 | 98.28 | |
| 2 hours | 40 | 99.40 | |
| 5 " | 40 | 100.71 | |
| 1 hour | 20 | | 91.49 |
| 2 hours | 20 | | 95.77 |
| 5 " | 20 | | 96.59 |

These results show that the effect of time is appreciable in both series I and II at least when the excess of alkali is small, the effect being greatest in series II and this effect, disregarding the ten minutes to one hour interval, being observed most in the interval between one hour and two hours.

In some of the experimental work mentioned under the oxidation of formaldehyde by alkaline hydrogen peroxide, it will be noticed that errors are caused by allowing the alkali to stand with the formaldehyde before the addition of the hydrogen peroxide, and the longer the standing the greater the error. On this basis, and on the basis of experimental error, the obtaining of more than 100% conversion, as in the last of the above series of experiments, may be explained by assuming that such an error was made in the standardization of the formaldehyde solution; this standardization having been made before the precaution was known to be necessary.

In general it may be said that in order to get quantitative results series I or II should be used although it may be possible, with a larger excess of alkali, to make series III quantitative also. Increase in excess of alkali does not seem to effect series I, but it does series II. The element of time, however, is of importance in both series I and II; this effect may perhaps be overcome by using a larger excess of alkali.

## Part III

### Acetaldehyde

### Historical

In a manner analogous to formaldehyde, acetaldehyde might also be expected to be quantitatively oxidized. Stipp and Engelhardt (23) state that the iodometric method gives low~~er~~ results. A method for the quantitative estimation of acetaldehyde is that used by Bourcart (24) which depends upon its oxidation with excess standard potassium dichromate by heating the two with sulphuric acid in a sealed tube on a water-bath for two to three hours, using the excess dichromate to liberate iodine from potassium iodide, the amount of which is determined by titrating with thiosulphate. Even though the iodometric method has not given quantitative results it was thought to be of sufficient importance to study the effect of the order of addition of reactants and the excess of alkali used.

## Experimental

An aqueous solution of acetaldehyde was prepared by acidifying about 30.cc of paraldehyde with three drops of concentrated sulphuric acid, distilling over the acetaldehyde by heating on a water bath and condensing the vapour in a freezing mixture at -4° C, pipetting approximately 10 grams into a flask and making up to 2000 cc with previously cooled distilled water. The solution was kept in a greased glass-stoppered bottle and stored in a cool place.

The solution prepared was considered to contain .1 grams of acetaldehyde in 20 c.c. and a series of experiments similar to those on acetone and formaldehyde was performed. Calculations were made in accordance with the reaction.

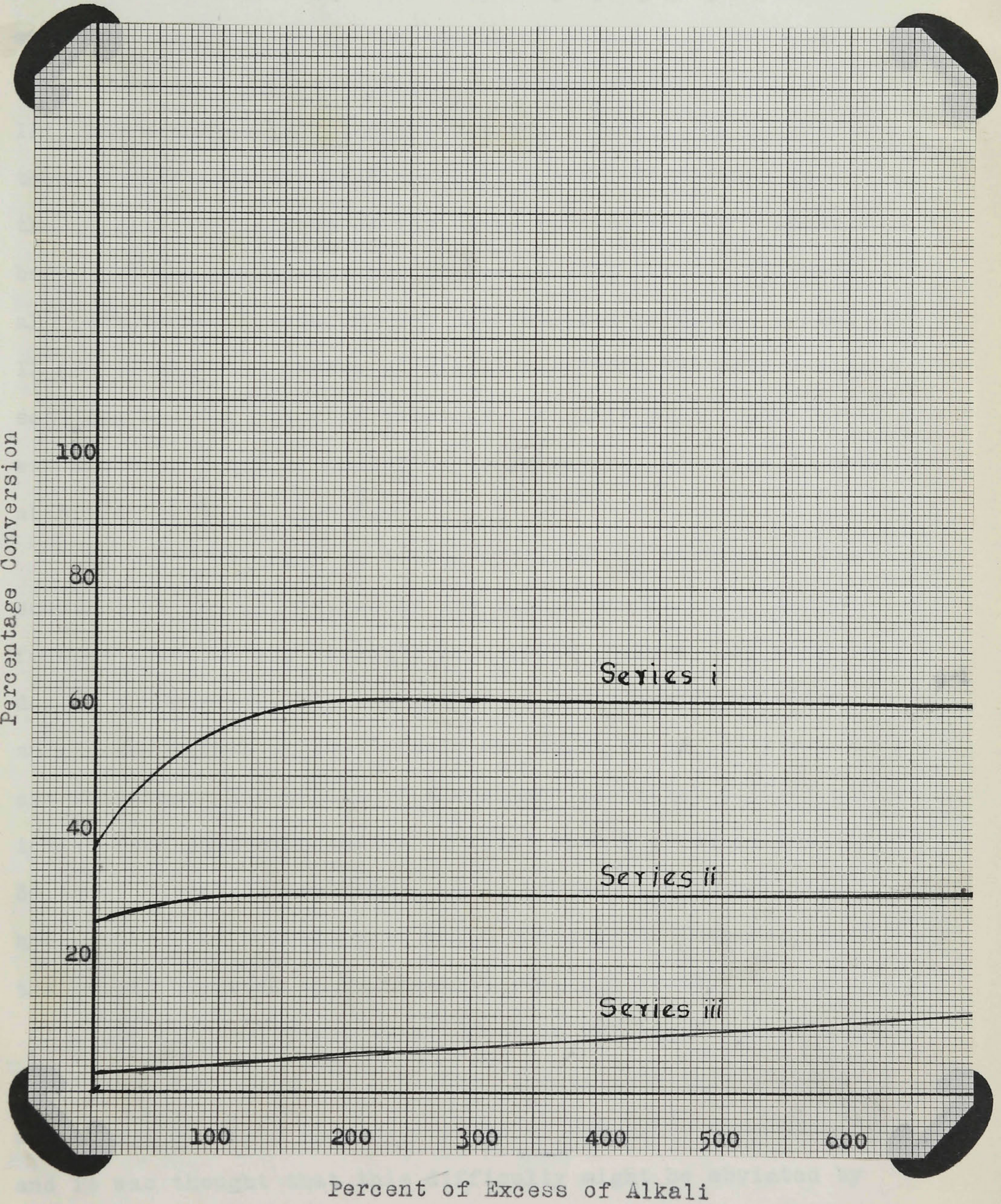
$$CH_3C\overset{O}{\lessgtr}_{H} + 3I_2 + 4NaOH \rightarrow CHI_3 + HC\overset{O}{\lessgtr}_{O}\text{-}Na + 3NaI + 3H_2O$$

