WAR RESEARCH

THE CHEMISTRY
THE IDENTIFICATION, AND THE
QUANTITATIVE ESTIMATION OF NITRODICYANDIAMIDINE

A Thesis

by

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Abstract

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War Research

The Chemistry, The Identification, and the Quantitative Estimation of Nitrodicyandiamidine.

In the investigation of the properties of nitrodicyandiamidine, a flashless propellant component, it was found that the susbstance is a weak acid since a number of stable metal salts could be isolated. Salt formation of nitrodicyandiamidine may be used as a basis for its quantitative estimation. Similar to other urea and guanidine derivatives it couples with aryldiazotates to yield arylazo substituted nitrodicyandiamidine, reacts with hydrazine hydrate to form N (1,1 bishydrazino) methyl N^1 nitrourea, and decomposes when formaldehyde is added to its aqueous alkaline solution. Also at elevated temperatures it undergoes rearrangement reactions. The formation of the N (1,1 bishydrazino) methyl N^1 nitrourea can be used for the identification of nitrodicyandiamidine. In one of a series of attempts to prove the structure of nitrodicyandiamidine by synthetic methods, the phenyl substituted nitrodicyandiamidine was prepared.

Acknowledgement.

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The importance of a flashless propellant is self evident even to the non military man, especially so in night combat. Just after the last "Great War" it was found that nitroguanidine, a previously known compound of only academic interest had an explosive power equal to T.N.T. Furthermore it had the exceptional property of exploding with a cool flame, and hardly any visible flash (1). When this compound was incorporated with nitrocellulose and nitroglycerine, the resulting cordite was found to possess both the cool explosion temperature of nitroguanidine and the same propellant power of ordinary cordite.

But picrite, as nitroguanidine is industrially called, crystallizes out of the reaction mixture in large crystals and is difficult to incorporate uniformly with ordinary cordite. This presented the problem of either improving the picrite or of finding a substitute for it. It was during the investigation of the latter proposal that nitrodicyandiamidine was proposed as a substitute for it. This compound previously reported in the literature (2)(3) has been thoroughly studied both from the technical and ballistic points of view by the Department of Munitions and Supply and has been found to fulfil all the specifications required of flashless cordite. Furthermore, it is prepared from the same primary products as that used for picrite, by a much simpler process with a production cost of less than one third the cost of picrite. It also possesses many of the desired properties of bulk and crystal structure which are lacking in the latter.

Thus several tons were prepared industrially for large scale tests. This preparation was carried out in vats which had previously been used for dye production and thus the crystalline product was yellow in colour instead of the white crystals which are described in the literature. Also the product obtained did not appear to be of uniform purity. Therefore a request was made for the developement of a quantitative method for the estimation of nitrodicyandiamidine.

In conjunction with this problem an attempt was made to prove the structure of nitrodicyandiamidine. Although many methods were tried with this objest in mind, none of them were successful. But in the course of these studies, several reactions of nitrodicyandiamidine which up to now have been unknown, have been elucidated. Thus the first part of the theses will deal with the study of the reactions of nitrodicyandiamidine.whose chemical formula is written as follows:-

$$NH_2.C(NH)NH.CO.NH.NO_2$$

From an examination of its chemical structure it can be seen that this compound can undergo three types of chemical reactions.

(1). The reactions of the nitramide group

(2). The reactions of an amido group of the guanidine and urea series

(111). The reactions of the "Urea Dearrangement."(4)

The second part will discuss the attempts to prove the structure of nitrodicyandiamidine.

HISTORICAL INTRODUCTION

The Chemistry of Nitro Derivatives

(a). Nitroparaffins

The nitroparaffins were first prepared by Victor Meyer (5) by replacing a halogen atom by a metallic nitrite. His method was to heat an alkyl halide with silver nitrite. In the case of methyl iodide the product is almost entirely nitromethane (I) but in all other cases the isomeric alkyl nitrite RONO is formed as well.

$$CH_3I + AgNO_2 \longrightarrow CH_3NO_2 + AgI \qquad \underline{I}$$

These compounds are insoluble in water, and are slowly soluble in sodium carbonate, from which the free compound can be obtained by acidifying with dilute acid, or by passing through carbon dioxide gas. The fact that they cannot be recrystallized from sodium carbonate solution by diluting with water conveyed to Victor Meyer the idea, that the solubility of the nitroparaffins in base is due to salt formation, which, in turn, is due to the acidic properties of the nitro group.

It was evident that primary and secondary aliphatic nitro compounds differ from the aromatic and tertiary ones by having a hydrogen attached to the same carbon atom as the nitro group. The explanation offered by Victor Meyer was that the highly negative nature of the nitro group renders the hydrogen attached to the same carbon atom acidic, but that its influence does not extend over to the next carbon atom. His evidence (6) for this theory was, that the tertiary substituted carbon atoms were not acidic, and even though the monobromo compounds $RCHBrNO_2$ were stronger acids than the unsubstituted ones, the dibromo compounds, $RCBr_2NO_2$ did not exhibit any acidic properties at all, and were neutral.

The sodium salt of these nitro derivatives can be isolated by treating an alcoholic solution of the nitro compound with sodium ethoxide, or with sodium hydroxide in methanol. It crystallizes out with one molecule of alcohol in which form it is fairly stable (5).

It explodes upon heating, and it is unstable in water in which it decomposes very readily giving off heat. The potassium salt can be prepared in the same manner as the sodium salt. From a water solution of the alkali metal salts the insoluble mercury, silver, copper, iron, lead and barium salts can be prepared. Similar metallic derivatives can be obtained from secondary nitro paraffins, and from the monobromo substituted compounds (5).

As the acidic properties of these nitro derivatives were thought to be due to the hydrogen attached to the same carbon atom as the nitro group, Victor Meyer reasoned that the sodium atom was attached to this carbon atom, and thus gave the following structure (11) for these sodium salts (5).

$R.\overset{Na}{CH}.NO_2$ or $R_2\,\overset{Na}{C}.NO_2$ II

Victor Meyer's theory was challenged by Nef who made the following observations (7).

I. Although the sodium salt behaves as though it were derived from a strong acid, the free nitro compound exhibits no acidic properties and only dissolves in caustic alkali quite slowly.

II. Upon acidification of the sodium salt by either hydrochloric or sulfuric acid an aldehyde (III) or ketone (IV) is obtained.

$$2RCH.NO_2Na + 2HCl \longrightarrow 2RCHO + N_2O + 2NaCL \qquad \underline{III}$$

$$2R_2C.NO_2Na + 2HCl \longrightarrow 2R_2CO + N_2O + 2NaCl \qquad \underline{IV}$$

Thus Nef suggested, that the salt is derived from a tautomeric form of the nitro compound (V) for which he proposed the following structure.

$$RCH_2NO_2 \rightleftharpoons RCH{=}N\begin{matrix}\nearrow OH\\ \searrow O\end{matrix} \qquad \underline{V}$$

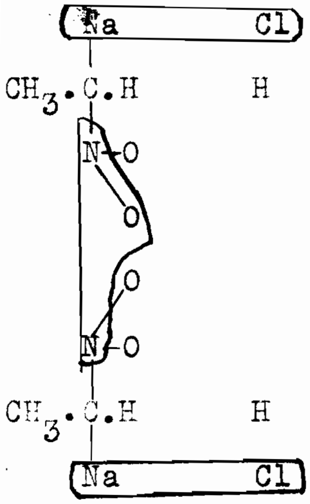
or

$$R_2CHNO_2 \rightleftharpoons R_2C{=}N\begin{matrix}\nearrow OH\\ \searrow O\end{matrix} \qquad \underline{V}$$

It was from this tautomer that the sodium salt (VI) was formed.

$$RCH.NO.OH + NaOH \longrightarrow RCH.NO.ONa \qquad \underline{VI}$$

Although Nef's theory was criticized by Meyer who showed that his formula could also give rise to aldehydes or ketones (VII) (8)



$$\longrightarrow 2CH_3CHO + N_2O + H_2O + 2NaCl \qquad \underline{\text{VII}}$$

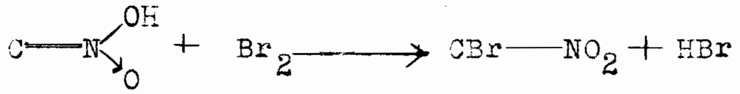
support for Nef's views was rapidly forthcoming.

It was found by Holleman (9) that p-nitrophenylnitromethane gave a yellow sodium salt. When a dilute aqueous solution of this salt is treated with an equivalent amount of hydrochloric acid, the yellow colour does not immediately disappear but on the contrary, depending on the concentration, it fades slowly and disappears after a few minutes. Also, the conductivity of this yellow salt is greater than can be explained by its sodium chloride content. On standing, the colour disappears and the conductivity falls to that of sodium chloride. This shows that the first effect of adding the mineral acid is to produce a yellow acidic compound, which in time goes over to the colourless non-dissociated nitro compound. Hence, the salt must be derived not from the ordinary non acidic, non conducting compound, but from a more acidic tautomer.

Almost immediately these two forms were isolated in two cases (10). If carbon dioxide gas is passed into an aqueous sodium hydroxide solution of phenylnitromethane, an oil, which is the true nitro form, separates slowly. But, if to the ice cold solution a mineral acid is added, a white crystalline solid is precipated which, when rapidly heated, melts at 84°. Both compounds were shown to have the same molecular weights and composition. On standing, the solid tautomer changed into the ordinary liquid form.

With p-bromophenylnitromethane the two isomers, similarly obtained, are both solids. The nitro form melts at 60°, and the isonitro at 89-90°.

Both compounds exhibit different solubilities and reactions. The true nitro form is only slowly soluble in caustic alkalis, gives no colour with ferric chloride, and forms no salt with dry ammonia in a solution of dry benzene. The aci form is a strong acid, which dissolves immediately in aqueous sodium hydroxide or sodium carbonate. It gives a brown red colour with ferric chloride, and forms salt with dry ammonia. It also reacts with bromine (VIII).



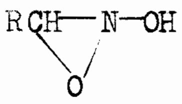
$$C{=}N(OH)(\rightarrow O) + Br_2 \longrightarrow CBr{-}NO_2 + HBr \qquad \text{VIII}$$

The presence of an active hydrogen in the acidic tautomer is shown by the fact that it reacts with phenylisocyanate and yields methane when treated with methylmagnesiumiodide.

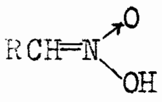
In both cases the acidic tautomer reverts to the true nitro form upon standing (11). As a class, these acids were called pseudo acids because here ionization and neutralization proceed at a much slower rate than with ordinary acids.

This difference in rates of protolytic transfer has been employed by Hantzsch (12) to differentiate between a pseudo acid, where salt formation is a function of time, and a true acid where neutralization is essentially instantaneous. He states further that, "If the salt formation is a function of time, then it is evidence that the molecule undergoes a change in the salt formation process; it is also evidence for the fact that the undissociated substance and its ions are constitutionally different."

Two structures have been proposed for the acidic tautomer (IX) (X).



IX



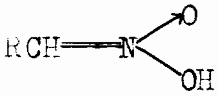
X

Formula (IX) has been put forward by Hantzsch since it was his belief that this structure was analogous to certain oxime derivatives (10). This structure has always been regarded as a possibility, but never received general acceptance chiefly because the existence of such carbazoxy rings has not been absolutely established. Furthermore, it was noticed that an isonitro compound readily reverts to the true nitro form on standing and this seems hardly compatible with a structure in which the carbon and oxygen atoms are united by a covalency link. Also, this structure does not satisfactorily explain the ready conversion of the salts into the bromo nitro compounds.

Thus this formula was later abandoned by Hantzsch (13).

Formula (X) has been proposed by Michaels (14) and represents the structure which is generally accepted today. Thus, after Hantzsch's experiments, it was generally accepted that primary and secondary nitro compounds can exist in two tautomeric forms (XI) (XII).

RCH_2NO_2



XI — nitro tautomer

XII — aci or isonitro tautomer

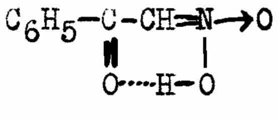
In order to study the various factors which affect the equilibrium between the aci and nitro form, a method had to be obtained by which the amount of one isomer could be estimated in the presence of the other. The fact that the aci form reacted instantaneously with bromine at room temperature, (11), while the true nitro compound did not, was used by Meyer and Wertheimer as a method for estimating the amount of the aci form (15). Utilizing this method, the following factors were found to influence the equilibrium:-

1. The effect of solvents on the equilibrium is known to be dependent on the relative solubilities of the two tautomers in the solvent. This relationship is given by the van't Hoff-Dimroth relation. i.e., if one form (A) is more soluble than the other (B) in one solvent, but less soluble in a second solvent, then on going from the first solvent to the second, the equilibrium will shift in favor of (B) (16). It therefore follows

from this relationship that the position of the equilibrium is affected by solvents and by substituent groups (which affect the solubility of a compound).

Thus in hydroxylic solvents, especially so in aqueous methyl alcohol, the equilibrium of the aci form of p-nitrophenylnitromethane is higher than in hydrocarbon solvents. This is in agreement with the fact that a hydroxylic substance, such as the aci form, would be expected to show a greater solubility in hydroxylic solvents than the isomeric true nitro form, and an abnormally small solubility in hydrocarbons. In pyridine, 16% of p-nitrophenylnitromethane exists as the aci form.

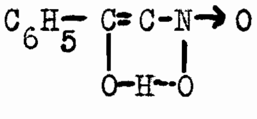
Nitroacetophenone shows the opposite behaviour. In toluene there exists 10.3% of the aci form at equilibrium, and in aquous methyl alcohol only 2.7%. Thus, with the nitroketone the relative solubilities are exactly the reverse of p-nitrophenylnitromethane, and the aci form does not behave as a hydroxylic solute. The reason for this behaviour is that a six membered chelated ring can be formed between the hydrogen atom of the hydroxyl group (XIII) (XIV) and the oxygen atom of the carbonyl group.



$$\begin{array}{l} C_6H_5-C-CH=N\rightarrow O \\ \qquad\quad\;\; \| \qquad\quad | \\ \qquad\quad\;\; O\cdots H-O \end{array}$$

XIII

or



$$\begin{array}{l} C_6H_5-C=C-N\rightarrow O \\ \qquad\quad\;\; | \qquad\;\; | \\ \qquad\quad\;\; O-H\cdots O \end{array}$$

XIV

The structure of the chelated ring can be represented by either of these formulae. The first is an aci nitro compound with a hydrogen bond to the ketonic oxygen atom of the nitro group (XIV), and the second, an enol with the hydrogen bond to the oxygen atom of the nitro group. Thus, Meyer (15) found it impossible to decide whether the acidic tautomer was due to the aci form of the nitro group, or to the enolic form of the ketone group. According to the resonance theory this difficulty does not exist since both formulae are identical. Hence, when the nitro ketone is treated with diazomethane, both esters are formed. The enol is converted into its methyl ester (XV) and the aci nitro form gives its ester derivative (XVI) (17).

$$C_6H_5COH:CHNO_2 + CH_2N_2 \longrightarrow C_6H_5COCH_3:CHNO_2 \qquad \underline{XV}$$

$$C_6H_5COCH:NO_2H + CH_2N_2 \longrightarrow C_6H_5COCH:NOOCH_3 \qquad \underline{XVI}$$

The latter comprises about two thirds of the total product.

2. The rate at which the aci tautomer of a nitro compound changes into the true nitro form, is affected to an enormous extent by traces of acids and bases which act as catalysts. This was most clearly shown by Lowry and Magson (18) (19) with nitrocamphor. As nitrocamphor is optically active, the two tautomers can be conveniently followed in the polarimeter. Hence, it was observed that in carefully purified benzene, twelve days were required for 99.5% change of the aci to the nitro form. The time

necessary is halved if piperidine is added in a concentration of $\frac{N}{10^7}$. If the piperidine concentration is raised to $\frac{N}{10^4}$, the the period is ten minutes. Traces of alkali from glass have an enormous effect, as one solution gave a period of sixty-six days in glass and six years in silica. The result of this effect, is that the addition of a trace of an acidic substance to a solution in a glass vessel reduces the rate of change because it neutralizes the alkali from the glass. The further addition of acid accelerates the change as the acid itself can act as a catalyst. It was abserved that in chloroform with $\frac{N}{1000}$ trichloracetic acid the rate of change was infinitely slow, while the period for $\frac{N}{100}$ acid was five and one half hours, and for one tenth normal acid, thirty-three minutes.

The rate of change of the aci into the nitro form can be measured by Meyer's titration method (20) and by conductivity methods, taking advantage of the fact that the aci tautomer is an electrolyte and the nitro form is not (10) (21) (22).

The first kinetic studies of the isomerization of nitroparaffins were carried out by Hantzsch and Ley (23). They have postulated that the primary and rate determining step in the neutralization of a nitroparaffin by a base is the isomerization of the nitro to the aci form with subsequent rapid neutralization of the latter (XVII).

$$RCH_2NO_2 + B \xrightarrow[k_1]{} RCH{:}NOOH + B \xrightarrow[k_2]{} RCH{:}NOO^- + BH^+ \qquad \underline{XVII}$$

and $k_1 \ll k_2$. In this mechanism the sequence of transformation is nitroparaffin → undissociated aci acid → aci ion.

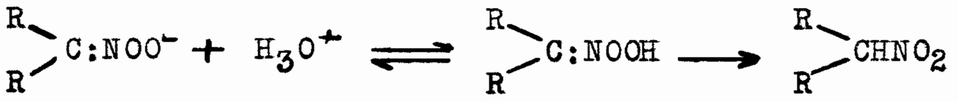
However, Pedersen (24) has shown that this view is inconsistent with present ideas of acid-base catalysis as outlined by Brönsted (25). The isomerization of a nitroparaffin must be considered as a prototropic process, and as such it cannot take place spontaneously, but must involve the intermediary of an acid or basic catalyst. In conformity with this view he actually found the isomerization of nitromethane to the aci form to be a reaction subject to general base catalysis. He consequently postulated as the mechanism of neutralization (XVIII)

$$RCH_2NO_2 + B \xrightarrow[k_1]{} R\overset{-}{C}HNO_2 + BH^+ \xrightarrow[k_2]{} RCH{:}NO_2^- + BH^+ \qquad \underline{XVIII}$$

i.e. the nitro form donates a proton to the base, and the residue is converted rapidly by an electron shift to the ion. Thus $k_1 \ll k_2$ and is rate determining. The aci ion may associate under the proper conditions to form the aci acid. In this scheme the sequence is nitroparaffin → aci ion → aci acid.

Pedersen's formulation of the mechanism of isomerization of the nitroparaffins has been accepted by Junell (26)(27), Wynne-Jones (28), Reitz (29), and Maron and La Mer (30).

The mechanism of regeneration of nitroethane from the aci form was first proposed by Ley and Hantzsch (23), to proceed according to the scheme (XIX).



$$ {}^{R}_{R}\!>C{:}NOO^{-} + H_3O^{+} \rightleftharpoons {}^{R}_{R}\!>C{:}NOOH \longrightarrow {}^{R}_{R}\!>CHNO_2 \qquad \underline{\underline{XIX}} $$

However Junell (27), studied the kinetics of this reaction at a later date and he found that the reisomerization of aci-nitroethane proceeds through the nitroethane ion rather than the undissociated acid according to (XX).

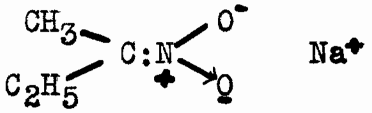
$$ CH_3CH{:}NOOH + H_2O \longrightarrow CH_3CH{:}NOO^{-} + H_3O^{+} \longrightarrow CH_3CH_2NO_2 \qquad \underline{\underline{XX}} $$

These results were later confirmed by Maron and La Mer (31).

The structure of the salts of nitro derivatives were studied by Kuhn and Albrecht (32), by investigating the effect of salt formation on optically active 2-nitrobutane. They observed that if excess sodium hydroxide was added to an alcoholic solution of the optically active nitro compound, the resulting sodium salt was inactive. If the alkali was not in excess, there was an activity due to incomplete salt formation. If however, a methyl alcoholic solution of sodium or potassium hydroxide was added, then an optically active salt resulted. This activity could be shown to be due to the salt of the nitro compound, since the optically active nitro compound could be regenerated from it.

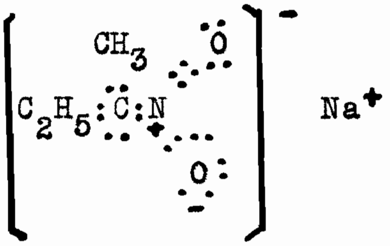
These results were confirmed by Schriner and Young with a different optically active nitro compound, 2-nitrooctane (33), and by Mills (34), who resolved phenylcyanonitromethane, and converted it into the active sodium salt.

It was pointed out by Kuhn (32), that according to the classical structure of the aci sodium salt, no optically active salt is possible as it contains a double bond (XXI).



XXI

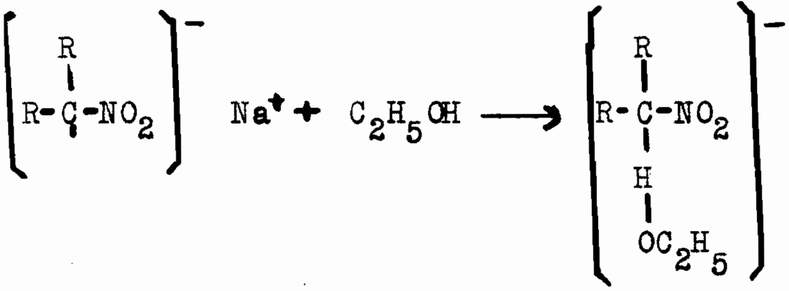
Therefore, it was assumed that the aci compounds can exist in another form which give optically active salts. Kuhn proposed the following structure to represent the other aci form(XXII).