The excess of iodine used was slightly over 100% and the total volume increased, due to the concentrations of the standard solutions, to 225 cc except with the higher excesses of alkali, when a volume of 300 cc was used. The results are as given in table X.

Table X

| | | Series I | | | Series II | | | Series III | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Expt. No. | Excess NaOH | C.C's Thio. a | b | % Conversion | CC's Thio. a | b | % Conversion | CC's of Thio. a | b | % Conversion |
| 1 | 40 | 140.67 | | 47.75 | 157.71 | 157.66 | 28.88 | 181.01 | 181.34 | 2,79 |
| 2 | 80 | 133.51 | 131.01 | 57.09 | 155.66 | 155.63 | 31.16 | 180.71 | 180.55 | 4.83 |
| 3 | 150 | 118.31 | 118.11 | 58.30 | 140.21 | 140.36 | 31.08 | 161.76 | 160.69 | 5.37 |
| 4 | 400 | 104.03 | 104.63 | 54.54 | 123.61 | 123.55 | 31.69 | 139.71 | 137.50 | 12.18 |
| 5 | 600 | 100.41 | 98.71 | 60.40 | 123.53 | 123.11 | 31.04 | 140.10 | 137.31 | 12.03 |

Action of Alkali on Acetaldehyde



The results, along with the accompanying graphs, indicate that an increase in the excess of alkali used has little effect upon the percentage conversion except in series III, the reaction is by no means a quantitative one under these conditions, and that there is a great difference in the relative efficiency of the three series, series I again being the most efficient and series III the least. The usual precipitate of iodoform was not obtained in either series II or III when the excess of alkali was 150%, but only a slight settling and the odour of iodoform. At this point also there was a strong odour of acetaldehyde in series III while it was absent in series I and II.

In order to check up on the acetaldehyde content of the solution it was determined by the method of Bourcart (see reference above). All reagents were cooled before they were added to the mixture, viz., 19.98 cc of acetaldehyde solution, sufficient dilute sulphuric acid and 50.11 cc of .2N dichromate solution. The excess of dichromate liberated sufficient iodine from potassium iodide to react with I 32.30 cc and II 32.15 of .1686N thiosulphate. This corresponds to an aldehyde content of 0.09870 grms which corresponds favorably with the amount supposed to be present, viz. 0.1 grams.

Some difficulty was experienced in getting a definite endpoint when titrating the liberated iodine with thiosulphate and starch solution in the presence of the green chrom~~at~~ic ion, and it was thought that this difficulty might be obviated by using potassium permanganate as the oxidizing agent. Consequently 19.98cc of acetaldehyde solution, 140cc of water, 20cc of 2.7N sulphuric acid, and 10cc of .2694N potassium permanganate were mixed and allowed to stand for two hours at room temperature, then excess of hydrogen peroxide solution, whose strength relative to the permanganate solution was known, was added and this excess titrated with more of the permanganate. In duplicates I 16.62cc and II 16.38cc of .2694N permanganate were used up corresponding to an aldehyde content of 0.09779 grams.

These results indicate that the permanganate oxidation is quantitative and a series of experiments was carried out varying the excess of sulphuric acid, and the time of reaction, the permanganate added being about 100% in excess. The results are given in table XI.

Table XI

| Time | Excess of H SO | Permanganate used up | grams of acetaldehyde |
|---|---|---|---|
| 30 min. | 100% | 16.25 | 0.09631 grms |
| 30 " | 300% | 16.30 | 0.09661 " |
| 1 hour | 100% | 16.15 | 0.09572 " |
| 1 " | 300% | 16.05 | 0.09523 " |
| 1 " | 600 % | 16.46 | 0.09756 " |

According to the above results it is possible to determine acetaldehyde volumetrically if 100% excess of sulphuric acid permanganate required by the reaction -

$$2KMnO_4 + 3H_2SO_4 + 5CH_3C\genfrac{}{}{0pt}{}{\nearrow O}{\searrow H} \longrightarrow K_2SO_4 + 2MnSO_4 + 5CH_3C\genfrac{}{}{0pt}{}{\nearrow O}{\searrow OH} + 3H_2O$$

be used, the time of reaction being 30 minutes. Aside from the advantage of a definite end-point in this method there is no need for heating the mixture and therefore no need for a sealed tube, while the oxidation is complete in at least 30 minutes.

A similar experiment was carried out using hydrogen peroxide in alkaline solution as oxidizing agent. 19.98 cc of the acetaldehyde solution, 100 cc of 3 % hydrogen peroxide whose acidity was known, and 15 cc of .3751 N sodium hydroxide solution were mixed in a tightly-stoppered flask and shaken for a time. This was heated at about 50° C for 30 to 45 minutes and then the solution, which no longer had the odour of acetaldehyde, was titrated with standard hydrochloric acid and phenolphthalein. In two experiments I 6.46 cc and II 6.51 cc of .3751 N sodium hydroxide were used to neutralize the acetic acid formed corresponding to an acetaldehyde content of 0.1071 grams.

It has been possible to obtain two concordant quantitative results on the acetaldehyde content of the solution, viz., 1. by oxidation with potassium dichromate and 2. by oxidation with potassium permanganate, while oxidation with hydrogen peroxide in alkaline solution might be suggested as a third possible method. Calculating on the theoretical acetaldehyde content of the solution only 60 % oxidation is obtained with an alkaline solution of iodine. This may account in some measure for the low results obtained by Wieland (25) for his estimation of acetaldehyde by this method. The relative efficiency of the three series has again been shown to be decreasing from series I to series III.

## Part IV.

## Pyruvic Acid

### Historical

Pyruvic Acid being a simple ketonic acid would, by virtue of its keto group, be expected to react with an alkaline solution of iodine. Wieland, (26) in his studies on oxidation, estimated pyruvic acid by the addition of 700 % excess of alkali, 200 % excess of .1 N iodine and, after allowing the mixture to stand for one and one-half hours, titrating the unused iodine. The results obtained by this method agree with those obtained by titrating it as a monobasic acid with alkali.

### Experimental

A sample of Schuchardt's pyruvic acid was purified by distillation at 12 m.m. pressure collecting first between 61 and 71 then redistilling this fraction and collecting between 64 and 68 . 18 grams of this dissolved in 1 litre of solution was the stock solution on which all experiments were performed. The alkali used was .2498 N sodium hydroxide and the iodine .3442 N. The procedure was the same as before and the quantities calculated in accordance with the reaction.

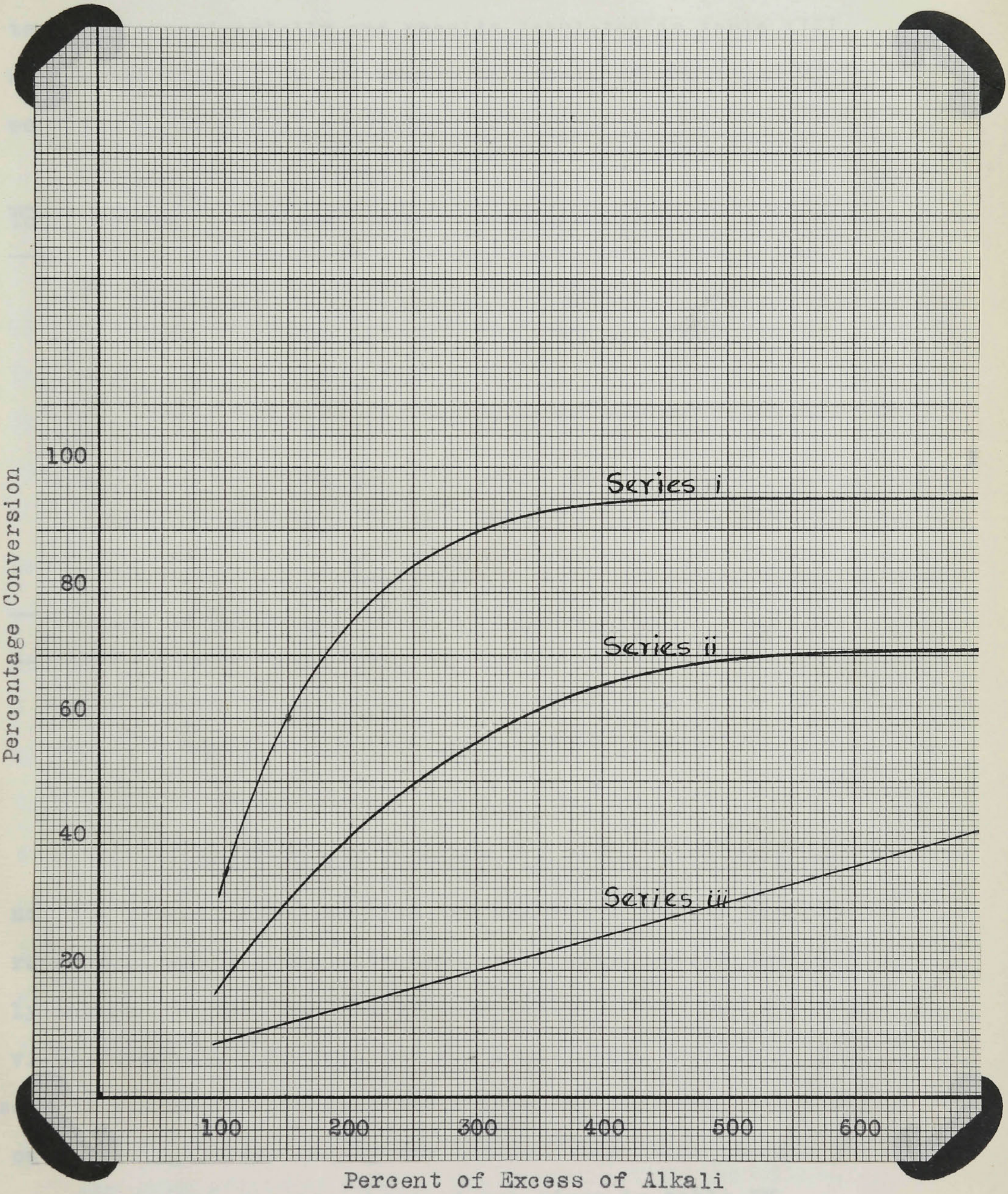
$$CH_3C\overset{=O}{-}\overset{=O}{C}OH + 3I_2 + 5NaOH \rightarrow CHI_3 + 3NaI + (COONa)_2 \; 5H_2O$$