XXII

The presence of two forms of the aci tautomer is in agreement with the experiments of Branch and Deelman (22). They studied the change in conductivity which takes place on the addition of hydrochloric acid to the sodium salt of the aci nitro derivative. They noticed an abnormal conductance drop at the start, followed by a slow gradual drop for the conversion of the greater part of the aci nitro salt back to the normal nitro form.

Hence, the experimental data on the conductivity and optical activity of the salts indicate the presence of two different forms of the negative ion in solution. The chief objection to such an assumption, is the fact that racemization does not occur readily. This may be due to the stabilization of the aci form by combination with the solvent (the anion forming a hydrogen bond with the ethanol)(XXIII).



$$\left[\begin{array}{c} R \\ | \\ R{-}C{-}NO_2 \end{array}\right]^- Na^+ + C_2H_5OH \longrightarrow \left[\begin{array}{c} R \\ | \\ R{-}C{-}NO_2 \\ | \\ H \\ | \\ OC_2H_5 \end{array}\right]^- Na^+$$

XXIII

This explanation is supported by the fact that some sodium salts retain a molecule of alcohol in the solid state (5) (33).

(B). Aliphatic Nitramines

The aliphatic nitramines were first prepared by Franchimont by passing ammonia gas through a solution of N-alkylnitrourethane(XXIV)(35).

$$CH_3N(NO_2)COOCH_3 + 2NH_3 \longrightarrow NH_2COOCH_3 + CH_3N{:}NOONH_4$$

$$CH_3N{:}NOONH_4 \longrightarrow CH_3NHNO_2 + NH_3 \qquad \underline{\underline{XXIV}}$$

The primary nitramines are acidic like the primary and secondary nitroparaffins. Their aqueous solution turns blue litmus red. They also form lithium, sodium, potassium, copper, barium, zinc, nickel and cobalt salts. A solution in water of the potassimm and sodium salts reacts basic to litmus (36).

(C) Nitro Derivatives of the Urea Series

The nitrocompounds of the urea series are nitramides and contain the typical structure - $NH - NO_2$. The general procedure for their preparation consists in treating the parent compound at temperatures close to 0°C with either (a) fuming nitric acid (b) a mixture of concentrated sulfuric or nitric acids or (c) treating the nitrate salt of the derivative with concentrated sulfuric acid.

The mechanism through which nitration occurs would appear to be; first, the formation of the nitrate salt, then the dehydration of this salt by either sulfuric or fuming nitric acid. Although this has been the generally accepted mechanism, it does not explain all the known facts concerning the nitration of these compounds.

The introduction of an alkyl group into the guanidine (or urea) molecule would be expected to increase the basicity of the nitrogen and hence that of the whole molecule. If nitration occurs through salt formation, then the nitro group should be attached to the same carbon atom as the alkyl group. But this is found to be contrary to most of the experimental evidence since further investigation of alkylated ureas, guanidines and biurets (37)(38)(39) has shown that when a nitro derivative of these compounds has been formed by direct nitration, the nitro group entered the non-alkylated amino group. There is one exception and that is methyl urea which forms N nitro

N methyl urea (40). It would then appear that generally the nitro group may enter only the non alkylated amino group. This is further substantiated by the fact that N,N^1 di alkyl ureas and guanidines cannot be nitrated at all.

From all this data, Davis has concluded that the mechanism of nitration in this series is not necessarily the dehydration of the nitrate salt and suggests that the basicity of urea, guanidine, biuret and their alkyl derivatives, is distributed through the molecule as a whole. This is substantiated by the fact that both urea and guanidine can exist in many resonating forms, and in the case of guanidine, its strength as a base is partially due to resonance. Thus, mono methyl and N,N dimethylguanidine are slightly weaker bases than guanidine itself, while N,N^1 di alkyl guanidines are weak bases. Pauling has been able to explain this through the consideration of the effect of the substituents on resonance (41). It is because of resonance in the guanidine and urea molecules that no simple mechanism can be formulated for the formation of its nitro derivatives.

Nitrourea is prepared by treating the nitrate salt with cold concentrated sulfuric acid (42)(43)(44)(45). It is nearly four times as strong an acid as acetic acid and like other nitro derivatives, it forms potassium, silver, mercury and ammonium salts. Its potassium salt reacts neutral in aqueous solution (42).

The reduction of nitrourea to semicarbazide takes place quite readily and is carried out industrially by means of an electrolytic process (46). This reduction can also be accomplished with ammonium amalgam (47) and with zinc in acidic media (43).

Free nitroso urea is not known but on the reduction of nitrourea with zinc and sodium hydroxide at low temperatures Thiele obtained for a short period of time a positive test for a nitroso group (a red colour with a ferrous sulfate solution) (42). This colour rapidly disappears indicating that the nitroso compound is too unstable and decomposes very readily. The methyl substituted nitrosourea derivative (N nitroso N methylurea) can be prepared by dissolving the methylurea in dilute sulfuric acid and then adding sodium nitrite at a low temperature (49).

N nitro N methylurea cannot be prepared by the direct methylation of nitrourea. This was observed by Thiele who found that methyliodide had no effect on the potassium salt of nitrourea (42). Diazomethane was then used as the methylating agent, but this reagent caused the decomposition of the nitrourea (42)(XXV).

$$NH_2CO.NHNO_2 + CH_2N_2 \longrightarrow HNCO + NH_2NO_2 \qquad \underline{XXV}$$

Nitrobiuret which is formed in the same manner as nitrourea also exhibits acidic properties. Its potassium salt like the potassium derivative of nitrourea reacts neutral (50).

Nitroguanidine is prepared from its nitrate salt by the action of cold concentrated sulfuric acid (51)(52)(53)(54)(55)(56)(57)(58). It exhibits both acid and basic properties. It is soluble in basic solutions, from which it can be reprecipitated by passing through carbon dioxide gas. It forms both hydrochloric and nitric acid salts from hot concentrated hydrochloric and nitric acid solutions (53).

It can be reduced to both the nitroso and the amino derivative. The reduction to the nitroso derivative can be carried out with zinc and sulfuric acid (53), zinc and ammonium chloride (58) and by catalytic hydrogenations over Adams platinum (59) and over Raney nickel catalyst (60). The amino derivative can be prepared from nitroguanidine by reducing with zinc and acetic acid (53)(61)(62).

(D). Nitrodicyandiamidine

Nitrodicyandiamidine was first prepared by Thiele by the action of concentrated sulfuric acid and nitric acids on dicyandiamide at -4° C with a 95% yield (XXVI)(2).

$$NH_2C(NH)NHCN + HNO_3 \xrightarrow{H_2SO_4} NH_2.C(NH)NH.CO.NH.NO_2 \quad \underline{XXVI}$$

It can also be obtained by the action of (i) mixed acids on the sulfonic acid of dicyandiamidine (63) (ii) of fuming, and of dilute nitric acid on dicyandiamide (64). It is insoluble in water, ethanol, ether, (2) benzene, carbondisulfide, carbontetrachloride, chloroform, petroleum ether, acetone, acetic acid, aniline, pyridine, dioxane, ethyl acetate (65), formamide and liquid ammonia. It is soluble in alkaline solutions from which it can be reprecipitated by acidifying with mineral acids or with carbon dioxide gas. It is also soluble in concentrated mineral acids and in warm aqueous sodium carbonate (2). Like other nitro derivatives, it forms a silver salt when silver nitrate is added to nitrodicyandiamidine-sodium hydroxide solution.(2). It can be reduced to aminodicyandiamidine with zinc and hydrochloric acid. (2) (66).

Reactions of The Amido Group of The Urea and Guanidine Series

(A). With Aromatic Diazotates

The coupling of aromatic diazotates with dicyandiamide was discovered by Walther and Greishammer (67). This coupling occurs in the following manner:-

An ice cold solution of an aromatic diazomium chloride is added to an equivalent amount of dicyandiamide dissolved in water. This solution is made basic with a small excess of aqueous sodium hydroxide whereby the colour of the solution changes from yellow to red. After about thirty seconds the solution becomes turbid and it is then acidified with dilute hydrochloric acid. This causes the precipitation of the aliphatic-aromatic diazo amido compound. The precipitate is collected on a filter but here only part of the reactants undergo the coupling reaction. It is necessary to repeat the process of alkalination and acidification of the filtrate several times in order to obtain the full yield of product. No satisfactory explanation has been proposed for the fact that the full yield of the product is not obtained upon the first alkalination and acidification. The reaction between dicyandiamide and the diazotate was represented to occur in the following manner (XXVII).

$$NH_2C(NH)NHCN + C_6H_5N{:}NONa \longrightarrow C_6H_5N{:}NNNa.C(NH)NHCN + H_2O$$

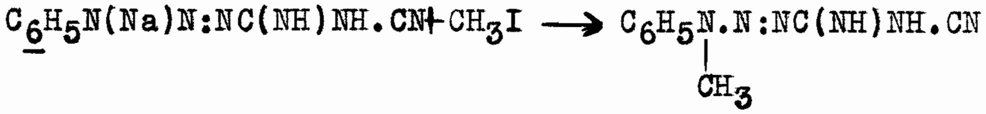
$$C_6H_5N{:}NNNa.C(NH)NHCN \longrightarrow C_6H_5N{:}NNH.C(NH)NHCN$$ XXVII

phenylazodicyandiamide or

1 phenyltriazeno 2 cyanoiminoaminomethane

Following this procedure the o, m, p, tolulazo; p-chlor and p-bromo benzeneazo and o-carbonic acid benzeneazo derivatives of dicyandiamide were prepared.

These compounds are acids and form sodium and ammonium salts. The methyl derivative can be prepared by reacting the sodium salt with methyl iodide (XXVIII) or dimethylsulfate.

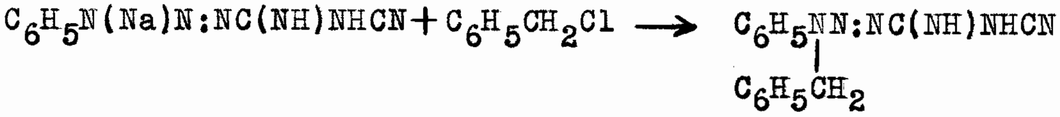


$$C_6H_5N(Na)N{:}NC(NH)NH.CN + CH_3I \longrightarrow C_6H_5\underset{\displaystyle CH_3}{\underset{|}{N}}.N{:}NC(NH)NH.CN$$ XXVIII

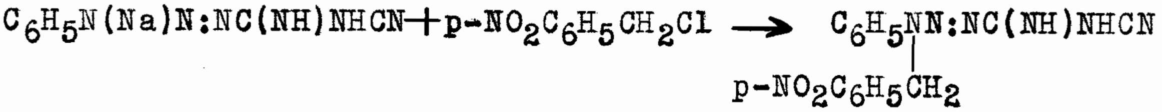
2 phenyl 2 methyltriazeno

1 cyanoiminoaminomethane

The benzyl and the nitrobenzyl derivative can also be prepared from the sodium salt by reacting it with benzyl chloride (XXIX) or with p-nitrobenzylchloride (XXX).

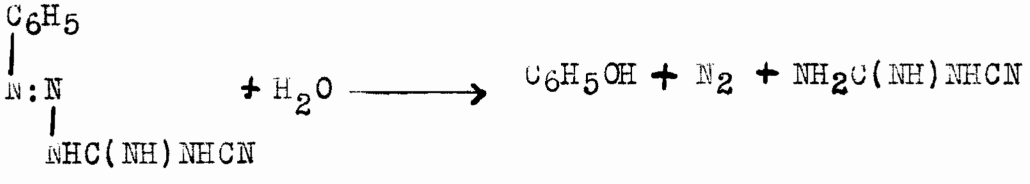


$$C_6H_5N(Na)N{:}NC(NH)NHCN + C_6H_5CH_2Cl \longrightarrow C_6H_5\underset{\displaystyle C_6H_5CH_2}{\underset{|}{N}}N{:}NC(NH)NHCN$$ XXIX



$$C_6H_5N(Na)N{:}NC(NH)NHCN + p\text{-}NO_2C_6H_5CH_2Cl \longrightarrow C_6H_5\underset{\displaystyle p\text{-}NO_2C_6H_5CH_2}{\underset{|}{N}}N{:}NC(NH)NHCN$$ XXX

These diazo compounds undergo two types of decompostion. One of the decompostions occurs when it reacts in the anti form (XXXI).

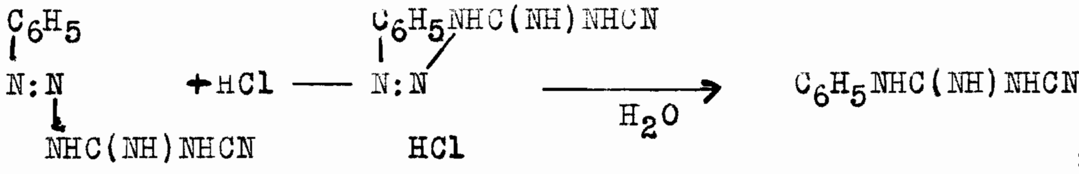


$$\underset{\text{NHC(NH)NHCN}}{\overset{C_6H_5}{N:N}} + H_2O \longrightarrow C_6H_5OH + N_2 + NH_2C(NH)NHCN$$

anti form

XXXl

and the other when it reacts in the syn form. (XXXll)



$$\underset{\text{NHC(NH)NHCN}}{\overset{C_6H_5}{N:N}} + HCl \text{ — } \underset{HCl}{\overset{C_6H_5NHC(NH)NHCN}{N:N}} \xrightarrow[H_2O]{} C_6H_5NHC(NH)NHCN$$

XXXll

syn form phenyldicyandiamide

In ethanol-hydrogen chloride solution the product of the decomposition of the syn isomer is hydrolysed to phenyldicyandiamidine (XXXlll).

$$\overset{C_6H_5NHC(NH)NHCN}{N:N} + H_2O \longrightarrow C_6H_5NH.C(NH)NH.CONH_2$$

XXXlll

syn form phenyldicyandiamidine

Decomposition (XXXl) occurs when the diazo compound is boiled with water or with dilute sulfuric acid. In order to explain the two different types of decompositions, this type of reaction is said to occur from the anti form which is the more stable of the two.

Decomposition (XXXll) occurs when the hydrogen chloride salt, which has been formed by passing hydrogen chloride gas through a suspension of the diazo compound in ether, is gently heated with water.

Decomposition (XXXIII) occurs by heating the diazo compound with dilute hydrochloric acid, with a solution of hydrogen chloride in absolute ethanol, or with a solution of hydrochloric acid in 95% ethanol.

By the application of these decompositions the phenyl; p-chloro and p-bromo benzene; o, m and p-tolyl; and o-benzoic acid dicyandiamidine; phenyl, m and p-tolyl, p-chloro and bromo dicyandiamide derivatives were prepared.

The structure of these compounds was proven by synthesizing phenyldicyandiamide following the procedure outlined by Wheeler and Jamieson (68), and hydrolysing it to phenyldicyandiamidine.

(B). With Hydrazine Hydrate

Hydrazine hydrate reacts with urea and guanidine and its derivatives by replacing an amido and, or imido group by a hydrazino or a hydrazono group. The products obtained depend upon the proportions used and the temperature at which the reaction is carried out,since certain conditions may cause cyclization of the products.

When equivalent amounts of urea and hydrazine hydrate are heated, semicarbazide and hydrazodicarbonamide are formed (69)(70). When guanidine is treated with hydrazine hydrate the product is triamino guanidine (71). The product with dicyandiamide depends upon the temperature and the proportions used. When dicyandiamide is treated with hydrazine hydrate, aminodicyandiamidine, aminobiguanide; amino, diamino and triamino guanidine can be obtained depending on the reaction condition (72). These products may cyclise to give cyclic compounds (73). Similarly biuret gives aminobiuret and other dearrangement products (72).

(C) With Formaldehyde

The general reaction between formaldehyde and an amido group entails the formation of methylolamines. These are unstable and lose water forming higher products derived from the corresponding methyleneamines (XXXIV)(74).

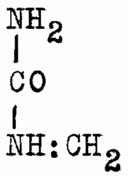
$$RNH_2 + CH_2O \longrightarrow RNHCH_2OH$$

$$xRNHCH_2OH \longrightarrow \{R\text{-}N{:}CH_2\}x + xH_2O \qquad \underline{XXXIV}$$

Thus the first condensation products of urea and formaldehyde were isolated as resins. But monomethylol urea can be prepared from a neutral solution of urea and formaldehyde (XXXV)(75).

$$NH_2.CO.NH_2 + HCHO \longrightarrow NH_2CO.NH.CH_2OH \qquad \underline{XXXV}$$

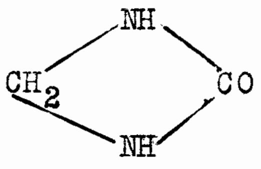
If this addition is made at an acidic pH a high molecular weight product is obtained (75). A different substance has been obtained from the same materials by Halzer (76) and by Ludy (77)(78) in the form of methylene urea. This compound can be represented in two different ways, namely (XXXVI)(XXXVII).



$$NH_2\text{-}CO\text{-}NH{:}CH_2$$

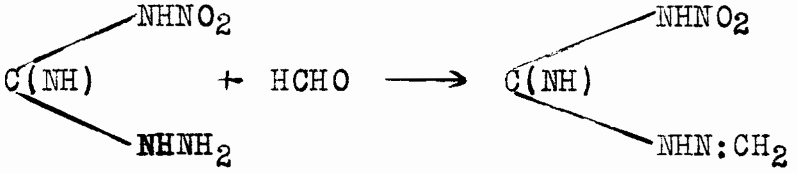
XXXVI

and



XXXVII

Nitroguanidine undergoes a condensation with formaldehyde similar to that of urea. This was observed by Bowen (79) in the polymerization of nitroguanidine and formaldehyde, when the methylol derivative of nitroguanidine was isolated. A similar reaction was observed by Phillips and Williams with N nitro N^{I} aminoguanidine. In this case the methylene derivative was isolated (80)(XXXVIII).



XXXVIII

Dicyandiamide also undergoes a similar condensation to form methyloldicyandiamide (81)(82).

The Urea Dearrangement

The conversion of the cyanates of ammonia and primary amines to urea and substituted ureas by the evaporation of their aqueous solutions has long been known as examples of the "Urea rearrangement." This type of reaction is best exemplified in Wohler's preparation of Urea (83)(XXIX).

$$NH_4OCN \longrightarrow NH_2.CO.NH_2 \qquad \underline{XXXIX}$$

This reaction can proceed along two lines. (I). The cyanic acid functions as an acid and the ammonia as a base in which case ammonium cyanate is first formed (XL).

$$NH_3 + HOCN \longrightarrow NH_4OCN \qquad \underline{XL}$$

(2). Cyanic acid reacts in its unsaturated character and an addition occurs of an amine type compound to the isocyanate linkage (XLI).

$$H.NH_2 + HN:C:O \longrightarrow NH_2CO.NH_2 \qquad \underline{XLI}$$

The latter mechanism portrays the addition of ammonia to isocyanic acid. This changes from the enol (or normal) to the keto (or iso) form, was postulated by Werner (84). This has been confirmed by recent Raman spectrum studies in which it was found that cyanic acid exists and reacts solely in its unsaturated character i.e. as isocyanic (85)(86).

Similar "Urea rearrangements" occur when isocyanic acid is treated with substituted amines or an isocyanate with ammonia. Two examples of this rearrangement are the preparation of methylurea from ammonia and methylisocyanate (87)(88).

Thus it can be said that the Urea rearrangement consists of two types of reactions;

(a) The reaction between a substituted amine and isocyanic acid (XLII).

$$R.NH_2 + HNCO \longrightarrow RNH.CO.NH_2 \qquad \underline{XLII}$$

(b) The reaction between a substituted isocyanate and ammonia (XLIII).

$$R.NCO + NH_3 \longrightarrow RNH.CO.NH_2 \qquad \underline{XLIII}$$

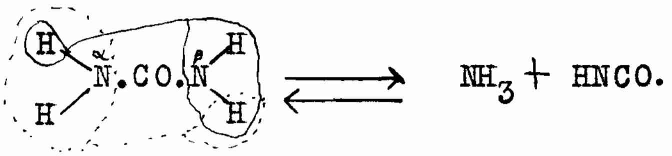
The Urea rearrangement can be applied to the formation of guanidine and thiourea and their derivatives. In the case of guanidine, cyanamide (89) is used instead of isocyanic acid, and in the case of thiourea, isothiocyanic acid is used (90).

The reverse of the urea rearrangement does also occur, and has long been known. As early as 1838 it was noted that a boiling aqueous solution of urea gave a precipitate of silver cyanate when silver nitrate was added to it (91)(92). Additional examples of this type of reaction were observed when urea was heated above its melting point. Here, certain compounds were formed in addition to biuret which could only result from the dry heating of ammonium cyanate (93)(94)(95). The implications of these reactions caused

Emil Werner to suggest that the "Urea rearrangement" represented a reversible system (84). Although Werner in his many publications has contributed greatly to the knowledge of the structure of the chemistry of the urea series, he failed to give a simple picture of the mechanism of reaction in this series:- one, which would explain the many apparent complex reactions which occur.

The first, and only, widely applicable theory that has been advanced was proposed by T. L. Davis (96). Davis named the reverse reaction of Urea rearrangement, the "Urea Dearrangement." (97). In his own words, the urea dearrangement "consists of the breaking apart of the urea derivative, (usually on heating) in such a way that the hydrogen, previously attached to one of the nitrogen atoms goes off in combination with the other, and the atoms or groups previously attached to it, deserting the rest of the molecule."

Thus, in the case of urea, a hydrogen attached to the α nitrogen goes off with the β nitrogen and the hydrogen attached to it forming ammonia and leaving isocyanic acid. In the same way, a hydrogen attached to β nitrogen can go off with the α nitrogen and its hydrogens to form ammonia and leave isocyanic acid (XLIV).