The results obtained are given in table XII.

Table XII

| | | Series I | | | Series II | | | Series III | | |
|---|---|---|---|---|---|---|---|---|---|---|
| No. of Expt. | Excess of NaOH | cc of thio. a | b | % Conversion | CC's of thio. a | b | % Conversion | CC's of thio. a | b | % Conversion |
| 1 | 100 | 60.80 | 61.70 | 34.88 | 66.92 | 67.47 | 18.52 | 72.32 | 69.47 | 8.83 |
| 2 | 200 | 47.38 | 45.87 | 75.66 | 58.00 | 58.60 | 43.51 | 68.63 | 67.80 | 16.20 |
| 3 | 250 | 56.78 | 55.90 | 80.67 | 68.50 | 72.00 | 49.08 | 84.65 | 85.80 | 17.46 |
| 4 | 300 | 51.75 | 53.40 | 88.93 | 69.95 | 68.90 | 52.05 | 85.74 | 84.80 | 17.38 |
| 5 | 350 | 50.10 | 49.95 | 94.50 | 65.80 | 63.55 | 62.43 | 83.20 | --- | 21.90 |
| 6 | 400 | 50.20 | 50.50 | 93.81 | 64.68 | 64.70 | 62.39 | 82.20 | 81.87 | 24.46 |
| 7 | 500 | 49.95 | 50.10 | 94.50 | 62.00 | 61.48 | 68.83 | 77.60 | 79.25 | 32.36 |

Action of Alkali on Pyruvic Acid



The effect of dilution and time of standing was also determined experimentally and results tabulated in table XIII and XIV respectively. An excess of alkali of 250 % and Series I were the experimental conditions existing.

Table XIII

| Total volume | CC's of thio. | % Conversion |
|---|---|---|
| 200 c.c. | ----- | 80.67 |
| 400 c.c. | 57.60 | 77.86 |
| 600 c.c. | 57.40 | 78.35 |
| 800 c.c. | 57.80 | 77.49 |
| 800 c.c. | 70.00 | 50.79 |

Table XIV

| Time of Standing | % Conversion |
|---|---|
| 1 hour | 80.67 |
| 2½ hours | 84.49 |
| 6 " | 84.25 |

The procedure in the last experiment in Table XIII was not the same as usual in that the mixture of alkali and pyruvic acid was diluted with water before the iodine was finally added. If the reaction were an instantaneous one all previous experiments on dilution would have been a failure, consequently a series of experiments like the above one was carried out diluting before adding the iodine. The excess alkali used was 500 %. The results obtained are given in table XV.

Table XV

| Volume | CC's of thiosulphate |
|---|---|
| 200 | 96.30 |
| 400 | 96.80 |
| 600 | 96.65 |
| 700 | 96.75 |

96.30 CC's of thiosulphate corresponds to 92.73 % conversion. The results indicate that if the excess of alkali is great enough dilution has no effect upon the conversion if the concentration of pyruvic acid is 0.013 %.

A similar series of experiments was performed with acetone and it was found that the percentage conversion did not commence to drop until the concentration of acetone was diluted to 0.012 %.

An examination of table XII and its accompanying graph shows 1st that the efficiency of the three series decreases from series I to series III, 2nd that the increase in conversion with increase in alkali excess is greater here than in any of the previous compounds except formaldehyde, 3rd that the variation in readings is larger than usual until a sufficiently large excess of alkali is reached, and 4th that the reaction is a quantitative one in series I and indications point toward a quantitative reaction in series II and perhaps III if the excess of alkali be increased sufficiently.

An examination of table XIII shows that if the alkali excess is not sufficiently high, time increases the conversion.