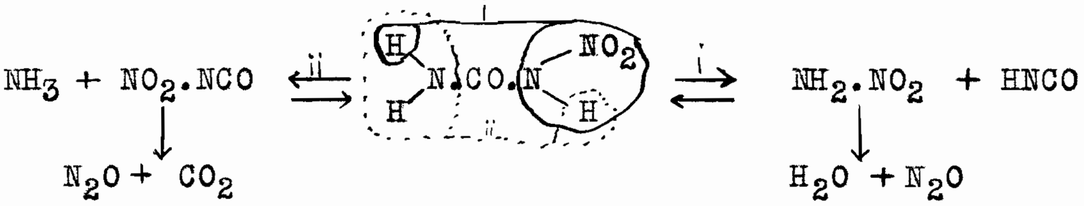


XLIV

It may be noted that the urea dearrangement may be looked upon as a reversible process. This has been found to be true. The urea, thiourea, and guanidine derivatives dearrange to yield smaller molecules which recombine to give other compounds (98). This theory has been found to apply to the reactions of urea, thiourea and guanidine; in fact to all the members of this series and their substituted derivatives.

The two compounds of mono-substituted urea which are of special interest are nitrourea and nitroguanidine. Davis has made a detailed study of these compounds and has found that the introduction of a nitro grouping into the molecule of the urea series greatly increases its tendency to dearrange (98)(99).

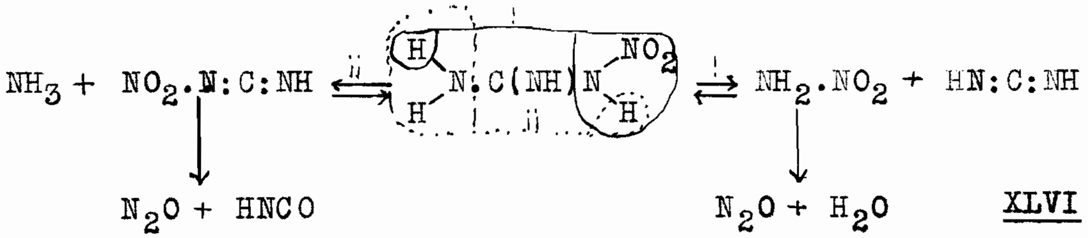
Nitrourea in boiling water dearranges in two ways (99), forming mainly isocyanic acid and nitramide (i), together with small amounts of ammonia and nitroisocyanic acid (ii)(XLV).



XLV

The ease with which nitrourea dearranges has caused Davis to suggest it as a ready source of isocyanic acid for synthesis. This method has the unique advantage, that all other compounds formed decompose into gases.

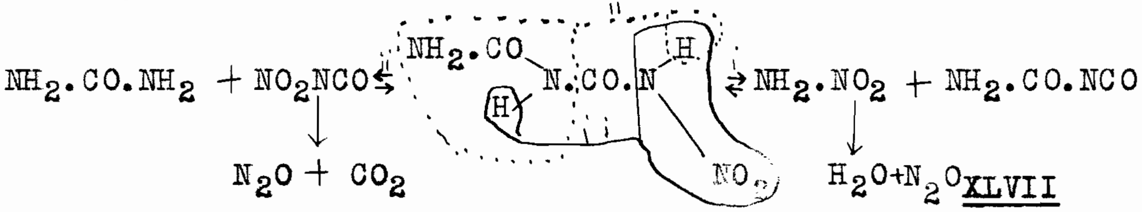
Nitroguanidine, on heating, dry or in aqueous solution dearranges along the same pattern (98) to yield nitramide and cyanamide by one mode, and ammonia and nitrocyanamide by the other (XLVI).



XLVI

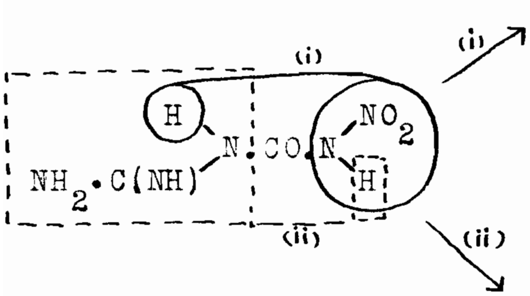
In cases where a urea derivative undergoes dearrangement in two modes--both reactions occur simultaneously. Although the velocity of one may be greater than that of the other, this system represents a reversible equilibrium reaction. For, if one of the decomposition products is removed from the system, by taking part in some reaction, the whole system shifts to reestablish the equilibrium; and thus, these dearrangements can be used to synthesize substituted urea or guanidine derivative in good yields. This has been illustrated by Davis who prepared alkylnitroguanidines in good yields (98).

Nitrobiuret has been found by Davis to behave like a symmetrical disubstituted urea and on dearranging, forms nitrous oxide, carbon dioxide, urea, and cyanic acid (100) (XLVII).



XLVII

Nitrodicyandiamidine differs from nitrobiuret only in having the oxygen atom furthest removed from the nitro group replaced by an imido group. Thiele (2) has reported that this compound dissolves in boiling water evolving carbon dioxide and nitrous oxide, and forming guanidine which can be recovered as the carbonate salt by evaporating the solution to dryness. A more detailed study of the decomposition (65) has shown the presence of isocyanic acid during the decomposition and that the final residue contains small amounts of ammeline. Thus the dearrangement can occur in the following manners (XLVIII), (XLIX).



$$NH_2.C(NH)NOC + NH_2.NO_2 \longrightarrow H_2O + N_2O$$

XLVIII

$$NH_2.C(NH)NH_2 + O:C:N.NO_2 \longrightarrow N_2O + CO_2$$

XLIX

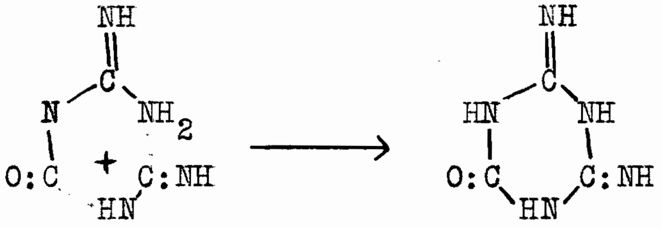
The experimental results of the decomposition of nitrodicyandiamidine in water indicates that dearrangement (XLVIII) occurs. The presence of guanylisocyanate can be proven by its reaction with ammonia to form dicyandiamidine. This reaction takes place when the decomposition is carried out in aqueous ammonium carbonate (L).

$$NH_2.C(NH)NCO + NH_3 \longrightarrow NH_2C(NH).NHCO.NH_2 \qquad \underline{L}$$

Furthermore, the decomposition of nitrodicyandiamidine gives rise to carbethoxy guanidine which can only be formed from guanylisocyanate (101)(LI).

$$NH_2.C(NH)NCO + C_2H_5OH \longrightarrow NH_2.C(NH)NHCO_2C_2H_5 \qquad \underline{LI}$$

The presence of the small amounts of ammeline can be explained by assuming that a partial decomposition of guanylisocyanate to cyanamide and isocyanic acid occurs. The undecomposed portion of the guanylisocyanate can then react with cyanamide to form small amounts of ammeline (65)(LII).



LII

When nitrodicyandiamidine is dearranged in concentrated ammonium hydroxide, in which it is partly soluble, carbon dioxide, nitrous oxide, urea and guanidine carbonate are formed. The presence of large amounts of urea can be explained by the dearrangement of the products of the primary dearrangement products. This can occur in either one of the following manners depending upon whether dearrangement (LIII) or (LIV) is followed.

$$NH_2 \cdot C(NH).NH.CO.NHNO_2 \longrightarrow NH_2C(NH)NCO + NH_2NO_2$$

$$NH_2.C(NH)NCO + NH_3 \longrightarrow NH_2.C(NH)NH.CONH_2$$

$$NH_2.C(NH)NH.CO.NH_2 \longrightarrow NH_2.C(NH)NH_2 + HNCO$$

$$HNCO + NH_3 \longrightarrow NH_2.CO.NH_2 \qquad \text{LIII}$$

or by considering dearrangement (LIV):-

$NH_2.C(NH)NH.CO.NH.NO_2 \longrightarrow NH_2.C(NH)NH_2 + NO_2.NCO$

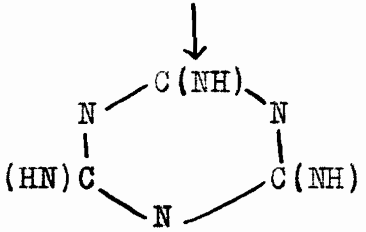
$NH_2.C(NH)NH_2 \longrightarrow HN:C:NH + NH_3$

$HN:C:NH \xrightarrow{H_2O} HNCO + NH_3$

$HNCO + NH_3 \longrightarrow NH_2.CO.NH_2$ LIV

In warm sodium hydroxide, nitrodicyandiamidine yields carbon dioxide, nitrous oxide, guanidine carbonate, isocyanic acid and ammonia. In warm dilute sulfuric acid the products are the same as in water except that melamine is formed as well as ammeline. In this case melamine can be formed from the polymerization of cyanamide (LV)(102)(103).

$HN:C:NH + HN:C:NH \longrightarrow NH_2.C(NH)NH.CN + NH:C:NH$



LV

A kinetic study of the rate of decomposition of nitrodicyandiamidine has shown that its rate of decomposition is dependent upon the ratio of nitrodicyandiamidine to water, and is not affected by either acid or base (104).

Reactions of Cyanamide

Cyanamide can exist and react according to its two tautomeric forms, the acidic or imide form NH:C:NH and the basic or nitrile form NH_2CN. Raman studies have shown the free form and various derivatives to have the nitrile structure. Instances of the imide form are also evident (105). When cyanamide is heated in the dry state it polymerizes to its dimer dicyandiamide and its trimer melamine (106)(107). This reaction also occurs in aqueous solution, but here there is a simultaneous hydrolysis of cyanamide to urea. The amount of this hydrolysis is dependent on the pH. In alkaline solutions (pH 12) cyanamide is quantitavely hydrolysed to urea while polymerization occurs in solutions of a pH less than 6 (108)(109).

Cyanamide reacts with ammonia and amines to form guanidine and substituted guanidines. Thus it reacts with hydroxylamine hydrochloride to give oxyguanidines (110); with methylamine hydrochloride to form methylguanidine hydrochloride (111). A similar reaction can be carried out with aniline hydrochloride (112)(113); with hydrazine hydrochloride (114)(115); and with guanidine to give biguanide (116). Cyanamide also adds to many amino acids to form guanidine derivatives (117), (118),(119), (120).

Though the reaction of cyanamide with amines is very well known, in no case has cyanamide been known to react with an amido group of the urea series of compounds.

This type of reaction was first attempted by Bauman. He attempted to form carbethoxy guanidine from urethane and cyanamide. This reaction was attempted in water, absolute alcohol, and by fusing the reactants. In all these cases cyanamide did not add to the urethane but dimerized to form dicyandiamide (121). Attempts to add cyanamide to urea also met with similar results.

Bauman's experiments were repeated by Pink and Blair in 1927 (122). In their investigation they attempted the synthesis of carbethoxy guanidine under the following conditions:-

Two moles of cyanamide + one mole of urethane

(a). at 150 in water.
(b). anhydrous ethanol at 170 .
(c). fusing of the reactants.

These reactions gave dicyandiamide, urea, guanidine carbonate, ammelide, ammonium hydroxide and unreacted urethane.

THEORETICAL DISCUSSION

Introduction

One of the objects of the experiments carried out in this laboratory was to find a method for the quantitative estimation of N.D.C.D. (In the following sections of this thesis nitrodicyandiamidine will be denoted by N.D.C.D.) It can be seen from the historical survey that little is known about the chemistry of N.D.C.D. which can be used as a basis for its estimation. In the experiments carried out in this laboratory advantage was taken of two of the known reactions.

1. The formation of the silver salt of N.D.C.D.
2. The solubility of N.D.C.D. in dilute alkaline solutions and its insolubility in both neutral and dilute acid solutions.

A. The formation of the silver salt of N.D.C.D.

1. Gravimetric Method. It was noticed by Thiele (2) that the silver salt of N.D.C.D. which was formed upon the addition of silver nitrate to a solution of N.D.C.D. in sodium hydroxide was colloidal in nature. This colloid tended to adsorb silver ions and thus it was found that the silver content of the salt did not agree with the calculated value.

By using equivalent amounts of sodium hydroxide and N.D.C.D., and by adding, with vigorous stirring, less than the equivalent amount of silver nitrate solution, a silver salt was obtained which analyzed for the silver salt of

N.D.C.D. But in order to dissolve all the N.D.C.D. and to insure the full precipitation of its silver salt an excess of both sodium hydroxide and silver nitrate is necessary. This excess of sodium hydroxide tends to cause the formation of silver oxide instead of the silver salt of N.D.C.D. After several experiments it was noticed that if the mode of addition was reversed and the N.D.C.D.-sodium hydroxide solution was added slowly and with stirring to the silver nitrate solution, there was no precipitation of silver oxide. This is probably due to the fact that the silver salt is less soluble than the silver oxide. Only after the formation of the salt is there an excess of silver ions and at that time the pH of the mixture is 7.5 which is too low for the formation of the silver oxide.

The second difficulty encountered was that the silver salt of N.D.C.D. formed a colloidal sol with the water present which was difficult to filter and to wash. This colloid adsorbed other ions and thus the yields obtained gave the "purity" of N.D.C.D. to be about 106%, e.g. three samples of N.D.C.D. were found to contain 45.07%, 45.9% and 47.7% of silver instead of the theoretical amount of 42.5%. Although various methods were tried it was found impossible to coagulate the sol and as this method gave erroneous results any further investigation of this method was abandoned.

2. Volumetric Method. As the silver salt of N.D.C.D. is very insoluble it was believed that a quantitative estimation could

be evolved by noting the change in the concentration of the silver ions during the formation of the silver salt. This was done by substituting a silver electrode for the glass electrode in a Beckman pH meter and by plotting the change in +M.V. versus the number of millilitres of standard silver nitrate.

This method gave the purity of N.D.C.D. to be about 91%. Previously, the same precipitation used as a gravimetric method for the estimation of N.D.C.D. gave the "purity" of N.D.C.D. to be about 106%. But in the gravimetric method there was an excess of silver ions during salt formation. The salt, which was colloidal, adsorbed the silver ions and thus gave high values. In the volumetric method there was always an excess of "N.D.C.D." ions during salt formation. As the salt here was also colloidal it adsorbed N.D.C.D. ions and hence gave low values. Conductivity measurements also gave an apparent value of about 91%. Thus, due to the colloidal properties of the silver salt of N.D.C.D., it was found impossible to base any quantitative method upon the formation of this salt.

(B) Formation of the Mercury, Nickel and Copper Salts of N.D.C.D.

These salts were prepared in the same manner as the silver salt. Like the silver salt they separate out of the solution as colloids and hence adsorb other ions. Thus it was found that the metallic contents of the salts varied with the conditions that is, with the initial amount of metallic salts added to the reaction mixture. Because of this property the metallic salts of N.D.C.D. cannot be used for the quantitative estimation of N.D.C.D. However they are interesting as possible contaminants during the manufacture of N.D.C.D., since under the proper conditions they may be formed as impurities. (LVI).

$$\mathrm{2NH_2C(NH)NH.CO.N{:}NO_2Na + Hg^+ \longrightarrow (NH_2C(NH)NH.CO.N{:}NO_2)_2Hg + Na^+}$$

$$\mathrm{2NH_2C(NH)NH.CO.N{:}NO_2Na + Ni^+ \longrightarrow (NH_2.C(NH)NH.CO.N{:}NO_2)_2Ni + Na^+}$$

$$\mathrm{2NH_2C(NH)NH.CO.N{:}NO_2Na + Cu^+ \longrightarrow (NH_2.C(NH)NH.CO.N{:}NO_2)_2Cu + Na^+}$$

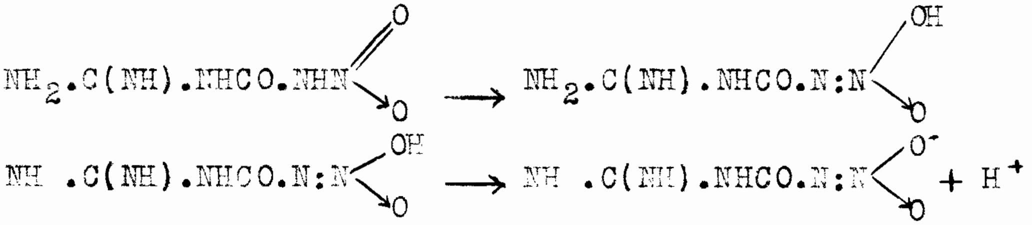
<u>LVI</u>

(C). Formation of the Sodium Salt of N.D.C.D.

As a class primary and secondary nitroparaffins have long been known as pseudo acids. This property is also exhibited by nitramines and nitramides; for example it is found that nitro urea is four times as strong an acid as acetic acid.

The fact, that N.D.C.D. which is a nitramide also exhibits acid properties was first mentioned by Caro (3). The evidence which he presented was that N.D.C.D. is soluble in alkaline solutions from which it can be reprecipitated with mineral acid or carbon dioxide. But the acidic character can be inferred from the fact that when N.D.C.D. is added to distilled water and the suspension well stirred, the pH of the system decreases (Table III, fig. 3.). This indicates that N.D.C.D. can exist in both nitro and aci forms. The presence of hydronium ions in a suspension of N.D.C.D.

and water is further demonstrated when sodium hydroxide is added to this suspension and the change in the conductivity denoted. Here the conductivity of the suspension decreases at first (Table IV and Fig. 4). This observation can only be explained by assuming that sodium hydroxide neutralizes the mobile protons. Thus N.D.C.D. can exist in the following tautomeric forms.



$$NH_2.C(NH).NHCO.NHN\left\langle\begin{matrix}O\\O\end{matrix}\right. \longrightarrow NH_2.C(NH).NHCO.N{:}N\left\langle\begin{matrix}OH\\O\end{matrix}\right.$$

$$NH\ .C(NH).NHCO.N{:}N\left\langle\begin{matrix}OH\\O\end{matrix}\right. \longrightarrow NH\ .C(NH).NHCO.N{:}N\left\langle\begin{matrix}O^-\\O\end{matrix}\right. + H^+$$

LVII

It has been previously mentioned that N.D.C.D. dissolves in alkaline solutions from which it can be reprecipitated by acidifying with dilute mineral acids or by carbon dioxide (2). It was this property of the nitro derivatives which led Victor Meyer to assume that the solubility of nitro compounds in alkali was due to salt formation. This same property of salt formation was demonstrated in N.D.C.D. by the observed changes in conductivity and pH.upon the addition of sodium hydroxide to an aqueous suspension of N.D.C.D. The buffer action revealed here (Table III and Fig. 3); and also when solutions of N.D.C.D. in sodium hydroxide were back-titrated with standard hydrochloric acid can only be explained by salt formation (Table V and VI, and Fig. 5 and 6).

It is found upon examination of the literature that the acidic strength of nitro derivatives depends upon the basic strength of the parent compound. Thus the nitroparaffins represent nitro derivatives of neutral compounds. It is therefore found that these nitro compounds are strong acids and their alkali salts are neutral. This corresponds to the neutralization of a strong acid with a strong base (7).

On the other hand, the nitramines typify nitro derivatives of weak bases. Thus these nitro derivatives are weaker acids than the nitroparaffins. This is noted from the fact that their alkali salts are basic (36), as are the salts which are formed from weak acids and strong bases.

Nitrourea, a nitramide, represents a nitro derivative of a compound which is a weak monoacid base. Thus, it is four times as strong an acid as acetic acid. Accordingly its potassium salt is neutral (42).

Nitroguanidine differs from nitrourea by having an amido group in place of the oxygen. It represents a nitro derivative of a compound, guanidine, which is nearly as strong a base as sodium hydroxide. Thus its nitro derivative exhibits both acid and basic properties (53).

N.D.C.D. as the nitro derivative of dicyandiamidine, is the nitro derivative of a compound which is a strong base, since dicyandiamidine adsorbs carbon dioxide from the air, and forms various acid salts. However, it is not as strong a base of guanidine. Thus N.D.C.D. is a weak acid and, as expected, an aqueous solution of its sodium or potassium salt reacts basic to litmus. It also differs from nitroguanidine by not forming any stable acid salts.

It has been mentioned in the historical section that N.D.C.D. is insoluble in water and in all common organic solvents, but it has been proven that a soluble sodium salt exists. Hence, when an alkaline solution of this sodium salt is back-titrated with standard mineral acid, there should exist equivalent amounts of N.D.C.D. and sodium hydroxide, that is, a quantitative amount of sodium N.D.C.D., just at the point where upon the addition of more acid the N.D.C.D. begins to reprecipitate out of the solution. Therefore, it was necessary to prove that even though an excess of alkali is necessary to dissolve the N.D.C.D., once the N.D.C.D. is in solution, it will remain in solution as long as there are equivalent amounts of N.D.C.D. and sodium hydroxide in the solution.

In an attempt to prove this, the following observations were made about the behaviour of N.D.C.D. in water and in aqueous alkali medium:-

1). When N.D.C.D. is added to water, it causes a lowering of the pH. This shows that N.D.C.D. ionizes in aqueous medium (Table III, Fig. 3).

2). To dissolve all of the N.D.C.D. in aqueous alkali, an excess of alkali is necessary. This excess of alkali varies inversely with its concentration. As the concentration of the alkali decreases, the excess of alkali necessary for complete solution of the N.D.C.D. increases.

3). When N.D.C.D. was dissolved in excess alkali and the solution back-titrated with standard acid the following observations were made.

(a). At first, upon addition of the standard acid, the acid neutralizes the excess base (Table V and VI, and Fig. 5 and 6). Upon the addition of further acid the N.D.C.D. begins to reprecipitate from the solution. If, after the precipitation begins, more acid is added, the pH of the solution rises. The latter part of these curves show the same buffer effect as when N.D.C.D. is dissolved in alkali.

(b). There exists equivalent amounts of N.D.C.D. and sodium hydroxide, at the point where further addition of acid begins to reprecipitate N.D.C.D. from the solution. This point will be denoted in the following discussion as the point of incipient cloudiness. If at the point of incipient cloudiness the reprecipitated N.D.C.D. is separated by filtration, the addition of one drop of acid to the filtrate is sufficient to cause incipient cloudiness.

(c). If at the point of incipient cloudiness 0.2 to 0.5 mls. of standard acid is added, several more observations can be made.

1. At this point there occurs a rise in the pH.

11. The N.D.C.D. which has separated out is greater than can be explained by the excess of added acid. This amount, of excess N.D.C.D. is greater for higher concentrations of N.D.C.D. in solution.

III. If this N.D.C.D. is separated by filtration, about 0.4 mls of acid is necessary to cause incipient cloudiness again.

IV. The amount of N.D.C.D. which has separated out is of the same order as the amount of excess acid added after incipient cloudiness, plus the amount of acid necessary to cause incipient cloudiness after the N.D.C.D. has been separated by filtration.

It must be noted that points III and IV do not occur if a very small amount of excess acid is added (that is at the point of incipient cloudiness).

V. When acid is added after the point of incipient cloudiness, the first fact that is observed is a lowering of the pH. Upon stirring for a minute or several minutes the pH rises to an equilibrium value.

(d). When the conductivity is plotted against the number of mls. of standard acid added, the part of the curve after incipient cloudiness denotes the titration of the sodium salt. After this part of the curve the conductivity rises rapidly. This is due to the fact that all of the sodium N.D.C.D. has been neutralized, that is the conductivity rises because of the further addition of mobile protons. But the titration graph of the sodium salt should be a straight line. Instead a curve is obtained whose slope is greater at the beginning of the titration of the sodium salt than it is at the end of the titration.

(e). When N.D.C.D. is added to an equivalent amount of aqueous alkali and the insoluble portion is separated by filtration, the amount of acid necessary to cause incipient cloudiness is of the same order as when upon the back-titration of sodium N.D.C.D., acid was added, the reprecipitated N.D.C.D. separated, and acid added again to cause incipient cloudiness.

The first point that has to be explained is why an excess of alkali is necessary for complete formation of the sodium salt of N.D.C.D. The following representation may assist in explaining the observed behaviour (LVIII):

$$NH_2.C(NH).CO.NHNO_2 \overset{H_2O}{\rightleftharpoons} NH_2.C(NH)NH.CO.N{:}NO_2H \qquad \underline{i}$$

$$\downarrow$$

$$NH_2.C(NH)NH.CO.N{:}NO_2^- + H^+ \qquad \underline{ii}$$

$$NH_2.C(NH)NH.CO.N{:}NO_2^- + H^+ + Na^+ + OH^- \rightleftharpoons NH_2C(NH)NH.CO.N{:}NO_2^- + Na^+ + H_2O \qquad \underline{iii}$$

<u>LVIII</u>

It has been shown that step i and ii take place when N.D.C.D. is added to water. Now when an equivalent amount of aqueous alkali is added to N.D.C.D., the alkali can neutralize all of the N.D.C.D. to form the soluble sodium N.D.C.D. But sodium N.D.C.D. hydrolyses to give insoluble N.D.C.D. Hence excess alkali is necessary to suppress the ionization of the sodium salt, and to prevent any N.D.C.D. from separating out of the solution. The amount of excess alkali necessary for the suppression of the sodium N.D.C.D. will depend upon the concentration of the solution. For, the more dilute the solution, more excess base will be necessary to reach the pH at which the ionization of the sodium N.D.C.D. is completely suppressed.

Before discussing the significance of the curves obtained by plotting the pH versus the amount of acid added to sodium N.D.C.D. in excess aqeuous sodium hydroxide, it should be pointed out that even though the ordinary glass electrode is not very accurate in alkaline solutions above pH 8.5, what is important is not the absolute pH of the solution, but the shape of the curves. According to Dole (123), these curves are valid and reproducible.

The next point that has to be explained is why there is a rise in the pH at the point of incipient cloudiness. According to Clarke (124), this rise is due to supersaturation and should not be gradual but abrupt. Thus, this experiment was repeated, and if at the point of incipient cloudiness the mixture is allowed to stir for thirty minutes, the pH rises gradually to a value which does not increase upon further stirring. The pH, at equilibrium, in cases where supersaturation occurs can be expressed by the following equation (124).

$$pH = Ka + \log \frac{(A-)}{(AH)}$$

Where Ka = the dissociation constant of the acid, aci N.D.C.D.

(A-) = the concentration of the dissociated N.D.C.D. in solution

(AH) = the concentration of the undissociated N.D.C.D. in solution

But the rise in the pH is not as great as that which is noted upon the further addition of acid. Also, it is necessary to explain why the N.D.C.D. which separates out of the solution, upon the further addition of acid, beyond the point of incipient cloudiness, is greater than the amount that can be expected from the amount of the added acid.

It has been mentioned that up to the point of incipient cloudiness, the addition of acid neutralizes the excess alkali. If at this point an excess of acid is added, two changes may occur:- (i) An amount of N.D.C.D. equivalent to the amount of acid may separate from the solution, (ii) after which, since there is now no excess alkali to suppress the ionization of sodium N.D.C.D., the partial hydrolysis of this salt occurs. This liberates N.D.C.D. and sodium hydroxide. This hydrolysis continues until it has liberated enough sodium hydroxide for the suppression of the ionization of sodium N.D.C.D.

This explains why excess N.D.C.D. is obtained, why it is necessary to add 0.4 mls. of acid to cause incipient cloudiness, and also why upon the addition of acid after the point of incipient cloudiness, what is noted is at first a drop in the pH which rises slowly to an equilibrium value. For the first addition of the acid neutralizes the excess alkali causing a drop in the pH. The proposed scheme also explains why the amount of N.D.C.D. that is obtained, after the insoluble N.D.C.D. has been separated, and excess acid is added, is of the same order as that of the acid necessary to cause incipient cloudiness, plus the excess of added acid; and also why for salt formation and for the back-titration with excess acid the same excess of sodium hydroxide was found to exist in suspension of N.D.C.D. in sodium N.D.C.D.

But why do not all these observations occur at incipient cloudiness when all of the excess alkali has been neutralized and only a small amount of insoluble N.D.C.D. is present? Why must there be a certain excess of insoluble N.D.C.D. before the hydrolysis of the sodium N.D.C.D. gives rise to the excess sodium hydroxide? For this, the author has no satisfactory explanation. It could be a time factor, but as N.D.C.D. decomposes to some extent in any aqueous media this cannot very well be investigated with any degree of accuracy. On the whole it is the author's opinion that many more experimental data are necessary before the behaviour of N.D.C.D. and sodium N.D.C.D. can be fully explained. The above suggestions offer an explanation for some, but not all, of the observable facts.

(E) Quantitative Estimation of N.D.C.D.

The purity of the N.D.C.D. which is obtained from the reaction mixture was first discussed by Caro(3). He claimed that the unpurified N.D.C.D. gave the following analysis:- C, 19.8; H, 5.3; N, 49.4; whereas pure N.D.C.D. gives quite a different analysis:- C, 16.2; H, 3.4; N, 47.6. Caro claimed that the impurity was dicyandiamidine nitrate. But how can an impurity which has a lower carbon and nitrogen content than N.D.C.D. raise the carbon and nitrogen content of the impure product? Qualitative tests carried out in this laboratory have shown that dicyandiamide is the impurity. This impurity has a higher carbon, hydrogen and nitrogen content than N.D.C.D. and hence would fit in with Caro's analytical data.

The use of the precipitation of an insoluble compound as an end-point has long been known in quantitative analysis (125). It can be seen from the preceding discussion that, when N.D.C.D. is dissolved in an excess of sodium hydroxide and back titrated with acid, there exist equivalent amounts of N.D.C.D. and sodium hydroxide in the solution at the point of incipient cloudiness. The question arises as to what concentration of N.D.C.D. is necessary in order to give a sharp and reproducible end point; also what concentration of acid will give a sharp enough end point. Although usually in acid-base titrations 0.1N standards are used - these standards were found to be too dilute for the estimation of N.D.C.D. By varying the concentration of the standards it was found that standards of 0.3-0.4N will give reproducible results.

It is inherent in the method that any compound besides N.D.C.D. which will react with either the acid or the base will cause an error in the results. This was borne out in experiments where N.D.C.D., which had been contaminated with other organic compounds, was analysed. But since N.D.C.D. is insoluble in all of the common organic solvents, any contaminant which might interfere with its estimation can be dissolved in a suitable solvent and the N.D.C.D. can be estimated by the method outlined in this report.

(F) Isolation of Sodium and Potassium N.D.C.D.

These salts can be isolated when acetone and, or, methanol is added to concentrated aqeuous solutions of N.D.C.D. and sodium or potassium hydroxide. They separate out of the solution contaminated with N.D.C.D. This may be due to the inability of the excess alkali in acetone or methanol to completely suppress the hydrolysis of the sodium or potassium N.D.C.D., hence giving rise to sodium or potassium N.D.C.D. contaminated with N.D.C.D. This results in low sodium or potassium contents. When provisions are madefor the contaminant, N.D.C.D., by separation, by filtration, and titrating with acid, the sodium content is found to check with the calculated value, while the potassium content remains low.

The titration curves of aqeuous solutions of these salts are the same as those obtained when a solution of N.D.C.D. in excess sodium hydroxide is back titrated with acid. For an aqeuous solution of the contaminated product represents a condition where there exists free N.D.C.D. and sodium N.D.C.D. Here also, when the N.D.C.D. is separated by filtration, the presence of excess sodium hydroxide can be demonstrated. If the N.D.C.D. is not separated from the solution, then the curve is the same as during salt formation.

(G) The Formation of Nitrosodicyandiamidine

In the histrorical section it was noted that although nitrosoguanidine is a stable compound, free nitrosourea is not known. The only indication that such a compound does exist is obtained when nitrourea is reduced with zinc and sodium hydroxide. Here the presence of this group can be noted in the reaction mixture for a very short period of time. This is due to the instability of the nitroso compound (142).

When N.D.C.D. is reduced with zinc and sodium hydroxide, the presence of a nitroso group can be noted in the reaction mixture. (LIX).

$$NH_2.C(NH)NH.CO.NHNO_2 \xrightarrow[NaOH]{Zn} NH_2.C(NH)NH.CO.NHNO \qquad \underline{\underline{LIX}}$$

As in the case of nitrourea this test is only noted for a short period of time for the nitroso compound is unstable in the reaction medium.

(H) Methylation of N.D.C.D.

N.D.C.D. is similar to nitrourea (42) in the fact that it cannot be methylated with either methyl iodide or methylsulfate (126).

(I) Formation of Aryl Azo Derivatives of N.D.C.D.

It has been mentioned in the historical section that cyanamide, dicyandiamide, and dicyandiamidine couples with aryl diazotates in basic medium (67). Two observations were noted about this reaction. (i) The reaction takes place in a basic medium. (ii) The whole product does not separate out upon acidifying the reaction mixture. It is necessary to repeat the process of alkalination and acidification of the reaction mixture several times to obtain the full yield of product.

In the case of N.D.C.D., the N.D.C.D. must be dissolved in aqueous alkali. Hence, here the coupling occurs between the sodium N.D.C.D. and the aryl diazotate. Also there must be enough excess alkali to neutralize the aryl diazonium chloride to the sodium diazotate, and to keep the reaction basic for the coupling to occur.

During the reaction the same colour changes of the reaction medium can be observed as with dicyandiamide. Here upon acidification the whole product must separate out. If not, then the product would be contaminated with N.D.C.D.

It is found that the coupling is complete when the coupling is between N.D.C.D. and benzenediazotate. But when the o-carbonic acid benzenediazotate or the p- tolyldiazotate is used, the analysis indicates that the products are mixtures of the azo compounds and N.D.C.D. The author cannot offer any explanation as to why with dicyandiamide it is necessary to repeat the process of alkalination and acidification of the reaction mixture several times to obtain the full yield of the azo derivative. Also why, with N.D.C.D. and the benzene diazotate a full yield of the derivative is obtained without having to repeat this process, and again why the N.D.C.D., o-carbonic acid benzene, and o-toluene azo couplings react in the same manner as in the dicyandiamide couplings. It is impossible to purify these compounds as they have the same solubilities as N.D.C.D. (LX).

$$C_6H_5N{:}NONa \; + \; NH_2.C(NH)NH.CO.N.NO_2Na \xrightarrow{NaOH}$$

$$C_6H_5N{:}N.N(Na)C(NH)NH.CO.N.NO_2Na \xrightarrow{HCl} C_6H_5N{:}NNH.C(NH)NH.CO.NHNO_2$$

$$p\text{-}CH_3.C_6H_4N{:}NONa \; + \; NH_2C(NH)NH.CO.N.NO_2Na \longrightarrow$$

$$p\text{-}CH_3C_6H_4N{:}N.NH.C(NH)NH.CO.NHNO_2$$

$$o\text{-}COOH.C_6H_4N{:}NONa \; + \; NH_2.C(NH)NH.CO.NNO_2Na \longrightarrow$$

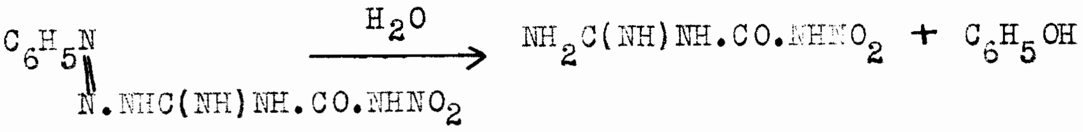
$$o\text{-}CH_3C_6H_4N{:}N.NH.C(NH)NH.CO.NHNO_2 \quad \underline{LX}$$

The structure of N. phenylazo N^1 nitrodicyandiamidine can be represented in the following formula (LXI).

$$C_6H_5N{:}N.NHC(NH)NH.CO.NHNO_2 \quad \underline{LXI}$$

This structure is chosen because in dicyandiamide the coupling has been proven to occur at that end of the molecule. Also in basic medium, sodium N.D.C.D. is formed, and it is well known that a sodium oxy group does not couple with a diazotate. Thus it must be the amido end of the molecule which undergoes the coupling.

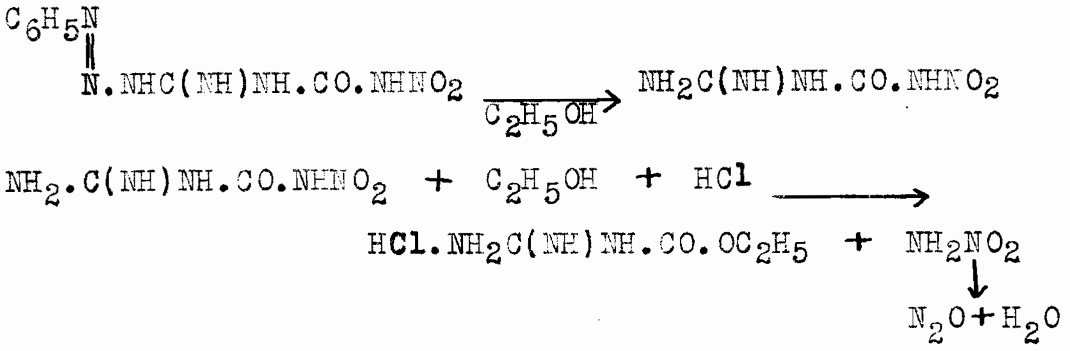
It has been mentioned that the aryl azo derivatives of dicyandiamide can decompose in two different manners to give either dicyandiamide or phenyldicyandiamide (67). With the aryl azo derivatives of N.D.C.D., only one type of decomposition occurs to give N.D.C.D. According to Hantzsch's theory the azo compound of N.D.C.D. must exist as its anti form (67), since the syn form would give N aryl N^1 nitrodicyandiamidine. Hence the decomposition of N phenylazo N^1 nitrodicyandiamidine occurs in the following manner. (LXVII).



$$\begin{matrix}C_6H_5N \\ \| \\ N.NHC(NH)NH.CO.NHNO_2\end{matrix} \xrightarrow{H_2O} NH_2C(NH)NH.CO.NHNO_2 + C_6H_5OH$$

anti form LXII

If this decomposition is carried out in absolute ethanol-hydrogen chloride solution at 100°C, carbethoxy guanidine hydrocholoride is formed (LXIII).



$$\begin{matrix}C_6H_5N \\ \| \\ N.NHC(NH)NH.CO.NHNO_2\end{matrix} \xrightarrow[C_2H_5OH]{} NH_2C(NH)NH.CO.NHNO_2$$

$$NH_2.C(NH)NH.CO.NHNO_2 + C_2H_5OH + HCl \longrightarrow HCl.NH_2C(NH)NH.CO.OC_2H_5 + \begin{matrix}NH_2NO_2 \\ \downarrow \\ N_2O + H_2O\end{matrix}$$

LXIII

(J) Attempted Preparation of Methylol N.D.C.D.

From the historical point of view, if sodium or potassium N.D.C.D. reacts with formaldehyde in the same manner as other urea and guanidine derivatives do, then the product should be sodium or potassium methylol N.D.C.D. (LXIV).

$$H.CHO + NH_2.C(NH)NH.CO.N:NO_2Na \longrightarrow HOH_2.C.NH.C(NH)NH.CON:NO_2Na$$

LXIV

The fact that some sort of a reaction does occur can be observed when an equivalent amount of formaldehyde is added to an aqeuous solution of either sodium or potassium N.D.C.D. Here the reaction mixture begins to decompose giving off a gas. The only product that can be isolated from the decomposition is sodium carbonate.

It may be mentioned here that both nitroguanidine and nitrourea decompose quantitatively to sodium carbonate when they are treated with concentrated sodium hydroxide at high temperatures (127). But in these cases a quantitative amount of ammonia is also given off and in the decomposition of a sodium N.D.C.D.-formaldehyde solution, ammonia is not one of the decomposition products.

As salts of N.D.C.D. are rather stable, and as the usual decomposition products of N.D.C.D. are guanidine salts, it must be assumed that some sort of reaction resulting in a non stable compound has taken place. More evidence for this assumption is observed when small aliquot portions of the reaction mixture are acidified during the course of the reaction. At first the acidification causes the separation of unreacted N.D.C.D., but as the decomposition progresses the acidification does not appear to cause any separation of N.D.C.D., since no solid product separates out. In fact this acidified solution decomposes in a different manner than the basic one. Here the gassing becomes more violent and large volumes of nitrogen dioxide are given off. This decomposition is exothermic since the reaction mixture becomes very hot.

The decomposition is not so noticeable when formaldehyde is added to a cold aqueous solution of an N.D.C.D. salt. Thus it was thought that perhaps the sodium or potassium methylol derivative of N.D.C.D. could be isolated when a cold sodium or potassium N.D.C.D. formaldehyde solution is treated with excess methanol. But the product that was obtained appeared to be the contaminated sodium or potassium salt of N.D.C.D.

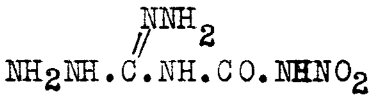
It is evident that not enough is known about this decomposition to propose any mechanism for it.

(K) Reaction Between N.D.C.D. and Hydrazine Hydrate.

When N.D.C.D. is added to a five times excess solution of 100% hydrazine hydrate, the N.D.C.D. dissolves completely in the hydrazine hydrate giving off a gas. This reaction is exothermic as the resulting solution becomes warm. When this solution is shaken for several minutes, a white crystalline product separates out of the solution.

From a historical point of view, assuming the accepted structure of N.D.C.D., this type of a reaction should give rise to either N(1 hydrazino 1 imido) methyl N^1nitrourea (LXV) or N(1 hydrazino 1 hydrazono) methyl N^1nitrourea (LXVI).

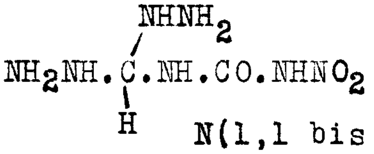
$NH_2NH.C(NH)NH.CO.NHNO_2$ LXV



$$NH_2NH.\overset{NNH_2}{\overset{//}{C}}.NH.CO.NHNO_2$$

LXVI

But the observed carbon, hydrogen and nitrogen content of the product did not agree with the calculated values of either one of these compounds. Assuming the analysis to be correct, it is the author's opinion that the following compound represents the product of the reaction (LXVII).



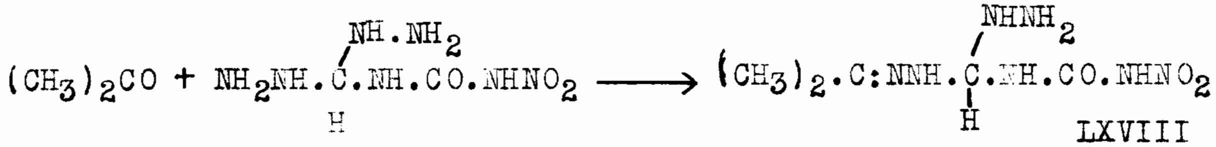
$$NH_2NH.\underset{H}{\overset{NHNH_2}{C}}.NH.CO.NHNO_2$$

LXVII

N(1,1 bis hydrazino) methyl N^1nitrourea

If the above formula represents the structure of the product, then the hydrazine hydrate has acted as a reducing agent. This would represent a different type of a reaction from the usual reactions of hydrazine hydrate with members of the guanidine and urea series.