In order to determine whether the final product of oxidation was oxalic acid the following experiment was carried out. The pyruvic acid in a 10 cc aliquot was oxidized as under series I, hydrochloric acid being used to acidify instead of sulphuric acid. After filtering, the oxalic acid was precipitated as the calcium salt and determined as oxalic acid by oxidizing with potassium permanganate. In duplicate experiments, where 94.5% of the calculated amount of pyruvic acid had been oxidized, I 6.55 cc and II 6.50 cc of .2694 N permanganate were used to oxidize the oxalic acid present, corresponding to 0.07026 grams of oxalic acid or 0.07729 grams of pyruvic, while the amount present according to calculations was 0.08505 grams. Although the results are not quantitative, due perhaps to experimental error when dealing with such small amounts, yet they indicate that pyruvic acid is oxidized to oxalic acid.

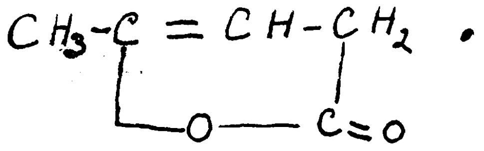
## Part V

## Laevulinic Acid

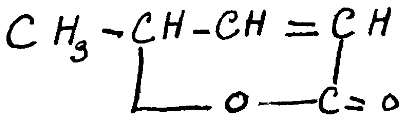
### Historical

Laevulinic acid, like other keto compounds, was observed to react with an alkaline solution of iodine with the formation of iodoform. Tollens (27) and Savaré(28) has used this reaction in the estimation of hexoses in presence of pentoses; the latter, on treatment with hydrochloric acid, yields furfural the former yielding laevulinic acid.

Savaré, by keeping a sample of commercial laevulinic acid, because of its hygroscopic nature, in a vacuum for fifteen days, immediately weighing out a sample and titrating with $\frac{N}{10}$ alkali, found that his results did not agree with the sample weighed out. Re-distilling the same product three times at ordinary pressure (B.Pt. $240^\circ$ -$241^\circ$ ), weighing a sample, and estimating the acid iodometrically, did not give concordant results, but results varying according to the amount of alkali added. These results led him to the conclusion that the product was impure and that it may have contained some of the unsaturated lactone of the formula



This, along with the lactone



is supposed to be present if the acid is distilled slowly at ordinary pressure, Wolff (29). He next tried the calcium salt which corresponded to the formula $(C_5H_7O_3)_2Ca.2H_2O$, so far as $H_2O$ and Ca were concerned, and was able to get quantitative results. The method used, so far as it is described, differs from the one used here in the use of potassium instead of sodium hydroxide and in filtering off the iodoform before acidifying and titrating the excess of iodine. The excess of iodine used was 142 %, and of alkali from 3400 % to 8500 % and in no case do the results obtained differ from the theoretical by more than 0.28 %.

## Experimental

The laevulinic acid used in this investigation was Schuchardt's product which was a viscous and slightly brown liquid at room temperature. This was slowly cooled with continual stirring and after crystallization had taken place, the mother liquor filtered off by suction. The temperature at which crystallization took place was much below that of the melting point of the final product. After a second crystallization the resulting white crystals melted at approximately 30° into an almost colourless liquid. A 9.8880 gram sample of the crystals was weighed out immediately and made up to one litre of solution in water. Titrating an aliquot of this solution with $\frac{N}{10}$ alkali and phenolphthalein showed the litre to contain 9.802 grams of acid.

In an attempt to follow the purification by estimating the acid present iodometrically the following results were obtained using series I and approximately 100 % excess of iodine and 500 % excess of alkali:-

| | | C.C. of $Na_2S_2O_3$ | % Conversion |
|---|---|---|---|
| I Belfore purification | (a) | 93.60 | 96.98 |
| | (b) | 93.18 | 91,44 |
| II After 1st crystallization | (a) | 98.20 | 91.92 |
| | (b) | 96.25 | 94.06 |

Using the same procedure as before the results obtained are as shown in table XVI.