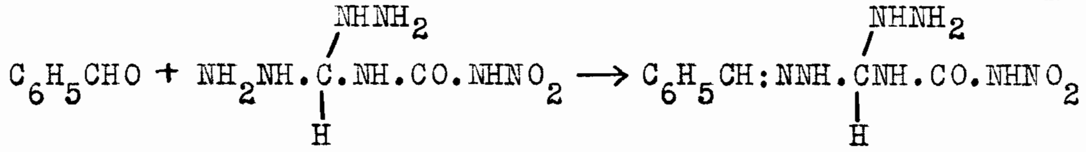
It can be noted from the formula that this compound has two hydrazino groups. Hence, the compound would be expected to form derivatives with aldehydes and ketones. This was found to be the case as it very easily forms an acetone (LXVIII) and a benzaldehyde derivative (LXIX).



$$(CH_3)_2CO + NH_2NH.\overset{NH.NH_2}{\underset{H}{C}}.NH.CO.NHNO_2 \longrightarrow (CH_3)_2.C:NNH.\overset{NHNH_2}{\underset{H}{C}}.NH.CO.NHNO_2$$

LXVIII

N(1 acetohydrazo 1 hydrazino)methyl N^1nitrourea



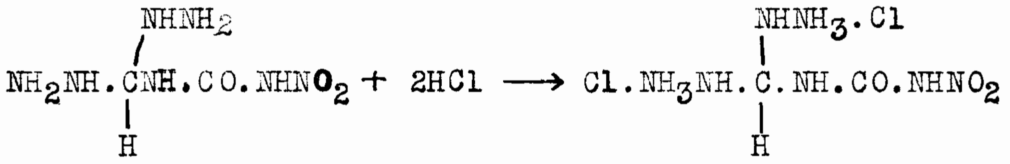
$$C_6H_5CHO + NH_2NH.\overset{NHNH_2}{\underset{H}{C}}.NH.CO.NHNO_2 \longrightarrow C_6H_5CH:NNH.\overset{NHNH_2}{\underset{H}{C}}NH.CO.NHNO_2$$

LXIX

N(1 benzalhydrazo 1 hydrazino) methyl N^1nitrourea

The analysis of the acetone derivative agreed very well with the calculated value, but the analysis of the benzaldehyde derivative gave a higher carbon and a lower nitrogen content. It has been the author's experience that the benzaldehyde derivatives of these nitrogen compounds adsorb benzaldehyde and this would cause high carbon and low nitrogen values. This seems to be what happened here. The benzaldehyde derivative gave a molecular weight of 250.

The compound also forms a di hydrochloride salt (LXX).



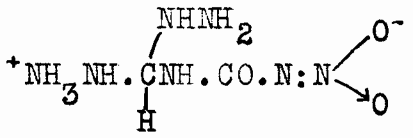
$$NH_2NH.\underset{H}{\overset{NHNH_2}{C}}NH.CO.NHNO_2 + 2HCl \longrightarrow Cl.NH_3NH.\underset{H}{\overset{NHNH_3.Cl}{C}}.NH.CO.NHNO_2$$

LXX

Here the analysis does not agree very well with the calculated values.

It was noticed that these derivatives had lower melting points than the parent compound. Since N(1,1 bishydrazino) methyl N^1nitrourea has both an acidic and a basic group it was suspected that this compound was a "zwitterion."

When the titration curve of an aqueous solution was determined it was noticed that this compound behaved as a "zwitterion", that is, it exhibited a buffer effect in both the acid and the basic regions. Thus N(1,1 bishydrazino) methyl N^1nitrourea can be represented in the following formula (LXXI).



$$^{+}NH_3NH.\underset{H}{\overset{NHNH_2}{C}}NH.CO.N{:}N\begin{smallmatrix}\nearrow O^- \\ \searrow O\end{smallmatrix}$$

LXXI

Hence, it appears that this compound exists in its aci form, whereas nitro derivatives usually exist in the nitro form.

It is well known that the addition of acid to an amino acid causes the suppression of the negative charge, until finally the equilibrium mixture contains the amino acid in its purely cationic form (LXXII).

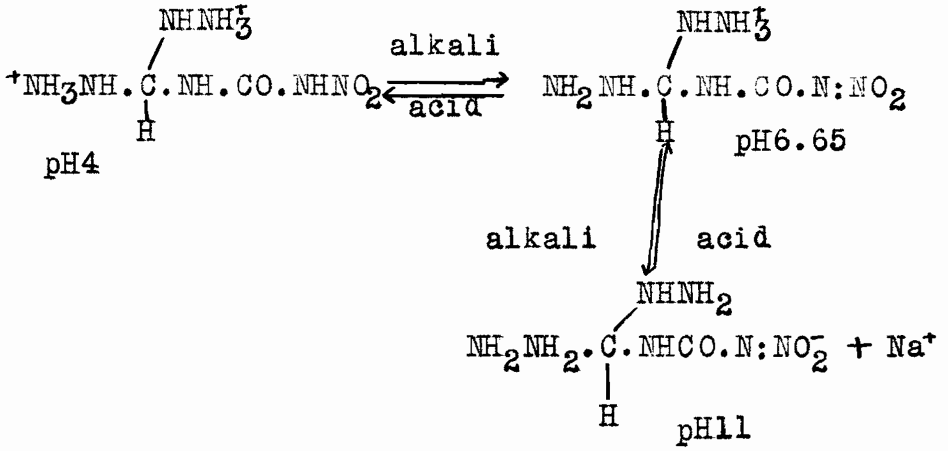
$$^{+}NH_3.CHR.CO_2^- + H^+ \rightleftharpoons {}^{+}NH_3.CHR.CO_2H \qquad \text{LXXII}$$

The addition of alkali to this system can be represented by the following equation (LXXIII):-

$$\underset{pH2}{^{+}NH_3.CHR.CO_2H} \xrightleftharpoons[H^+]{OH^-} \underset{pH4}{^{+}NH_3.CHR.CO_2^-} \xrightleftharpoons[H^+]{OH^-} \underset{pH7.6}{NH_2.CHR.CO_2^-} \qquad \text{LXXIII}$$

Thus in the case of the salts of the amino acids the first step in its neutralization is that of the carboxyl group, followed by that of the amino group (128). However, with N(1,1 bishydrazino) methyl N^1nitrourea the first step is the neutralization of the amino group followed by the neutralization of the nitro group. This is probably due to the fact that the nitro group is a pseudo acid.

Another point which can be noted upon examination of the titration curve is the fact that the solution acts as a buffer even when excess acid, over the amount necessary for salt formation is added. This makes it difficult to determine the pK_1value which appears to be about 4.5. It appears as this excess acid reacts with the nitrourea derivative. This may be the reason for the poor agreement between the calculated and the observed analytical values of the dihydrochloride salt. For the fact that the carbon, hydrogen, nitrogen and chlorine contents are greater than the calculated values suggests some sort of a reaction involving the loss of oxygen. If a reaction does occur it must be a reversible one for the curve can be retraced if alkali is added to this solution. Here, it appears that the compound has a pK_2 value of about 11. This is difficult to determine correctly because the buffer action occurs at such a high pH. Hence the neutralization of this compound can be presented in the following manner (LXXIV):-



$$\underset{pH4}{{}^{+}NH_3NH.\overset{NHNH_3^+}{\underset{H}{C}}.NH.CO.NHNO_2} \underset{acid}{\overset{alkali}{\rightleftharpoons}} \underset{pH6.65}{NH_2NH.\overset{NHNH_3^+}{\underset{H}{C}}.NH.CO.N{:}NO_2}$$

$$\text{alkali} \downarrow\uparrow \text{acid}$$

$$\underset{pH11}{NH_2NH_2.\overset{NHNH_2}{\underset{H}{C}}.NHCO.N{:}NO_2^- + Na^+}$$

LXXIV

N(1,1 bishydrazino) methyl N^1nitrourea is formed in very good yields in a very short period of time. It can be recrystallized very easily to its pure state, since only one recrystallization from aqueous ethanol or methanol is necessary. It has a characteristic melting point and readily forms recognizable derivatives. Also, it is a "zwitterion". All these properties make this reaction an ideal one for the identification of N.D.C.D.

Dearrangement of N.D.C.D.

(a) In Ethanol Medium

It has been noted by Savard (101) that when N.D.C.D. is decomposed in aqueous alcohol, carbethoxy guanidine is formed.(LI). A similar reaction occurs when N.D.C.D. is decomposed in absolute ethanol and in absolute ethanol-hydrogen chloride solution, In the case of the hydrogen chloride solution, the hydrochloride salt of carbethoxy guanidine is the product.

Actually these experiments were carried out in the presence of hydrazine dihydrochloride. It was hoped that this decomposition would result in the formation of aminodicyandiamidine dihydrochloride (LXXV).

$$NH_2.C(NH)NH.CO.NHNO_2 \longrightarrow NH_2.C(NH)N:C:O + NH_2NO_2$$

$$NH_2.C(NH)N:C:O + NH_2NH_2.2HCl \longrightarrow NH_2C(NH)NH.CO.NHNH_2.2HCl$$

LXXV

However, when the reaction was carried out in absolute ethanol or in ethanol-hydrogen chloride, most of the hydrazine salt was recovered unchanged and carbethoxy guanidine was the product. When the reaction was carried out in ethanol which had been saturated with ammonia, a high melting point compound was obtained as the product.

(b) In Hydrochloric Acid-Aniline Hydrochloride Medium

When N.D.C.D. is added to hot hydrochloric acid, it dearranges to give guanidine hydrochloride (65). When this dearrangement is carried out at a lower temperature in a hydrochloric acid solution which contains an equivalent amount of aniline hydrochloride, a different product is obtained.

From a theoretical viewpoint, the product that was expected was phenyldicyandiamidine hydrochloride. It was thought that this product would be formed in the following manner (LXXVI):-

$$NH_2.C(NH)NH.CO.NHNO_2 \longrightarrow NH_2.C(NH)N:C:O + NH_2NO_2$$

$$NH_2C(NH)N:C:O + C_6H_5NH_2.HCl \longrightarrow NH_2C(NH)NH.CO.NH.C_6H_5.HCl$$

LXXVI

Hence this reaction entails the addition of aniline hydrochloride to guanylisocyanate in the same manner as ethanol adds to it to give carbethoxy guanidine (101)(LI).

Actually it has been found that it is very difficult to purify this product since it has the same solubilities as the contaminant, aniline hydrochloride. Thus the quantitative analysis of the product does not specifically indicate any definite compound. But, taking into consideration that there is present a small amount of aniline hydrochloride as a contaminant, it does indicate a compound of the composition of $C_8H_{13}N_3Cl_2$. This indicates a compound of the following structure (LXXVII):-

$HCl.C_6H_5NH.C(NH)NH.CH_3.HCl$ <u>LXXVII</u>

N phenyl N^1methylguanidine dihydrochloride

The following can be proposed as a possible mechanism for the formation of this compound:- (LXXVIII).

$NH_2.C(NH)NH.CO.NHNO_2 + C_6H_5NH_2 \xrightarrow{i} C_6H_5NH.C(NH)NHCO.NHNO_2 \quad NH_3$

$C_6H_5NH.C(NH)NHCO.NHNO_2 \xrightarrow{ii} C_6H_5NHC(NH)N{:}C{:}O + NH_2NO_2$

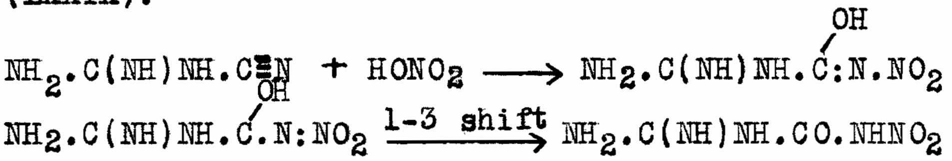
$C_6H_5NH.C(NH)N{:}C{:}O \xrightarrow{iii} C_6H_5NH.C(NH)NHCH_3$ <u>LXXVIII</u>

There is a possibility that dearrangement i and ii occur, since similar dearrangements occur with nitroguanidine (98)(37)(38); but the author cannot offer any explanation as to how step iii takes place, for this involves the reduction of substituted isocyanate to an amine derivative. But from the analysis it can be ascertained that the product does not contain any oxygen.

If this dearrangement is carried out in the presence of either o-toluidine hydrochloride, or methyl or butylamine hydrochloride, then N.D.C.D. dearranges in the usual manner to give guanidine hydrochloride (101), and the substituted amines are recovered unchanged.

Attempted Structure Proof of N.D.C.D.

N.D.C.D. was first prepared by treating dicyandiamide with cold, concentrated, sulfuric and nitric acids (2). Two mechanisms can be postulated for this reaction. The first consists of the addition of nitric acid in its pseudo form to the cyano group followed by rearrangement to the nitrourea form (65) (LXXIX).



$$NH_2.C(NH)NH.C\equiv N + HONO_2 \longrightarrow NH_2.C(NH)NH.\overset{OH}{C}{:}N.NO_2$$

$$NH_2.C(NH)NH.\overset{OH}{C}.N{:}NO_2 \xrightarrow{1\text{-}3\ \text{shift}} NH_2.C(NH)NH.CO.NHNO_2$$

LXXIX

The second mechanism assumes that first the dicyandiamide is hydrolysed to dicyandiamidine, and the mixed acids react with this intermediate to form N.D.C.D. If this mechanism is the correct one, then N.D.C.D. can be either one of two compounds (LXXX);-

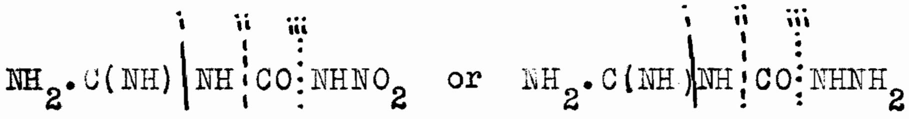
$$NH_2.C(NH)NH.CN + H_2O \longrightarrow NH_2.C(NH)NH.CONH_2 \quad (i)$$

$$NH_2.C(NH)NH.CONH_2 + HNO_3 \xrightarrow[H_2SO_4]{} NH_2.C(NH)NH.CONH.NO_2 \quad (ii)$$

$$NH_2.C(NH)NH.CONH_2 + HNO_3 \xrightarrow[H_2SO_4]{} O_2NNH.C(NH)NH.CONH_2 \quad (iii) \quad \underline{LXXX}$$

The only indication as to the structure of N.D.C.D. is obtained from the dearrangement of the N.D.C.D. in various media (2)(65). These dearrangements show that N.D.C.D. dearranges to give rise to either guanylisocyanate or guanidine. This indicates that N.D.C.D. has structure (ii). But the question was raised whether N.D.C.D. could be synthesized in a manner which would conclusively prove its structure, namely, on which side of the molecule the nitro group is on. For experimental purposes, it was assumed that N.D.C.D. has structure (ii).

Upon examination of the accepted structure of N.D.C.D. or its reduced form, aminodicyandiamidine, several methods suggest themselves for the synthesis of this compound (LXXXI).



$$NH_2.C(NH)\overset{i}{|}NH\overset{ii}{\vdots}CO\overset{iii}{\vdots}NHNO_2 \quad \text{or} \quad NH_2.C(NH)\overset{i}{|}NH\overset{ii}{\vdots}CO\overset{iii}{\vdots}NHNH_2$$

LXXXI

Thus, for synthetic purposes, the molecule can be divided in three ways. The first method can be carried out when cyanamide is reacted with nitrourea or semicarbazide (LXXXII).

$$NH_2.CN + NH_2.CONHNO_2 \longrightarrow NH_2.C(NH)NH.CONHNO_2$$

$$NH_2.CN + NH_2.CONHNH_2 \longrightarrow NH_2.C(NH)NH.CONHNH_2$$

LXXXII

In the case of semicarbazide, acetone semicarbazone was used to protect the hydrazino group.

The second method pre-supposes a reaction between N-nitrourethane or carbethoxy hydrazine with guanidine (LXXXIII)

$$O_2NNHCO.OC_2H_5 + NH_2.C(NH)NH_2 \longrightarrow NH_2.C(NH)NH.CONHNO_2$$

$$H_2NNHCO.OC_2H_5 + NH_2.C(NH)NH_2 \longrightarrow NH_2.C(NH)NHCONHNH_2$$

LXXXIII

While the third method assumes a reaction between carbethoxy guanidine and hydrazine (LXXXIV).

$$NH_2.C(NH)NHCO.OC_2H_5 + NH_2NH_2 \longrightarrow NH_2.C(NH)NHCONHNH_2$$

LXXXIV

(a) Reactions With Cyanamide

It is well known that cyanamide reacts with amines and substituted amines to form guanidine derivatives. Thus, it was thought that cyanamide would react with amides, that is, nitrourea, and acetone semicarbazone to give rise to N.D.C.D. or acetoneaminodicyandiamidine (LXXXII).

However, as was mentioned in the historical section, previous attempts to react cyanamide with amides were not successful and similar results were obtained here. In these attempted structure proofs of N.D.C.D. various compounds were isolated. In most cases no attempts were made to identify these products. The reason for this is because this is a war problem, and in such problems, the stress is laid upon results. Thus, if one method failed, another method was tried without fully investigating the previous one.

(b) Reaction With S-Methylisothiourea

Instead of cyanamide, s-methylisothiourea was used. This compound also adds to amines to form guanidine derivatives (129) (130) (131) (LXXXV).

$$RNH_2 + NH_2.C(NH).SCH_3 \longrightarrow RNH.C(NH)NH_2 \qquad \underline{LXXXV}$$

But when this compound was reacted with amide derivatives, the expected reaction did not take place.

(c). Reaction With Cyanogen Bromide

Another well known reaction which was tried was to use cyanogen bromide instead of cyanamide. This reagent reacts with amines and amides to form cyanogen derivatives (132)(133), which adds ammonia to form guanidine derivatives (131)(LXXXVI).

$$RNH_2 + CNBr \longrightarrow RNH.CN + NH_3 \longrightarrow RNHC(NH)NH_2 \qquad \underline{LXXXVI}$$

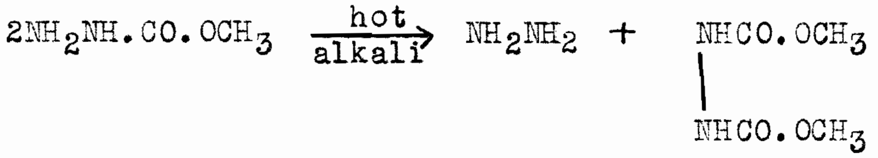
But no reaction occurred between cyanogen bromide and nitrourea.

(d) Reaction With Guanidine

The reaction between guanidine and esters to give guanidino derivatives is well known (134)(135)(136)(137)(138). Most of these reactions occur quite readily at room temperatures. Thus, it was thought that guanidine would react with N-nitrourethane or carbethoxy hydrazine to form N.D.C.D. or aminodicyandiamidine (LXXXII).

But nitrourethane is not like an ordinary ester of a mono carboxylic acid. For here the acid properties of the nitro group are greater than those of the carboxylic group. Thus no noticeable reaction was observed here. An attempt was made to overcome this apparent hindrance to the reaction by using N-ammonium nitrourethane, but here again no apparent reaction was observed.

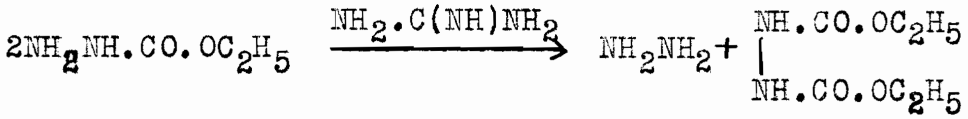
Similarly, carbethoxy hydrazine is not an ordinary ester. This compound is basic and reacts with acids to form acid salts. It decomposes when treated with hot alkali, in the same way as carbomethoxy hydrazine decomposes when treated with hot alkali to give hydrazine and biscarbomethoxy hydrazine (139) (LXXXVII).



$$2NH_2NH.CO.OCH_3 \xrightarrow[\text{alkali}]{\text{hot}} NH_2NH_2 + \begin{array}{l} NHCO.OCH_3 \\ | \\ NHCO.OCH_3 \end{array}$$

LXXXVII

A similar reaction appears to take place when carbethoxy hydrazine is treated with aqeuous guanidine, for hydrazine can be isolated as one of the products (LXXXVIII).



$$2NH_2NH.CO.OC_2H_5 \xrightarrow{NH_2.C(NH)NH_2} NH_2NH_2 + \begin{array}{l} NH.CO.OC_2H_5 \\ | \\ NH.CO.OC_2H_5 \end{array}$$

LXXXVIII

If anhydrous guanidine is used, no apparent reaction occurs.

Since it was believed that perhaps this reaction did not occur because carbethoxy hydrazine was a base, its hydrochloride salt was used instead of the unsubstututed compound, but the reaction that did occur did not give rise to aminodicyandiamidine.

(d) Reaction With Hydrazine Hydrate

The reaction between an ethyl ester and hydrazine or hydrazine hydrate is very well known and has been worked on intensively by Curtius (140). This reaction liberates ethanol and gives rise to hydrazides (LXXXIV). When carbethoxy guanidine is used this reaction should give aminodicyandiamidine. But here again carbethoxy guanidine is not an ordinary ester type of compound. It is a base and forms acid salts. Thus the product of this reaction was not aminodicyandiamidine. Here, as in the case of carbethoxy hydrazine hydrochloride, the hydrochloride salt was used, with similar results.

It may be mentioned here that Curtius attempted to react hydrazine with urethane (141) in order to form semicarbazide. Curtius also did not obtain the expected product.

(e) Fusion Reaction

The preparation of biuret or biguanide salts by heating urea or guanidine salts is well known (142)(143)(LXXXIX).

$$2NH_2.CONH_2 \longrightarrow NH_2.CONH.CO.NH_2 + NH_3$$

$$2NH_2.C(NH)NH_2.HCl \longrightarrow NH_2.C(NH)NH.C(NH)NH_2.HCl + NH_4Cl \qquad \underline{\text{LXXXIX}}$$

This type of a reaction can be applied to the synthesis of N.D.C.D. or its reduced form if one supposes that a reaction between guanidine and nitrourea, or semicarbazide would react in a similar manner (XC).

$$NH_2.C(NH)NH_2 + NH_2.CO.NHNO_2 \longrightarrow NH_2.C(NH)NH.CONH.NO_2 + NH_3$$

$$NH_2.C(NH)NH_2 + NH_2.CONH.NH_2 \longrightarrow NH_2.C(NH)NH.CONH.NH_2 + NH_3 \qquad \underline{\text{XC}}$$

For experimental purposes guanidine hydrochloride, semicarbazide hydrochloride and acetonesemicarbazone were used. Here the reaction can give rise to more diverse products because instead of urea, a substituted urea is necessary. Also this is a reaction between a guanidine salt and substituted urea, whereas previously the reaction was between either two molecules of guanidine or two molecules of urea.

There has been reported in the literature two reactions of a guanidine salt with urea. In one case the corresponding salt of dicyandiamidine was the product, and in the other fusion diguanylbiuret was the product (144). The fusion of acetonesemicarbazone with amines is also well known (145)(XCI).

$$(CH_3)_2C{:}NNH.CONH_2 + RNH_2 \longrightarrow (CH_3)_2C{:}NNH.CO.NHR + NH_3 \qquad \underline{XCI}$$

But no mention has been found in the literature of a reaction between a guanidine salt and a substituted urea. Under the conditions reported in the experimental section, this reaction did not give the expected product. Here an attempt was made to prepare N.D.C.D. by fusing guanidine hydrochloride with nitrourea (XC). An interesting observation was made here since hydrogen chloride is evolved upon mixing of the reagents. Upon the application of heat the mixture decomposes to gaseous products.

It was then thought that perhaps a reaction between nitroguanidine and urea would form the isomer of N.D.C.D.(XCII).

$$O_2NNH.C(NH)NH_2 + NH_2CO.NH_2 \longrightarrow O_2NNH.C(NH)NHCO.NH_2 \qquad \underline{XCII}$$

Although a large volume of ammonia was given off very readily during the reaction, the analysis did not indicate any such product.

(f) Formation of N-Phenyl N^1Nitrodicyandiamidine

It has been mentioned that Walther and Greishammer (67) have prepared phenyldicyandiamidine hydrochloride by the decomposition and hydrolysis of phenylazodicyandiamide.

It was thought that if from this compound N-phenyl N^1nitrodicyandiamidine could be prepared, and if from phenylazo N.D.C.D. N-phenyl N^1nitrodicyandiamidine could also be prepared, then if both were the same this would prove the structure of N.D.C.D. It has been previously mentioned that phenylazo N.D.C.D. does not decompose to give N phenyl N^1nitrodicyandiamidine, this compound was prepared from phenyldicyandiamidine by treating the hydrochloride salt with silver nitrate to form the nitrate salt, and then dehydrating the nitrate salt with sulfuric acid. The product that was obtained was N-phenyl N^1nitrodicyandiamidine sulfate (XCIII).

$$C_6H_5NH.C(NH)NH.CO.NH_2HCl + AgNO_3 \longrightarrow C_6H_5NH.C(NH)CO.NH_2.HNO_3$$

$$C_6H_5NH.C(NH)NH.CO.NH_2 + HNO_3 \xrightarrow{H_2SO_4} (C_6H_5NH.C(NH)CO.NHNO_2)_2.H_2SO_4$$

XCIII

When this compound is heated in water or in dilute acid for a short while, it converts into a compound of different melting point. The analysis of this compound indicated it to be the hydrate salt of N-phenyl N^1nitrodicyandiamidinesulfate.

The fact that the phenyl derivative of N.D.C.D. forms a sulfate salt and N.D.C.D. does not, indicates that phenyl N.D.C.D. can act as base whereas N.D.C.D. cannot. The only difference between the two compounds is that one has a phenyl group instead of a hydrogen, that is one is a di substituted guanidine whereas N.D.C.D. is a mono substituted guanidine. It is well known that a mono substituted guanidine is not as strong a base as guanidine. Pauling explained this by showing that the basic strength of guanidine is partly due to resonance (41). The number of resonating forms is decreased in a mono substituted guanidine giving rise to a weaker base. Following the same reasoning this explains for the fact that N, N^1di substituted guanidines are weaker bases than the mono substituted ones. Since N.D.C.D. can be considered a mono substituted guanidine, phenyl N.D.C.D. is a di substituted guanidine and should be less basic. But this is contrary to some of the experimental facts.

Contrary to the guanidines, substituted amines are stronger bases than the non substituted ones due to the greater tendency of the nitrogen to share its free electrons. Hence, the amino group of phenyl N.D.C.D. reacts more like an amine than a guanidine derivative. This would indicate that in N.D.C.D. and in phenyl N.D.C.D. resonance does not play a very great role in determining the basicity of the compound.

(g) Experimental Procedure

It will be noted in the experimental section on the attempted structure proof of N.D.C.D. that the following properties of N.D.C.D. and aminodicyandiamidine dihydrochloride were taken advantage of in order to identify these compounds:-

(i) When the expected product was the reduced derivative, advantage was taken of, (a) the easy formation of the benzaldehyde derivative of this compound, (b) the insolubility of this benzaldehyde derivative in ether, in methanol and in ethanol, (c) and of the insolubility of aminodicyandiamidine dihydrochloride in methanol. The benzaldehyde derivatives of the products were always decomposed in the usual manner, with hydrochloric acid.

(i) In working up of the reaction mixtures, when the expected product was N.D.C.D., the insolubilities of N.D.C.D. in all common organic solvents was used as a means of its identification.

From the preceeding discussion, it can be noted that no further proof was found as to the structure of N.D.C.D. All that can be said is that all the reactions of N.D.C.D. can be explained by assuming the accepted structure of N.D.C.D.

EXPERIMENTAL

1. Preparation of N.D.C.D. - Thiele's Method (2).

In a typical experiment a mixture of 100 mls. of concentrated sulfuric acid and 40 mls. of concentrated nitric acid were cooled to -4 °C in an ice-salt bath. Twenty-five g. (0.3M) of dicyandiamide were added in small portions over a period of twenty minutes with continuous mechanical stirring so that the temperature was maintained below 0 °C. After an additional hour of stirring the mixture was poured into approximately 1 kilog. of cracked ice and left standing overnight. The product which separated out was collected on a Büchner funnel and washed with water until neutral to litmus. It was air dried on the Büchner for an hour and then further dried at 100 °C. The weight of the product was 42.4 g. which corresponds to a yield of 95%.

2. Preparation of the silver salt of N.D.C.D. Thiele's Method (2)

a. A sample of N.D.C.D. (1.47 g. or .01 m) was added to an equivalent amount of 5% sodium hydroxide solution (8 mls.) The mixture was well stirred and the portion of N.D.C.D. which did not dissolve was filtered off. Slightly less than the equivalent amount of a 5% silver nitrate solution (25 mls.) was added and the silver salt separated out of the solution as a colloidal sol which was coagulated by further stirring. After standing in the refrigerator overnight, it was filtered, washed with alcohol and ether and dried in a desiccator. Like N.D.C.D. the silver salt has no melting point but explodes upon heating. A yield of 90% was obtained in this reaction.

b. The above method was modified in order to dissolve all the N.D.C.D. and to insure the full precipitation of the N.D.C.D. as the sodium salt, e.g. 1.42 g. of N.D.C.D. (.01 M) was dissolved in 10 cc. of 5% NaOH (0.0125 M) and to it was added 40 g. of 5% silver nitrate (0.0103 M). But this method gave a salt which was colloidal and absorbed other ions, e.g. three samples of N.D.C.D. prepared by this method were found to contain 45.07%, 45.9% and 47.7% of silver instead of the theoretical amount of 42.5%. The weight of the silver salt was 2.68 g., which represents a yield of 106%.

c. The following attempts were made to coagulate the colloid.

1. Thiele's method of vigorous stirring was tried;

2. The silver salt which was formed at room temperature was boiled for several minutes.

3. The N.D.C.D. in the sodium hydroxide solution was added to a hot silver nitrate solution and allowed to cool slowly with continuous stirring. The precipitate which formed was chocolate brown in colour and was assumed to be silver oxide (the silver salt of N.D.C.D. is white). As the mixture cooled the silver salt of N.D.C.D. was formed. This salt had the same colloidal properties as the one which was formed at room temperature.

4. Silver acetate was used instead of silver nitrate.

5. Various ions were added to the silver salt in order to coagulate it, i.e. sodium carbonate, sodium chloride, nitric acid and acetic acid. Upon acidification the salt decomposed into N.D.C.D. and the silver salt of the anion used.

None of the above attempts had any effect on the colloidal properties of the silver salt of N.D.C.D.

3. Change in the concentration of the silver ions upon the addition of silver nitrate to a solution of N.D.C.D. and sodium hydroxide.

In a typical experiment 0.229 g. of N.D.C.D. (1.56 m.eg.) was dissolved in twenty mls. of 0.0969 N sodium hydroxide (1.838 m.eg.). The excess sodium hydroxide was neutralized with 2.45 mls. of nitric acid (0.268 m.eg.). The silver electrode assembly was put into the solution and small portions of 0.2584 N. silver nitrate were added to the solution. After each addition the mixture was stirred vigorously for three minutes with a mechanical stirrer and the change in M.V. was recorded. The results are given in Table I and are recorded graphically in figure 1.

TABLE I

Addition of Silver Nitrate to Sodium Hydroxide-N.D.C.D. Solution

MV	Silver Nitrate Added (mls. of 0.2584N.)
1.59	0
1.87	1.09
1.96	2.14
1.98	3.38
2.06	3.87
2.08	4.18
2.10	4.52
2.16	4.85
2.17	5.10
2.19	5.20
2.26	5.26
2.29	5.32
2.35	5.38
2.42	5.44
2.64	5.50
2.98	5.59
3.28	5.63
3.41	5.67
3.50	5.72
3.90	6.25

The data in figure 1 show the equivalent point to be at 3 MV., i.e. when 5.59 mls. of 0.2584 N. silver nitrate had been added to the solution. This corresponds to a purity of N.D.C.D. of 91%.

4. Change in the conductivity of a N.D.C.D.-sodium hydroxide solution upon addition of silver nitrate solution.

Experiment 3 was repeated and the change in the conductivity was noted instead of the change in the concentration of the silver ions. In this experiment 0.217g. of N.D.C.D.(1.472m. eq.) was dissolved in 6.05 mls. of 0.3440 N sodium hydroxide (2.08 m.eq.). The excess of sodium hydroxide was neutralised with 5 mls. of 0.1125 N nitric acid (0.562 m. eq.). The results are shown in Table II and in figure 2.

Table II

Addition of Silver Nitrate to Sodium Hydroxide-N.D.C.D.Solution

Conductivity	Silver Nitrate Added (mls. of 0.2845N.)
4.18×10^{-3}	1.26
4.27×10^{-3}	1.96
4.41×10^{-3}	3.02
4.51×10^{-3}	4.04
4.74×10^{-3}	4.99
5.05×10^{-3}	5.64
5.16×10^{-3}	5.98
5.34×10^{-3}	6.34

According to figure 2 the equivalence point is reached when 4.70 mls. of 0.2845N silver nitrate has been added. This corresponds to a purity of N.D.C.D. of 90.5%.

5. The formation of mercury, nickel and copper salts of N.D.C.D.

(a). The formation of the mercury salt.

A sample of N.D.C.D. (0.294g. or 0.002M.) was dissolved in an excess of 5% potassium hydroxide solution. An excess of 2.5% mercuric chloride solution (15 mls.) was added with vigorous stirring, upon which, a white solid separated out of the solution as a colloidal sol. After standing in the refrigerator overnight it was collected on a filter, washed with alcohol and ether and dried at 60° to constant weight. The weight of the mercury salt was .532 g. which represents a yield of 109%.

Anal. Calcd. for $C_4H_8N_{10}O_6Hg$: Hg,40.76

Found: Hg, 43.4, 44.5.

The mercury salt is a white solid which is insoluble in all common organic solvents and which, like N.D.C.D. explodes upon heating.

The above method was repeated, using varying amounts of mercuric chloride solutions; but in no case was it possible to obtain a compound whose mercury content checked with the theoretical value. In fact, when 25 mls. of mercuric chloride was used, the mercury content increased to 53%.

(b). The formation of the nickel salt.

The nickel salt was prepared following the method given by Thiele for the preparation of the silver salt (2). Here, the following amounts of reagents were used:-

2.94 g. of N.D.C.D. (.02 M)
16 mls.---5% NaOH solution
90 mls.---2.5% $Ni(NO_3)_2.6H_2O$

An 80% yield of the nickel salt was obtained.

The nickel salt does not precipitate out of the solution as a colloidal sol, as the mercury and silver salts do.

It is a green solid which decomposes upon heating.

Calcd. for $C_4H_8N_{10}O_6Ni.2H_2O$: C, 12.4; H, 3.6; N, 36.2; Ni, 14.7

Found: C, 12.31; H, 3.89; N, 31.86; Ni, 15.12

The analysis would tend to indicate that a hydrate salt has been formed, but so far no compound can be proposed which would correspond to the found analytical values. It must be noted that the nickel salt cannot be recrystallized.

(c). Formation of the copper salt.

The copper salt was prepared following the same procedure as the nickel compound. It separates out of the solution as a colloidal sol and thus it is difficult to filter. It is a blue solid which decomposes upon heating.

6. Change in the pH of a suspension of N.D.C.D. in water upon the addition of standard sodium hydroxide.

To 1.612 g. of N.D.C.D. (which had been ground fine enough to pass through a fifty mesh screen) was added one hundred mls. of distilled water pH 6.65. The mixture was stirred with a mechanical stirrer for ten minutes and the pH of this mixture was noted using a Beckman pH meter. Standard sodium hydroxide solution (0.93N) was added in small portions. After each addition of the sodium hydroxide the mixture was stirred for three minutes. The stirring was then stopped and the pH was noted. As excess sodium hydroxide was added all of the N.D.C.D. dissolved completely in it. The colour of the N.D.C.D. sodium hydroxide solution was yellow and the intensity of colour depends upon the concentration of the N.D.C.D. The results of this experiment are given in table III, and graphically in figure 3.

TABLE III

Addition of Sodium Hydroxide to a Suspension of N.D.C.D. in Water.

Sodium Hydroxide Added (Mls. of 0.93N)	pH
0	4.75
0.3	9.2
0.78	9.85
1.6	10.18
3.65	10.55
5.65	10.72
7.60	10.88
9.70	11.12
11.55	11.32
13.70	11.50
14.65	11.57
15.73	11.60
16.65	11.62
18.23	11.67

7. Change in the conductivity of a suspension of N.D.C.D. in water upon the addition of standard sodium hydroxide.

This experiment was carried out under conditions similar to those of experiment 6. In this case a conductivity cell where vigorous mechanical stirring was possible was used and the change in the conductivity was noted instead of the change in the pH. Here 1.48 g. of N.D.C.D. was added to seventy mls. of distilled water. Precautions were taken to keep the sodium hydroxide-N.D.C.D. solution away from the carbon dioxide of the air. The results are represented in Table IV and graphically in figure 4.

TABLE IV

Addition of Sodium Hydroxide to a Suspension of N.D.C.D. in Water.

Sodium Hydroxide Added (Mls. of 0.3447N)	Conductivity
0	39.2×10^{-4}
0.2	38.2×10^{-4}
0.5	37.0×10^{-4}
0.7	36.2×10^{-4}
1.0	39.2×10^{-4}
2.0	45.5×10^{-4}
5.0	67.8×10^{-4}
10.0	95.2×10^{-4}
20.0	14.7×10^{-3}
25.0	18.7×10^{-3}
28,0	21.1×10^{-3}
29.0	21.7×10^{-3}
29.5	22.2×10^{-3}
31.0	23.0×10^{-3}
33.4	26.0×10^{-3}
35.1	28.5×10^{-3}

8. (a). Changes in the pH of a solution of sodium-N.D.C.D. in sodium hydroxide upon the addition of standard hydrochloric acid.

A sample of N.D.C.D. (1.719 g. or 11.46 m. eq.) was dissolved in 40.18 mls. of 0.3440N. sodium hydroxide solution (the theoretical amount necessary to form the sodium salt is 33.31 mls.). Vigorous stirring was necessary to dissolve the N.D.C.D. and precautions were taken to keep the sodium hydroxide out of contact with carbon dioxide of the air. Small portions of 0.4105N. hydrochloric acid were added to the solution. Upon the addition of the acid there occurred a lowering of the pH. But as the stirring was continued for three minutes the pH rose to the noted value. No further rise in pH was observed when this mixture was mechanically stirred for any further length of time. The results are presented in Table V, and graphically in figure 5.

TABLE V

Addition of Hydrochloric Acid to the Sodium Salt of N.D.C.D. in Sodium Hydroxide

Hydrochloric Acid Added (Mls. of 0.4105N)	pH
0	11.45
3	11.32
5.5	10.82
*5.82	10.28
5.90	10.28
6.0	10.03
6.12	10.08
7.0	10.42
8.0	10.45
13.0	10.45
25.0	10.10
30.0	9.78
33.0	7.0
33.5	3.18

---

* Point of incipient cloudiness; N.D.C.D. began to precipitate.

(b).

Experiment 8a was repeated. Here instead of stirring for three minutes at the point of incipient cloudiness it was stirred for thirty minutes. In this experiment 1.469 g. of N.D.C.D. (10 m.eq) was dissolved in 34 mls. of 0.3447 N. sodium hydroxide solution (11.7 m.eq). The results are given in

Table VI and in figure 6.

TABLE VI

Addition of Hydrochloric Acid to the Sodium Salt of N.D.C.D. in Sodium Hydroxide.

Hydrochloric Acid Added (Mls. of 0.4119N)	pH
0	11.58
2	11.50
4.0	11.00
*4.6	10.35
4.6	10.50
6.0	10.60
8.0	10.55
12.0	10.55
15.0	10.50
20.0	10.40
23.0	10.10
27.0	9.15
28.0	7.35
28.5	3.60

---

* Incipient Cloudiness stirred for 30 minutes.

9. (a). Change in the conductivity of a sodium hydroxide-N.D.C.D. solution upon the addition of standard hydrochloric acid.

To thirty-four mls. of 0.3447N sodium hydroxide (11.7 m.eq.) in a conductivity cell where mechanical vigorous stirring was possible was added 1.47 g. (10 m.eq.)of N.D.C.D. The procedure outlined in Experiment 8a was followed but the change in the conductivity was noted. The results are presented in Table VII and figure 7.

TABLE VII

Addition of Hydrochloric Acid to the Sodium Salt of N.D.C.D. in Sodium Hydroxide

Hydrochloric Acid Added (Mls. of 0.4119N)	Conductivity
0	34.40×10^{-3}
1.5	32.26×10^{-3}
3.9	28.90×10^{-3}
*4.3	29.15×10^{-3}
5.0	29.41×10^{-3}
7.0	30.49×10^{-3}
10.0	32.26×10^{-3}
14.0	34.01×10^{-3}
20.0	36.10×10^{-3}
25.0	37.74×10^{-3}
28.0	38.46×10^{-3}
29.0	40.49×10^{-3}
30.0	44.26×10^{-3}
31.0	47.62×10^{-3}

(b).

Experiment 9a was repeated with the additional feature that at the point of incipient cloudiness the mixture was stirred for thirty minutes instead of for three. The results are given in Table VIII and in figure 8.

TABLE VIII

Addition of Hydrochloric Acid to a Solution of the Sodium Salt of N.D.C.D. in Sodium Hydroxide.

Hydrochloric Acid Added (Mls. of 0.4119N)	Conductivity
0	31.75×10^{-3}
1.0	30.49×10^{-3}
2.5	28.57×10^{-3}
4.0	26.67×10^{-3}
*4.05	26.67×10^{-3}
----	----------
4.05	28.17×10^{-3}
5.05	28.57×10^{-3}
7.05	30.30×10^{-3}
10.15	31.95×10^{-3}
15.15	35.09×10^{-3}
23.0	38.17×10^{-3}
28.5	40.0×10^{-3}
30.0	46.51×10^{-3}
30.5	48.78×10^{-3}

---

* Point of incipient cloudiness. Stirred for thirty minutes.

10. (a). Evidence that supersaturation exists at the end point and (b) that there is no excess sodium hydroxide at the end point.

Ten milliequivalents of N.D.C.D. (1.47 g.) was dissolved in 34 mls. of 0.3440N sodium hydroxide (11.7 m.eq.) and 4.6 mls. of 0.4105N hydrochloric acid (1.9 m.eq.) were added to the solution in order to cause incipient cloudiness. The precipitate was filtered on a fine sintered glass crucible. Weight of the precipitate was 0.004g.

One drop of the standard hydrochloric acid was added to the filtrate and the solution became cloudy showing that there was no excess sodium hydroxide present.

This experiment was repeated. After the end point had been reached the mixture was stirred for one hour before the precipitate was filtered off. Weight of the precipitate was 0.007 g. The filtrate was then tested for excess sodium hydroxide with the standard acid with the same results as in the preceding case. Thus this experiment would tend to indicate that a small amount of supersaturation does exist at the end point.

11. (a). The amount of excess sodium hydroxide necessary to dissolve a given amount of N.D.C.D.

Ten milliequivalents of N.D.C.D. (1.47 g.) which had been ground fine enough to pass through an 100 mesh screen was added to 29.1 mls. of 0.3440N sodium hydroxide (10 m.eq.). The mixture was mechanically stirred for three hours in a closed system (carbon dioxide free). The insoluble portion was filtered off. Weight of the insoluble portion was 0.032 g. It was necessary to add 0.40 mls. of 0.4105 N hydrochloric acid in order to cause incipient cloudiness.

Actually the 0.032 g. of N.D.C.D. corresponds to 0.53 mls. of the standard acid. Thus the low amount of standard hydrochloric acid necessary to cause incipient cloudiness may be due to the unavoidable reaction between the sodium hydroxide and the carbon dioxide in the air during the filtration.

(b).