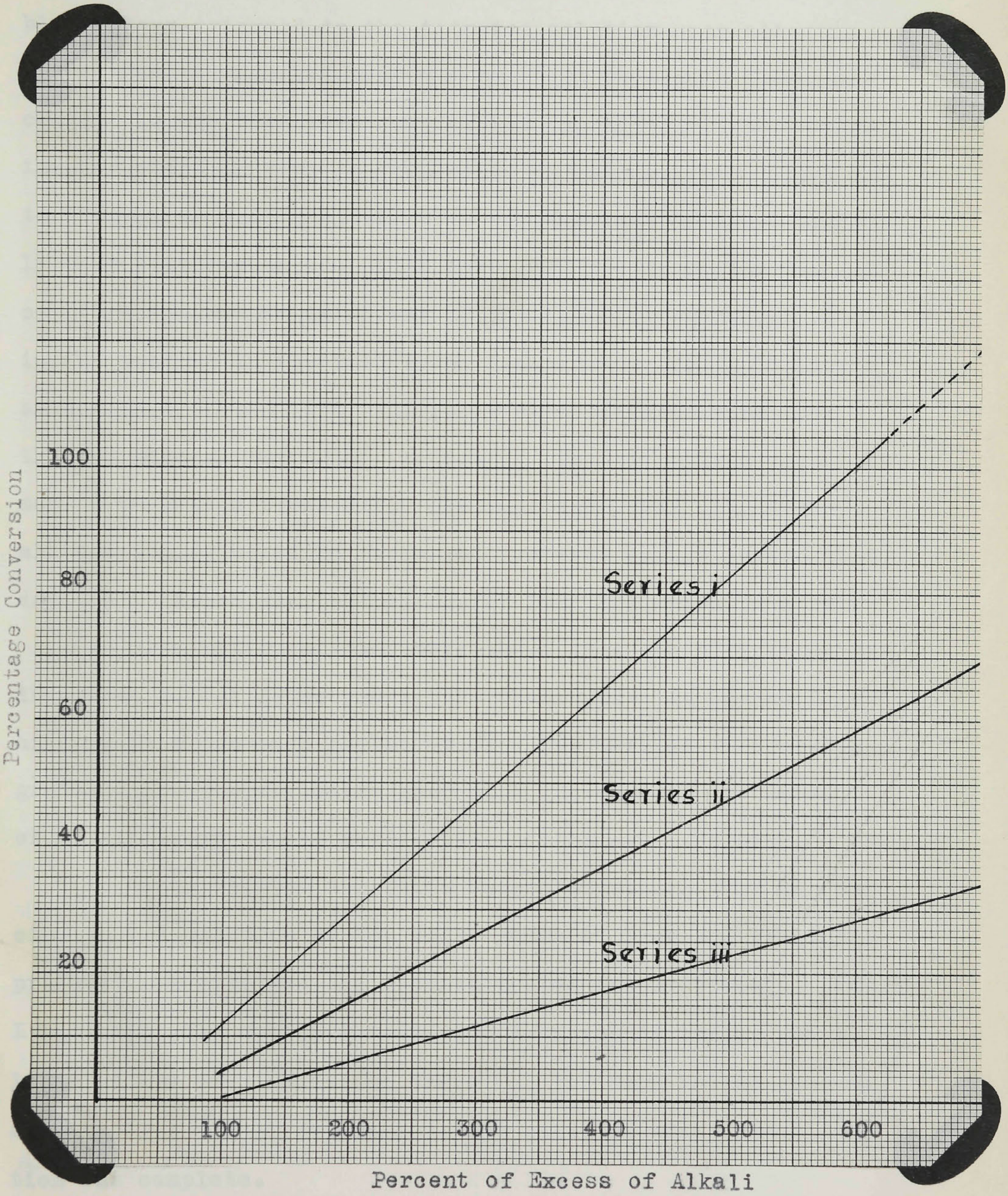
Calculations were made according to the reaction

$$C_5H_8O_3 + 3I_2 + 5\,NaOH \longrightarrow CHI_3 + 3\,NaI + C_4H_4O_4Na_2$$

Table XVI

| No.of Expt. | % X's NaOH | Series I Thio.used I | Series I Thio.used II | Series I % Low Convertio | Series II Thio. used I | Series II Thio. used II | Series II % Low Convertio | Series III Thio. used I | Series III Thio. used II | Series III % Low Convertio |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 100% | 90.20 | 90.30 | 11.86 | [illegible] | 93.10 | 4.36 | 95.00 | 94.90 | 0 |
| 2 | 200% | 83.60 | 85.00 | 27.49 | 88.95 | 88.45 | 15.92 | 91.60 | 91.25 | 8.78 |
| 3 | 300% | 78.00 | 77.70 | 44.39 | 84.20 | 84.10 | 27.88 | 88.50 | 88.65 | 16.27 |
| 4 | 400% | 69.30 | 71.65 | 63.74 | 79.85 | 81.35 | 37.15 | 92.45 | 91.90 | 6.84 |
| 5 | 500% | 109.20 | 109.41 | 81.90 | 128.81 | 129.06 | 51.93 | 142.76 | 151.35 | 24.31 |
| 6 | 600% | [illegible] | 96.55 | 101.3 | 126.96 | 126.86 | 55.01 | 144.81 | 141.66 | 30.11 |
| 7 | 700% | 86.90 | 86.90 | 115.0 | 128.66 | 130.81 | 50.69 | 149.11 | 148.36 | 21.73 |
|  | 1125% | --- | 83.48 | 121.3% | 122.90 | 116.45 | 66.07 | 145.10 | 135.80 | 34.38 |

Action of Alkali on Laevulinic Acid



During the series of experiments it was noticed that the blue colour returned to the titrated solution upon allowing it to stand. This tendency was greatest in series I and increased as the percentage conversion increased. After standing for about an hour, a few drops (amounts varying from 0.10 to 0.55 cc depending on the time of standing) of approximately 0.13 N sodium thiosulphate were required to decolorize the solution again. In an effort to account for the excess of iodine used up in the last three experiments the duplicates of series I of the last experiment were titrated with more thiosulphate as the colour returned. The titrations were made from 2 to 5 times daily for four days, but not nearly all the iodine could be accounted for even though in the last day the solution remained clear for four and one-half hours.

An examination of the table shows that the efficiency of the three series is as previously observed. In series I as high as 21 % too much iodine is used up. Series III shows a gradual increase of iodine used with increase in the amount of alkali added, while series III results are irregular.

In attempting to duplicate Savaré's results with the Calcium salt a solution of the salt, prepared from the original product, was made and the acid estimated iodometrically. Series I was used with approximately 100 % excess of iodine and a large excess of alkali, but there was too much iodine used up and the blue colour returned to the solution after the titration was complete.