Seven samples of N.D.C.D. (which had been passed through an 100 mesh screen) were weighed out. Various amounts of the standard alkali were added to each and the mixtures stirred for three hours. The results are shown in Table IX.

TABLE IX.

The Excess of Sodium Hydroxide Necessary to Dissolve A Given Amount of N.D.C.D.

Wt. of the N.D.C.D.	Sodium Hydroxide Added (Mls. of 0.134N)	Remarks
0.147 g.(1 m.eq.)	7.54 (1 m.eq.) + 0.1 ml.)	The N.D.C.D. did not dissolve
0.147 g.(1 m.eq.)	7.64 (1 m.eq.) + 0.2 ml.)	
0.147 g.(1 m.eq.)	7.74 (1 m.eq.) + 0.3 ml.)	
0.147 g.(1 m.eq.)	7.84 (1 m.eq.) + 0.4 ml.)	
0.147 g.(1 m.eq.)	7.94 (1 m.eq.) + 0.5 ml.)	
0.147 g.(1 m.eq.)	8.04 (1 m.eq.) + 0.6 ml.)	The N.D.C.D. dissolved
0.147 g.(1 m.eq.)	8.14 (1 m.eq.) + 0.7 ml.)	

As the excess of sodium hydroxide increased, the solution became clearer. When 0.6 mls. of sodium hydroxide was added, all of the N.D.C.D. dissolved.

(c).

Experiment 11b was repeated using a different weight of N.D.C.D. and different standard base. The results are given in Table X.

TABLE X.

The Excess of Sodium Hydroxide Necessary to Dissolve a Given Amount of N.D.C.D.

	Wt. of the N.D.C.D.	Sodium Hydroxide Added (mls. of 0.3440N)	Remarks
1.	0.441 g.(3 m.eq.)	8.72 (3 m.eq.)	
2.	0.441 g.(3 m.eq.)	8.82 (3 m.eq.+ 0.1. ml.)	The N.D.C.D. did not dissolve
3.	0.441 g.(3.m.eq.)	8.92 (3 m.eq.+ 0.2 ml.)	
4.	0.441 g.(3 m.eq.)	9.02 (3 m.eq.+ 0.3 ml.)	
5.	0.441 g.(3 m.eq.)	9.12 (3 m.eq.+ 0.4 ml.)	The N.D.C.D. dissolved

To number 2 of the above 0.3 mls. of the standard sodium hydroxide was added and all of the N.D.C.D. dissolved.

To number 3, 0.2 mls. of the standard base and ten mls. of distilled water was added and the N.D.C.D did not dissolve. Similar results were obtained when 0.1 ml. of the base and ten mls. of distilled water was added to No. 3.

To 0.441 g.(3 m.eq.) of N.D.C.D., 9.12 mls. of the standard sodium hydroxide and ten mls. of distilled water were added and all of the N.D.C.D. did not dissolve.

Thus it would seem that the equilibrium established depends upon the concentration of the N.D.C.D. and the concentration of the hydroxyl ions.

12. (a). Evidence that an equilibrium is established during the titration of the sodium salt.

A sample of N.D.C.D. (1.47 g.) was dissolved in 34 mls. of 0.3442N sodium hydroxide. Enough standard hydrochloric acid (4.05 mls. of 0.4119N) was added to cause incipient cloudiness. Then 0.5 mls. excess hydrochloric acid was added and after allowing the mixture to stand for thirty minutes the undissolved N.D.C.D. was filtered off. Hydrochloric acid was added to the filtrate in order to cause incipient cloudiness plus 0.5 ml. in excess. This procedure was repeated seven times and the results are presented in Table XI.

TABLE XI

Addition of Excess Acid to the Sodium Salt of N.D.C.D. in Sodium Hydroxide

Mls. of 0.4119N Hydrochloric Acid Necessary to Cause Incipient Cloudiness	Excess of 0.4112N Hydrochloric Acid	Wt. of the N.D.C.D which had precipitated out
4.05	.5 mls.	0.065 g.
0.25	.5 mls.	0.062 g.
0.30	.5 mls.	0.066 g.
0.4	.5 mls.	0.063 g.
0.4	.5 mls.	0.062 g.
0.4	.5 mls.	0.058 g.
0.4	.5 mls.	0.055 g.

In all of the cases 0.0303 g. of N.D.C.D. can be accounted for by the excess hydrochloric acid added. But what is actually obtained is more than twice this amount.

In experiment 10 the weight of the precipitate at the point of incipient cloudiness after one hour of stirring was found to be 0.007 g. This does not make up for the difference of the excess N.D.C.D. obtained in this experiment. Also in experiment 10 just one drop of hydrochloric acid was necessary to cause incipient cloudiness and here 0.2-0.4 mls. are necessary. Thus it would seem that some N.D.C.D. has precipitated out of the solution setting free some sodium hydroxide and establishing an equilibrium similar to the one noted when N.D.C.D. goes into solution.

As the solution becomes more dilute (due to the precipitation of the N.D.C.D. and to washing the precipitate during the filtration (this was kept down to a minimum) the weight of the N.D.C.D. which precipitates out decreases.

It was noted in Experiment 11 that when an equivalent amount of N.D.C.D. and sodium hydroxide is stirred for three hours 0.032 g. of N.D.C.D. did not go into solution. The amount of N.D.C.D. which did not go into solution is of the same order as the excess of N.D.C.D. which was noted at the same concentrations in this experiment.

(b).

Experiment 12a was repeated but here the amounts of excess acid were varied. The results are given in Table XII.

TABLE XII

Addition of Excess Acid to the Sodium Salt of N.D.C.D. in Sodium Hydroxide

	Mls. of 0.4119N Hydrochloric Acid Necessary to Cause Incipient Cloudiness	Excess of 0.4119N Hydrochloric Acid	Wt. of N.D.C.D. which had precipitated out	Wt. of N.D.C.D. equivalent to the excess acid
1.	4.10	0.2 mls.	0.042 g.	0.012 g.
2.	0.3	0.3 "	0.050 g.	0.019 g.
3.	0.4	0.4 "	0.060 g.	0.024 g.
4.	0.4	0.1 "	0.035 g.	0.006 g.
5.	0.4	0.05 "	0.027 g.	0.003 g.

In numbers 1, 2, 3, and 4 the mixture was allowed to stand for one hour. In number 5 the mixture was allowed to stand for sixteen hours before it was filtered. It was necessary to add 0.1 mls. of acid to the filtrate of number 5 in order to cause incipient cloudiness while in Experiment 10 just one drop was necessary to cause incipient cloudiness. Also the weight of the N.D.C.D. which had precipitated is greater. This result may not be valid as some decomposition of the N.D.C.D. may have occurred here. Again here, as in Experiment 12a, it would seem that an equilibrium has been established.

13. The Quantitative Estimation of N.D.C.D.

Reagents: 1. Standard, carbonate-free, sodium hydroxide solution between 0.3 - 0.4 normal;

2. Standard hydrochloric acid between 0.3 - 0.4 normal.

Procedure: A certain weight of N.D.C.D. (in this laboratory ten milliequivalents, i.e. 1.47 g. were used) is dissolved in an excess of the standard alkaline solution. To accomplish this the mixture is stirred vigorously for about five minutes. During the stirring care must be taken to keep the alkali out of contact with the air, or else the results will be slightly high - from 0.5 to 1%. When all of the N.D.C.D. has dissolved, standard hydrochloric acid is added until the solution becomes cloudy. The point of incipient cloudiness is taken as the end point of the titration, where there are equivalent amounts of N.D.C.D. and sodium hydroxide in the solution. It has been found that it is easier to note the end point if a beam of light is passed through the solution during the titration.

14. Results of analysis of different samples of N.D.C.D.

N.D.C.D. was prepared by Thiele's method and reprecipitated from sodium hydroxide solution. The samples obtained after each reprecipitation were tested by the method given in experiment 13. The results are given in Table XIII.

Table XIII

Amount of Times Reprecipitated from Sodium Hydroxide	% Purity
None	97.4, 97.1
Once	97.8, 97.6
Twice	99.8, 99.9
Thrice	100.2, 100.4
Four Times	99.8, 100.0

In another experiment N.D.C.D. which had not been reprecipitated from sodium hydroxide was well washed with water. This was done by stirring vigorously 10 g. of finely ground N.D.C.D. in 500 mls. of water for thirty minutes, and washing the N.D.C.D. on the Bűcher funnel with one litre of water. The purity of N.D.C.D. as analyzed by the given method went up to 99.3 and 99.5%. Subsequent washings raised the purity of N.D.C.D. up to 100%. Hence it is not necessary to reprecipitate the N.D.C.D. from sodium hydroxide in order to purify it.

15. Qualitative tests for possible impurities in N.D.C.D.

Forty grams of well ground N.D.C.D. (97.5% pure) were added to four hundred mls. of distilled water. The mixture was well stirred for one hour. The N.D.C.D. was filtered off and the filtrate was tested for cyanamide, thiourea, cyanide, dicyandiamide, thiocyanante, ammonia, guanidine and dicyandiamidine by the method outlined by Buchanan (146). A positive test was obtained for dicyandiamide only.

Following the procedure of experiment 15 a quantitative estimation of dicyandiamide (147) was carried out on 10g. of N.D.C.D. The results obtained are given in Table XIV.

TABLE XIV

Initial Purity of N.D.C.D.	97.5%
% Dicyandiamide Found	0.2%
Final Purity of N.D.C.D	98.8%

From the results it would appear that the amount of dicyandiamide is low but this procedure for the quantitative estimation of dicyandiamide usually gives low values (147).

16. Analysis of N.D.C.D. contaminated with related nitrogen compounds.

Various amounts of N.D.C.D. contaminated with dicyandiamide, nitroguanidine, guanidine carbonate, dicyandiamidine sulfate, melamine, and cyanuric acid were prepared. These samples were tested for their amounts of N.D.C.D. The results are shown in Table XV.

TABLE XV

Analysis of N.D.C.D. Contaminated with Related Nitrogen Compounds

Contaminant	Weight of Contaminant	Weight of N.D.C.D.	% N.D.C.D. Theoretical	% N.D.C.D. Found
Dicyandiamide	0.7376	0.2053	47.8	47.9
"	0.3391	1.1281	75.2	75.3
"	0.1189	1.3391	90.3	89.8
"	0.073	1.4547	94.9	94.4
Nitroguanidine	0.1518	1.6435	90.6	89.6
"	0.0696	1.432	95.3	94.6
Guanidine Carbonate	0.4081	1.1042	73.0	73.4
" "	0.0891	1.3661	93.9	94.4
Dicyandiamidine Sulfate	0.5464	1.3405	71.0	87.7
" "	0.202	1.4197	87.6	98.5
Melamine	0.0592	1.6129	96.5	96.2
Cyanuric Acid	0.0586	1.3923	95.9	97.9
" "	0.0838	1.465	98.4	102

Any compound which will react with the base will give high results. This is borne out in Experiment 16 in the case of cyanuric acid and dicyandiamidine sulfate.

In Experiment 16 nitroguanidine, melamine and cyanuric acid did not dissolve in the sodium hydroxide solution. Thus these impurities are not present in N.D.C.D. as prepared by Thiele's method (2). In the case of dicyandiamidine sulfate the precipitate which comes down during the addition of a small amount of acid has not the same appearance as the one which precipitates out in a pure N.D.C.D. sodium hydroxide solution. It is more voluminous and takes a longer time to dissolve. Thus dicyandiamidine sulfate is not present in the N.D.C.D. Guanidine carbonate which is used as a primary standard for the standardization of acids does not interfere here (148).

17. Isolation of the sodium salt of N.D.C.D.

(a). A sample of N.D.C.D. (3.7g. or .025M) was dissolved in fifteen mls. of 10% sodium hydroxide solution. A large excess of acetone was added to this solution until it became milky, and in a few minutes a white voluminous precipitate separated out of the solution. The precipitate was collected on a filter paper, washed with ethanol and ether, and dried at 60° C. The weight of the product was 4.1g. which corresponds to a yield of 88%.

Anal. Calcd. for $C_2H_4N_5O_3Na$;- Na. 13.6%
Found:- Na. 12.9%

The compound has no melting point but explodes upon heating. It is insoluble in ethanol, methanol, acetone, or ether. It decomposes in hot formamide giving off ammonia. When the salt is added to water, most of it dissolves leaving a small amount of residue which has the same properties as N.D.C.D.; but it dissolves completely in very dilute aqueous sodium hydroxide.

An aqueous solution of the salt turns red litmus blue. When its aqueous solution is acidified, a white precipitate which has the properties of N.D.C.D. separates from the solution. N.D.C.D. also separates from the solution when ammonium chloride is added to the aqueous salt solution.

To purify the sodium salt it was dissolved in water, the insoluble N.D.C.D. was removed by filtration, and the salt was again separated by the addition of a large excess of acetone.

This material, obtained by this treatment, behaved in the same manner as the original salt. When it was added to water, most of it went into solution, but a residue of N.D.C.D. remained. Obviously this method either yields sodium-N.D.C.D. contaminated with N.D.C.D., or possibly the sodium salt in water gives rise to a small amount of N.D.C.D.

(b). Sodium N.D.C.D. was prepared by the addition of excess methanol instead of acetone to an aqueous N.D.C.D.-sodium hydroxide solution. This method also resulted in impure sodium-N.D.C.D.

(c). The salt was prepared from a greater excess of sodium hydroxide and from methanol which had been saturated with sodium hydroxide. This procedure also resulted in sodium-N.D.C.D. contaminated with a small amount of N.D.C.D.

18. (a). Change in pH of an aqueous solution of sodium-N.D.C.D. upon addition of standard hydrochloric acid.

A sample of sodium-N.D.C.D. (1.083g. or 0.006M.) was added to 30 mls. of distilled water. The sodium-N.D.C.D. did not dissolve completely, but left a residue of insoluble N.D.C.D. Small portions of 0.4103N hydrochloric acid were added to the solutions and the mixture stirred mechanically for three minutes. Upon the addition of the acid, a small amount of N.D.C.D. separated out, and the pH dropped considerably, but with stirring the pH rose to a value which did not change after further stirring. Thus it was found that if a reading was taken after three minutes of stirring, the value did not change even after thirty minutes of stirring and the reading represents the equilibrium value of pH. The changes in the pH are represented in Table XVI and graphically in figure 9.

TABLE XVI

Addition of Hydrochloric Acid to Aqueous Sodium N.D.C.D.

Hydrochloric Acid Added (Mls. of 0.4103N.)	pH
0	11.4
1.4	11.25
2.44	11.14
5.0	10.85
8.0	10.68
10.0	10.59
14.0	10.12
16.0	2.8

(b). Experiment 18a was repeated but here the insoluble N.D.C.D. was separated by filtration. In this experiment 0.8738 g. of sodium N.D.C.D. (0.005M.) was added to 30 mls. of distilled water. The results are given in Table XVII and in figure 10.

TABLE XVII

Addition of Hydrochloric Acid to Aqueous Sodium N.D.C.D.

Hydrochloric Acid Added (Mls. of 0.4103N.)	pH
0	11.46
0.2	11.16
0.3 I.C.	11.08
0.5	11.12
3.0	10.97
6.0	10.85
11.0	10.04
11.65	8.97
11.70	7.43
11.75	6.65
11.80	5.05

According to these data, 11.75 mls. of 0.4103N. hydrochloric acid have neutralized 0.8738 g. sodium-N.D.C.D., corresponding to a sodium content of 12.75.

The weight of the insoluble N.D.C.D. was found to be 0.0731 g., but it was necessary to add 0.3 mls. of the standard hydrochloric acid to neutralize excess sodium hydroxide and to cause incipient cloudiness. This corresponds to 0.0181 g. of N.D.C.D.

Therefore, the actual weight of insoluble N.D.C.D. was:-

$$\begin{array}{r} 0.0731\text{g.} \\ -0.0181 \\ \hline 0.0550\text{g.} \end{array}$$

Thus the weight of sodium N.D.C.D. was:-

$$\begin{array}{r} 0.8738\text{g.} \\ -0.0550 \\ \hline 0.8188\text{g.} \end{array}$$

This corresponds to a sodium content of:-

$$\frac{11.75 \times 0.4103 \times 0.023}{0.8188} = 13.5\% \text{ Found}$$

.Theoretical 13.6%

19. Change in the conductivity of an aqueous sodium-N.D.C.D. solution upon the addition of standard acid.

Experiments 18a and b were repeated but here the change in the conductivity was noted instead of the change in the pH. In experiment 18a, 1.0282g. of sodium-N.D.C.D. (0.006M.) was added to 50 mls. of water, and in 18b 0.7962g. (0.005M.) was added to 70 mls. of water. The results are presented in Tables XXVIII and XIX, and graphically in figures 11 and 12.

TABLE XVIII

Addition of Hydrochloric Acid to Aqueous Sodium-N.D.C.D.

Hydrochloric Acid Added (mls. of 0.4103N.)	Conductivity
0	1.55×10^{-3}
0.2	1.58×10^{-3}
3.0	1.64×10^{-3}
6.0	1.78×10^{-3}
9.0	1.91×10^{-3}
12.0	2.06×10^{-3}
14.0	2.06×10^{-3}
15.0	2.08×10^{-3}
16.0	2.17×10^{-3}
17.0	2.63×10^{-3}

TABLE XIX

Addition of Hydrochloric Acid to Aqueous Sodium-N.D.C.D.

Hydrochloric Acid Added (mls. of 0.4103N.)	Conductivity
0	1.01×10^{-3}
0.1	1.0×10^{-3}
0.2	1.0×10^{-3}
0.35 I.C.	1.03×10^{-3}
1.0	1.06×10^{-3}
4.0	1.12×10^{-3}
7.0	1.37×10^{-3}
10.0	1.49×10^{-3}
10.8	1.51×10^{-3}
11.0	1.52×10^{-3}
11.6	1.76×10^{-3}
12.0	1.93×10^{-3}
12.5	2.16×10^{-3}

20. Isolation of the potassium salt of N.D.C.D.

The potassium salt of N.D.C.D. was prepared following the same procedure outlined in the preparation of the sodium salt. In this experiment 7.3g. (0.05M.) of N.D.C.D. was dissolved in 150 mls. of 3% potassium hydroxide. The weight of the product was 7.8g.which corresponds to a yield of 85%.

The potassium salt of N.D.C.D. is a white solid, with a shiny metallic lustre. It has the same solubility characteristics as the sodium salt, but it decomposes at 326-8°C(uncorr) without explosion. Like the sodium salt it does not precipitate as a pure compound, but separates contaminated with N.D.C.D. As with the sodium salt, free N.D.C.D. can be obtained from the potassium salt upon addition of hydrochloric acid or ammonium chloride to an aqueous salt solution.

Calcd. for $C_2H_4N_5O_3K$:-	K,	21.08
Found:-	K,	18.7

21. (a). Change in the pH of aqueous potassium N.D.C.D. upon the addition of standard hydrochloric acid.

A sample of potassium N.D.C.D. (0.9214g. or 0.005 M.) was added to 30 mls. of distilled water. The potassium salt did not dissolve completely but left an insoluble residue of N.D.C.D. Small portions of 0.4103N. hydrochloric acid were added to the solution. The mixture was stirred vigorously for five minutes by a mechanical stirrer and the change in the pH was noted. As soon as the standard acid was added to the mixture, N.D.C.D. separated and the pH showed a marked drop, but after a minute of stirring the pH rose to the value which is noted in Table XX and graphically in figure 13.

TABLE XX

Addition of Hydrochloric Acid to Aqueous Potassium N.D.C.D.

Hydrochloric Acid Added (mls. of 0.4103N.)	pH
0	11.18
0.1	11.18
0.5	11.13
2.0	11.03
5.0	10.91
10.0	10.36
10.9	6.65
10.95	5.87
11.0	4.25

(b). Experiment 21a was repeated, but here the insoluble N.D.C.D. was separated by filtration. In this experiment 0.9555g. of potassium N.D.C.D. (0.005M.) was added to 30 mls. of distilled water. The results are given in Table XXI and graphically in figure 14.

TABLE XXI

Addition of Hydrochloric Acid to Aqueous Potassium N.D.C.D.

Hydrochloric Acid Added (mls. of 0.4103N.)	pH
0	10.72
0.1	10.57
0.3 I.C.	10.4
after five minutes rose to	10.7
0.5	10.7
1.0	10.7
5.0	10.58
10.0	10.08
10.5	9.86
11.15	9.29
11.2	8.03
11.25	6.77
11.30	6.20
11.35	5.62

From Table XXI, 11.20 mls. of 0.4103N. hydrochloric acid have neutralized 0.9555g. of potassium-N.D.C.D., corresponding to a potassium content of 18.8%.

On the whole it is much more difficult to get a steady pH reading with the potassium salt than with the sodium salt. Also the insoluble N.D.C.D. formed from the potassium salt is much more difficult to filter than that from the sodium salt, as it tends to pass through the filter. Thus the method employed with the sodium salt of weighing the amount of insoluble N.D.C.D. was not applicable here as can be seen from the following calculations:-

Weight of insoluble N.D.C.D.	0.0364g
Weight of N.D.C.D. corresponding to 0.3 mls. acid	- .0181
Actual weight of insoluble N.D.C.D.	.0183g.

Thus actual weight of sample of KN.D.C.D.	0.9555
	- .0183
	0.9372g.

Therefore %K = 17.1%

22. Change in the conductivity of an aqueous potassium-N.D.C.D. solution upon the addition of standard acid.

Experiment 21b was repeated, but here the change in conductivity was noted instead of the change in pH. In this case 0.9627g. (.005M.) of potassium N.D.C.D. was added to 50 mls. of distilled water. The results are presented in Table XXII and graphically in figure 15.

TABLE XXII

Addition of Hydrochloric Acid to Aqueous Potassium-N.D.C.D.