As was pointed out by Savaré (ibid.) the inconsistency of the results might be due to the impurities in the acid used. Although the titration with alkali indicated that it was fairly pure, there is a possibility, however, that, due to the hygroscopic nature of the acid, the loss in molecular weight resulting from lactone formation could be balanced by the absorption of water by the crystals. It hardly seems reasonable that this should be so nearly compensated for and the acid used was either impure or the method used is not applicable for quantitative methods. Because of the persistence in the absorption of iodine even when the calcium salt is used the method is perhaps not applicable as a quantitative one.

## Part VI

## Mesoxalic Acid

Mesoxalic acid containing a keto group would also be expected to be oxidized by an alkaline solution of iodine with the liberation of carbon dioxide according to the reaction,

$$COOH.\ CO.\ COOH + I_2 + 4NaOH \rightarrow CO_2 + 2NaI + (COONa)_2 + 3H_2O$$

### Experimental

The stock solution was prepared by decomposing a quantity of Schuchardt's barium mesoxalate in 200 CC of 0.8208 N sulphuric acid, the barium mesoxalate being added until the solution no longer gave a test for sulphate ion. The barium sulphate was filtered off and the filtrate made up to one litre which, calculating from the sulphuric acid decomposed, should contain 9.6894 grams of mesoxalic acid.

9.98 C.C. of the abpve solution, containing .0967 grams of mesoxalic acid, was oxidized under various conditions using series I as the order and a large excess of alkali, the actual quantities used being, 19.98 CC of .2550 N iodine and 100 CC of .3330 N alkali. After allowing the reaction mixture to stand approximately 12 hours at room temperature the unused iodine required I 56.10 CC and II 56.30 CC of thiosulphate corresponding to 0.05643 grams of mesoxalic acid. After standing at room temperature for 10 minutes and heating to 60° - 70° for 10 minutes other similar mixtures required I 55.50 CC and II 55.75 CC of thiosulphate, while a third experiment heated for 2 hours at the same temperature required I 55.30 CC and II 57.00 CC of thiosulphate.

These results indicatedthat the oxidation with sodium hypoiodite is not quantitative.

## Summary

An examination of the accompanying graphs in which the percent of excess of alkali has been plotted against percentage conversion in series I of the various compounds shows the relative ease with which these compounds are oxidized by sodium hypoiodite. Theyfall in the order, formaldehyde, pyruvic acid, acetone, laevulinic acid and acetaldehyde. With the other series quantitative oxidation is obtained only in the case of series II with formaldehyde,indications of quantitative oxidation in series II and III with pyruvic acid, while indications in other cases are that they will not be quantitative.. The order of addition of reactants and the excess of alkali are conditions which effect the progress of oxidation with alkaline iodine solution. In all cases the element of time is of importance, a short time of reaction yielding highest but most irregular results, while a longer time with a large excess of alkali yields concordant results. The reaction is sensitive in solutions of approximately 0.012% concentrations.

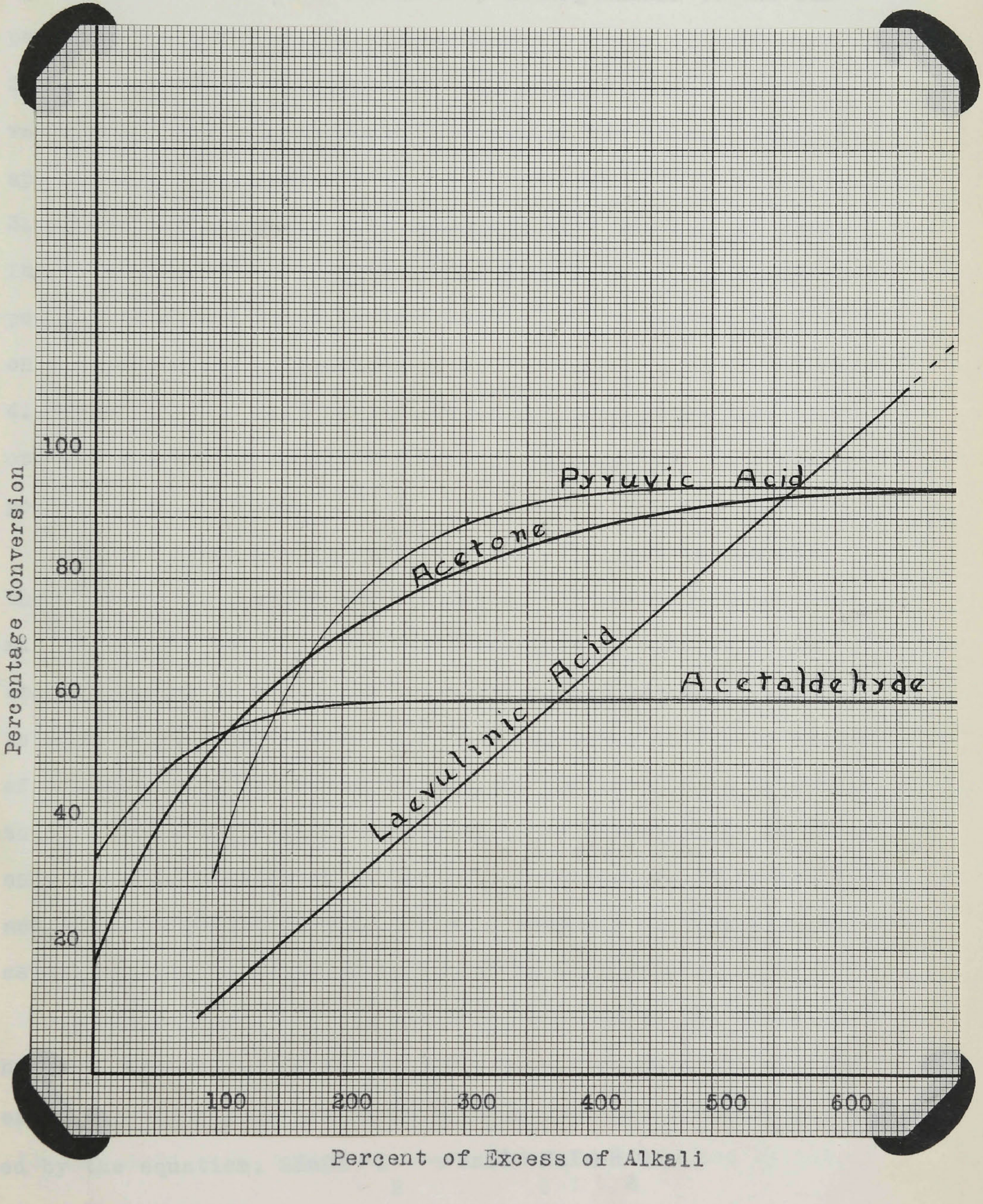
## Final Conclusions

The final conclusions regarding the effect of various experimental factors on this reaction are given in table VIII.

Table XVIII

| Compound studied | Best Series | Effect of time of standing | Effect of time of standing with NaOH | Effect of dilution |
|---|---|---|---|---|
| Acetone | I | inc. conversion | nil | inc. conversion |
| Formaldehyde | I or II | inc. conversion | | |
| Acetaldehyde | I | | | |
| Pyruvic Acid | I | inc. conversion | | dec. conversion |
| Laevulinic Acid | I | | | |
| Mesoxalic | | | | |

Comparison of Series 1



1. The best results are obtained by adding alkali to the compound followed by iodine, i.e. series I.
2. The percentage conversion to iodoform (or other compounds) varies directly with the concentration of the alkali, slowly approaching a maximum.
3. The percentage conversion increases with the time of standing of compound with mixtures. The time of standing of compound with alkali prior to the addition of iodine has no effect on the subsequent rate of reaction.
4. In the case of acetone, increased dilution gives rise to increased conversion to iodoform; while with pyruvic acid the opposite effect is true.

In the light of (1) and (3) it is difficult to see that these reactions involve any tautomeric change which might permit of iodination. If the alkali enolizes it must do so instantaneously; in that case one might expect series II and III to show greater conversion than they do, since the large excess of alkali would have caused sufficient enolization to give rise to higher results. It is noteworthy that formaldehyde is the only compound studied which gave equal conversion in series I and II: this indeed is also the only compound of them all (excepting mesoxalic acid) which cannot be enolized.

It is difficult to explain this reaction on the basis of hydroxyl ion concentration without suggesting that the mixture of iodine and sodium hydroxide acts in some manner not explained by the equation, $2NaOH + I_2 \longrightarrow NaOI + NaI + H_2O$

Nor is it reasonable to suppose that this reaction is influenced by the formation of any iodate because of the conditions of the experiments. The abnormally high results with laevulinic acid point to the loss of iodine in some manner other than that which will produce iodoform. Obviously formaldehyde and laevulinic acid afford the two extremes of cases where sodium hypoiodite acts purely as an oxidizing agent and iodinating agent respectively; this iodination in alkaline solution producing a more or less stable and soluble iodine compound might conceivably be reversed slowly when the solution was made acid prior to titration with thiosulphate.

It is suggested that such results as are obtained here in this systematic study provide evidence for iodination other than that resulting in the formation of iodoform.

Inasmuch as this work was undertaken as a quantitative study for the efficiency of iodine in alkaline solution on organic compounds, it must be emphasized that in none of the cases investigated can this method of estimation be regarded as a quantitative one where iodoform results from the reaction; for any method which requires such a huge excess of one reagent above the theoretical without an explanation for the necessity of this excess, and in which the order of addition of reagents plays such an important and varied part, can in no wise be considered a useful one even in the hands of a skilled technician. As evidence of this it may be pointed out that in several publications of recent date where acetone was estimated by this method values purporting to be checks varied anywhere up to 20 %.

In order to establish the reasons for this abnormal behaviour further investigation with other organic compounds is necessary; nor is it possible, it is believed, to formulate the mechanism of this method without a clearer conception of the interaction of iodine and a strong alkali.

1. The action of iodine and alkali on acetone, formaldehyde, acetaldehyde, pyruvic acid, laevulinic acid and mesoxalic acid has been studied under varying conditions.
2. The effect of varying the excess of alkali has been obtained.
3. The effect of the order of addition of reactants has given unexpected results.
4. Suggestions have been submitted as to how the abnormal results obtained may arise.

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