Hydrochloric Acid Added (mls. of 0.4103N.)	Conductivity
0	1.55×10^{-3}
0.2	1.51×10^{-3}
0.43 I.C.	1.55×10^{-3}
1.00	1.58×10^{-3}
4.00	1.73×10^{-3}
7.00	1.87×10^{-3}
10.00	2.08×10^{-3}
12.00	2.24×10^{-3}
12.50	2.5×10^{-3}
13.0	2.71×10^{-3}

23. Preparation of Nitrosodicyandiamidine.

(a). To one hundred mls. of a 15% sodium hydroxide solution 7.35g. (0.05M.) of N.D.C.D. was added. The suspension was mechanically stirred until all of the N.D.C.D. had dissolved in the sodium hydroxide. The solution was then cooled in an ice bath until the temperature had dropped to 10° C. Six and one half grams of zinc (0.1M.) was added in small portions with cooling so that the temperature was kept constant at 10° C. After the addition of the first portion of the zinc, the mixture was tested for the presence of a nitroso group by adding a few drops of the reaction mixture to aqueous ferrous sulfate. According to Thiele (42) a red colour indicates the presence of a nitroso group.

After the addition of the first portion of the zinc, the mixture was tested every two minutes. At first when a few drops of the reaction mixture was added to the aqueous ferrous sulfate, the colour of the solution turned green and a green precipitate separated out of the ferrous sulfate solution. But after several minutes the mixture gave a red colour with the ferrous sulfate denoting the presence of a nitroso group. A positive test for this group was only obtained for a short period of time, for, as the reaction continued, the red colour gave way to the previous green one.

When the reaction had subsided, the excess zinc was separated by filtration. Upon acidification of the filtrate a yellow, inorganic material separated out. This material is insoluble in all common organic solvents, in cold and in hot water. It does not burn and is probably some inorganic zinc salt.

(b). This reaction was repeated at 0°, 25°, and 40°. In all cases negative results were obtained.

(c). The reduction of N.D.C.D. was attempted with zinc and ammonium chloride (58) and with zinc and acetic acid (62). In both cases the N.D.C.D. was recovered unchanged.

24. Methylation of N.D.C.D.

(a). With methyliodide

To 1.47 g. of N.D.C.D. (0.01M.) dissolved in 16 mls. of 5% sodium hydroxide an 100% excess of methyliodide (1.24 mls. or .02M.) was added. The solution was mechanically stirred for three hours. It was then acidified with dilute hydrochloric acid which caused the separation of a white precipitate. This solid was collected on a filter, washed with methanol and air dried. The product weighed 1.45g. It exhibited all the properties of N.D.C.D. and had the same composition as N.D.C.D.

(b). With dimethylsulfate.

The procedure used here was the same as that used by Backer for the methylation of nitramines (126). A sample of sodium-N.D.C.D. (7.4g. or .05M.) was dissolved in 50 mls. of a sodium hydroxide-sodium bicarbonate solution (1 g. of sodium hydroxide and 4 g. of sodium bicarbonate). To this solution 9.5 g. (7.1 mls. or 0.075M.) of dimethylsulfate was added with stirring. This caused an increase in the temperature of the solution, and after ten minutes a white solid separated out of the solution and the temperature rose from 28 - 40°C. As the reaction continued the temperature started to fall. The white solid was then separated by filtration. The solid weighed 6 g., and exhibited the properties of N.D.C.D. The weight of the product corresponds to an 83% yield of N.D.C.D.

25. Preparation of N phenylazo N^1nitrodicyandiamidine

(a). To 7.3g. (0.05M.) of N.D.C.D. dissolved in 400 mls. of dilute sodium hydroxide (5.8g.) was quickly added an equivalent amount of benzenediazonium chloride composed of 4.6g. aniline, 3.6g. sodium nitrite and 11 mls. of concentrated hydrochloric acid. Here enough sodium hydroxide is necessary to form sodium N.D.C.D., to neutralize the hydrochloric acid, and to form the diazotate salt. The solution exhibited the same colour changes during the reaction as was reported in the formation of phenylazodicyandiamide (67), i.e. it turned red and after one minute became turbid. It was then quickly acidified with 12% hydrochloric acid, which resulted in the separation of a yellow solid. The product was collected on a filter, washed with hot ethanol, ether, and dried first at room temperature and then under reduced pressure at 60°C. The product wighed 10g. which represents a yield of 80%.

N phenylazo N^1 nitrodicyandiamidine is a yellow solid which explodes upon heating, and when added to concentrated sulfuric acid. It is insoluble in methanol, ethanol, ether, acetone, chloroform, formamide, petroleum ether, carbontetrachloride and aniline. It can be purified by dissolving in aqueous sodium hydroxide, followed by reprecipitation with hydrochloric acid. It decomposes after several days accompanied by colour change from yellow to brown.

Anal. Calcd. for $C_8H_9N_7O_3$:-	C, 38.2;	H, 3.58
Found:-	C, 37.9;	H, 3.68

(b). The aforementioned preparation was also attempted from a solution of N.D.C.D. in a slight excess of 10% sodium hydroxide and an equivalent amount of benzenediazonium sulfate. Upon the addition of diazonium salt a solid separated out of the solution, and the colour of the mixture turned orange yellow. Upon the further addition of the salt, the colour changed to yellow and the reaction mixture started to decompose (gassing). The mixture was stirred for eight hours during which the gassing continued and the colour of the solution turned dark brown.

The insoluble material was then collected on a filter, and dried at room temperature. Both the insoluble residue and the filtrate gave off a smell of phenol. When heated this residue burns with a white flash and appears to be a mixture of N.D.C.D. and a diazo compound.

A part of this residue was added to hot ethanol and the alcohol insoluble material was collected on a filter. This material exhibited all the properties of N.D.C.D.

(c). The reaction was repeated except that here enough sodium hydroxide was used to dissolve the N.D.C.D. and to neutralize the sulfuric acid (8g. sodium hydroxide in 100 mls. of water). Upon the addition of the diazonium salt the colour of the solution turned orange, and a gas was given off which had the same smell and lacrymator effect as acetyl chloride. As soon as the gassing had started, the solution was acidified with sulfuric acid which caused the separation of an orange precipitate. This material was collected on a filter and dried at room temperature. This product behaved as a mixture of an aromatic dye and N.D.C.D.

26. Decomposition of N phenylazo N^1nitrodicyandiamidine

(a). Ten grams of N phenylazo N^1nitrodicyandiamidine (.04M.) was added to a solution of 100 mls. 95% ethanol and 5 mls. concentrated hydrochloric acid. No decomposition of the N.D.C.D. derivative occurred in this medium at room temperature. The suspension was heated on a steam bath to 50° and the compound started to decompose, giving off a gas. The reaction mixture was heated to 75° and was kept at this temperature until no further gassing occurred.

The mixture was cooled and the insoluble material was collected on a filter and washed with methanol. It was then reprecipitated from aqueous sodium hydroxide (in the same manner as N.D.C.D.) and recrystallized from 12% hydrochloric acid. (N.D.C.D. can be recrystallized from 12% hydrochloric acid. Here some of the N.D.C.D. undergoes decomposition as it is necessary to heat the acid to 105° to dissolve the N.D.C.D.) The product exhibited all the properties of N.D.C.D., and had the composition of N.D.C.D.

Anal. Calcd. for $C_2H_5N_5O_3$ C, 16.3; H, 3.41.
Found:- C, 16.0; H, 3.44

The only indication of the product from the decomposition of the benzeneazo group was that the hydrochloric acid-alcoholic solution smelled of phenol.

(b). The N phenylazo N^1nitrodicyandiamidine was decomposed in (i) ethanol-nitric acid, (ii) ethanol-sulfuric acid, and (iii) butanol-hydrochloric acid. In all the cases the decomposition product was found to be N.D.C.D.

(c). The azo derivative was added to dry ether and hydrogen chloride gas was passed through the ether. The ether was evaporated at room temperature and the residue was decomposed in absolute ethanol. Here again the decomposition product was N.D.C.D.

(d). Five grams of N phenylzao N^1nitrodicyandiamidine was added to 50 mls. of absolute ethanol saturated with hydrogen chloride gas at 25°. The mixture was heated in a Carius bomb at 100° for thirty minutes. During the course of the reaction all of the solid material had dissolved in the ethanol, and upon opening the bomb a gas was given off. The ethanol was evaporated and the residue was recrystallized several times from aqueous ethanol. The product was composed of white needle-like crystals. This compound was recrystallized several times from dilute ethanol, and gave a m.p. of 136°C. A mixture of this compound and carbethoxy guanidine hydrochloride showed no depressions of the m.p.

Anal. Calcd. for $C_4H_{10}N_3O_2Cl$; C, 28.6; H, 5.97; N, 25.1; Cl, 21.2.
Found:- C, 28.2; H, 6.26; N, 24.5; Cl, 20.84.

27. Preparation of N p-tolylazo-N^1nitrodicyandiamidine.

The p-tolylazo derivative was prepared in the same manner as the benzeneazo one. The quantities used were:-

7.3g. N.D.C.D. (.05M.)
5.4g. p-Toluidine (.05M.)
11 mls. concentrated hydrochloric acid
3.6g. sodium nitrite
5.8g. sodium hydroxide
350 mls. water

The product was a yellow dye which did not decompose upon standing as did benzeneazo N.D.C.D. Like the phenylazo derivative it exploded upon heating. The weight of the product was 9g. which corresponds to a yield of 65%. The azo derivative was purified by reprecipitating from sodium hydroxide.

Anal. Calcd. for C H N O ;		C, 40.07;	H, 3.7
	Found:	C, 28.7;	H, 3.96

The analytical data show the product to be impure and since it is insoluble in all solvents, it cannot be purified.

This compound was decomposed in the same manner as the phenylazo derivative. In all cases N.D.C.D. was obtained as the decomposition product.

28. Preparation of N o-carbonic acid benzeneazo N^{1}nitro-dicyandiamidine.

This azo derivative was prepared in the same manner as outlined for the preparation of the same dicyandiamide derivative. The product was a red dye which exploded upon heating. Like the tolyl derivative the analysis did not agree with the calculated figures, but indicated this product to be a mixture of the azo dye and N.D.C.D. Decomposition of this compound produced N.D.C.D. as the product.

Anal. Calcd. for $C_9H_9N_7O_5$: C, 36.6; H, 3.05
Found: C, 26.8; H, 3.28

29. Attempted preparation of N methylol N^1nitrodicyandiamidine

(a). From sodium-N.D.C.D.

(i). A sample of N.D.C.D. (37g. or 0.025M) was dissolved in 15 mls. of 10% aqueous sodium hydroxide and an equivalent amount of formaldehyde (2 mls. of formalin 0.025M.) was added to this solution. After several minutes decomposition began and a gas was given off.

A small aliquot, taken at the beginning of the decomposition, was acidified with dilute nitric acid, which caused the separation of unreacted N.D.C.D. The N.D.C.D. was removed on a filter, and the filtrate tested for the presence of guanidine with negative results.

The decomposition was allowed to proceed for ten minutes and again an aliquot portion was acidified with dilute nitric acid. The gassing which occurred upon acidification indicated the presence of a carbonate. This time, no unreacted N.D.C.D. separated, but decomposition occurred at an accelerated rate giving off large volumes of nitrogen dioxide (by reduction of the added nitric acid?).

After gassing had ceased, the solution was evaporated at 50° by passing an air stream over it. The residue that remained was sodium carbonate. No trace was found of either guanidine or its salts, or of any organic compound.

(ii). The reaction was repeated. In this experiment the sodium-N.D.C.D.-sodium hydroxide solution was cooled to 0°C. The addition of the formalin again caused decomposition, but at a much slower rate than previously.

After ten minutes at 0°C., the addition of excess methanol caused the separation of an oil. The mixture was allowed to stand in the refrigerator overnight and white crystals separated from the solution. These crystals exhibited the same properties as sodium-N.D.C.D.

As it was impossible to recrystallize this product, analysis did not indicate whether it was a contaminated methylol derivative or the contaminated sodium salt of N.D.C.D.

Anal. Calcd. for $C_3H_6N_5O_4Na$:- C, 18.1; H, 3.13; N, 35.2; Na, 11.5.
Anal. Calcd. for $C_2H_4N_5O_3Na$;- C, 14.2; H, 2.37; N, 41.4; Na, 13.6
Found:- C, 15.0; H, 2.71; N, 36.8; Na, 14.0

Attempts were made to isolate the free compound by (a) acidifying the aqueous solution with hydrochloric or acetic acid, (b) by passing carbon dioxide gas through the aqueous solution, (c) by adding the salt to anhydrous ether and passing through hydrogen chloride, (d) by adding ammonium chloride to an ammoniacal solution of the salt.

All these attempts resulted in the formation of N.D.C.D.

(b). From potassium-N.D.C.D.

The formaldehyde reaction was studied in potassium hydroxide solution with identical results. The potassium salt exhibited the same properties as potassium-N.D.C.D. Here the analysis indicated that this was the contaminated potassium-N.D.C.D.

Anal. Calcd. for $C_3H_6N_5O_4K$: C, 16.8; H, 2.79; N, 32.5; K, 18.2
Anal. Calcd. for $C_2H_4N_5O_3K$: C, 13.0; H, 2.16; N, 37.8; K, 21.1
Found: C, 12.2; H, 2.77; N, 34.0; K, 18.7

30. Preparation of N(1,1 bishydrazino) methyl N^1nitrourea

To 6 mls. of 100% hydrazine hydrate (0.13M.) 3.7g. of N.D.C.D. (.025 M.) was added. Immediate exothermic decomposition of the N.D.C.D. occurred with gassing. After several minutes all of the N.D.C.D. had dissolved in the hydrazine hydrate. The solution was gently shaken for about five minutes upon which white crystals separated out of the solution. Twenty-five mls. of methanol was added to the mixture after which it was allowed to stand in a refrigerator for one hour. The product was collected on a filter and was washed with methanol. The weight of the product was 3.5g. After recrystallization from aqueous methanol the m.p. was 142° (uncorr.) but further recrystallizations from aqueous ethanol indicated no increase in m.p.

Anal. Calcd. for $C_2H_9N_2O_3$:- C, 13.40; H, 5.03; N, 54.7
Found:- C, 13.40; H, 4.86; N. 54.3

The compound is soluble in water, insoluble in methanol, ethanol, acetone, and ether. It explodes when added to cold concentrated sulfuric acid, and gives a positive nitramide test when treated with sodium hydroxide and ferrous sulfate.

When a 5% aqueous solution of ferric chloride was added to an aqueous solution of N(1,1 bishydrazino) methyl N^1 nitrourea, the resulting solution became turbid. It was then allowed to stand for several minutes during which time the nitrourea derivative began to decompose, giving off a gas, and the solution lost its turbidity!

31. The formation of the acetone, benzaldehyde, and the dihydrochloride derivative of N(1,1 bishydrazino) methyl N^1 nitrourea.

(a). Preparation of N(1 acetonehydrazo 1 hydrazino) methyl N^1 nitrourea.

A sample of N(1,1 bishydrazino) methyl, N^1 nitrourea (0.85g. or .005M.) was dissolved in a minimum amount of water, and an equivalent amount of acetone was added to it. A few drops of acetic acid was added to the solution, upon which white crystals immediately separated out. The mixture was allowed to stand in a refrigerator for one hour and the crystalline solid was collected on a filter. The product, recrystallized several times from aqueous ethanol, was a white crystalline material, soluble in hot water, insoluble in ethanol, methanol and ether; m.p. 135°C.

Anal. Calcd. for $C_5H_{13}N_7O_3$: C, 27.15; H, 5.58; N, 44.3

Found:- C, 27.10; H, 5.90; N, 44.1

(b) Preparation of N(1 benzalhydrazo 1 hydrazino) methyl N^1 nitrourea.

One two hundredth of a mole of N(1,1 bishydrazino) methyl N^1 nitrourea was dissolved in a minimum amount of water and an equivalent amount of benzaldhyde was added to it (0.65 mls.). Upon the addition of a few drops of hydrochloric acid a white solid separated out of the solution. This benzaldehyde derivative was collected on a filter and washed with ether. The product was recrystallized several times from absolute methanol, and then from absolute ethanol.

The benzaldehyde derivative, a white crystalline material, is very soluble in methanol and ethanol, insoluble in water and ether, m.p. 141°C (uncorr.). An m.p. of a mixture of this benzaldehyde derivative and the parent compound exhibited a depression of the m.p.

Anal. Calcd. for $C_9H_{12}N_7O_3$: C, 40.6; H, 4.52; N, 36.8.

Found: C, 45.8; H, 3.7; N, 26.7.

(c) Preparation of N(1,1 bishydrazino) methyl N^1 nitrourea dihydrochloride.

A sample of N(1,1 bishydrazino) methyl N^1 nitrourea (0.85g. or 0.005M.) was dissolved in a minimum amount of water and 3 mls. of concentrated hydrochloric acid was added to it. The liquid was distilled under reduced pressure and the residue was recrystallized several times from ethanol and methanol.

The hydrochloride derivative is very soluble in methanol, ethanol and water; and insoluble in ether, m.p. 108-9°C.

Anal. Calcd. for $C_2H_{11}N_7O_3Cl_2$: C, 9.54; H, 4.37; N, 38.9; Cl, 28.2
Found: C, 10.0; H, 4.83; N. 39.2; Cl, 29.6

32. The addition of standard acid and alkali to N (1,1 bishydrazino) methyl N^1 nitrourea.

A sample of N (1,1 bishydrazino) methyl N^1 nitrourea (0.3903g. or 0.002M.) was dissolved in 25 mls. of distilled water of pH 6.6 and the addition of the nitrourea derivative did not cause any change in the pH. Six mls. of 0.0957N. hydrochloric acid was added to this solution and the pH of the solution dropped to 4.22. Standard sodium hydroxide (0.1096N.) was added to this solution and the change in the pH was noted. When the solution was alkaline it was back-titrated with the standard acid. The results are represented in Table XXIII and in figure 16.

Table XXIII

Titration of N (1,1 bishydrazino) Methyl N^1 Nitrourea

Sodium Hydroxide Added		pH
Mls. of 0.1096N.	Milli Equivalents	
0	0	4.22
0.5	0.0548	4.314
1.1	0.127	4.37
2.1	0.232	4.52
3.03	0.332	4.68
4.0	0.438	4.96
4.4	0.483	5.13
4.7	0.515	5.36
5.03	0.552	5.76
5.24	0.575	6.64
5.45	0.597	9.32
5.65	0.62	9.91
5.82	0.638	10.22
6.0	0.658	10.42
6.9	0.756	10.88
7.3	0.8	10.93
7.6	0.84	10.99
8.2	0.9	11.08
8.8	0.965	11.15

Hydrochloric Acid Added		
Mls of 0.0957N.	Milli Equivalents	
0	0	11.15
0.5	0.0478	10.97
1.18	0.113	10.83
2.0	0.191	10.58
2.55	0.248	10.21
3.1	0.297	9.56
3.61	0.345	7.99
3.68	0.352	7.37
3.73	0.357	6.75

It can be noted from the above data that this compound has an iso ionic point of about 6.5; and a pK_1 value of about 4.5, and a pK_2 value of about 11.

33. Dearrangement of nitrodicyandiamidine.

(a) With hydrazine dihydrochloride in absolute ethanol - hydrogen chloride medium.

A mixture of 7.3g. N.D.C.D. (0.05M.), 5.3g. hydrazinedihydrochloride (0.05M.), and 75mls. of absolute ethanol which had been saturated at 25°C with hydrogen chloride, was heated at 100°C in a Carius bomb for six hours. Upon opening the bomb a gas was given off and at the same time a white solid separated out of the solution. The solid was separated from the alcoholic-hydrogen chloride and recrystallized from aqueous ethanol, m.p. 196°C. A mixture of this product with hydrazinedihydrochloride gave no depression of the m.p. Hence this compound was assumed to be hydrazinedihydrochloride.

The alcoholic-hydrogen chloride filtrate was evaporated at 50°C by passing a stream of air over it. The residue was then recrystallized from methanol in which it is very soluble, m.p.134°C. Further recrystallizations from water did not cause any raise in the m.p. The compound gave a positive Beilstein and a mixture of this compound and carbethoxy guanidine showed no depression of the m.p. The product weighed 3.9g. which corresponds to a 47% yield of carbethoxy guanidinehydrochloride.

(b) With hydrazine dihydrochloride in absolute ethanol.

The above reaction was repeated except that absolute ethanol was used instead of an ethanol-hydrogen chloride solution. As in the previous case the alcohol insoluble residue was unreacted hydrazine dihydrochloride. The unreacted salt weighed 3.1g. indicating that some decomposition of the hydrazine dihydrochloride had occurred.

The filtrate was evaporated and the residue recrystallized from water. The product was white crystalline material with an ester like odour. An aqueous solution turned red litmus blue. It exhibited an m.p. of 96°C, then hardened and remelted at 116°C. A mixture of this product and carbethoxy guanidine gave no depression of the m.p. The product weighed 3.9g. which corresponds to a 60% yield of carbethoxy guanidine.

(c) With hydrazine dihydrochloride in absolute ethanol - ammonia media.

The reaction was studied in ethanol-ammonia media, the products obtained being ammonium chloride and an organic material ,m.p.216-225°C (uncorr.).

(d) With aniline hydrochloride in dilute hydrochloric acid.

One twentieth mole of N.D.C.D.(7.3g.), and an equivalent amount of aniline (4.6 mls.) were added to 200 mls. of 12% hydrochloric acid. The mixture was boiled until all of the N.D.C.D. had dissolved (at about 104°C) after which the reaction mixture was cooled until the temperature fell to 50°C. The solution was then evaporated at 50° by passing a stream of air over it. A few minutes after the evaporation had started a white solid separated out but as the evaporation was continued the solid redissolved.

The solution was evaporated to 5 mls. and upon cooling the residue solidified. Fifty mls. of acetone was added to the solid residue, the mixture was well stirred and the acetone insoluble residue was collected on a filter.

This product was added to a small amount of methanol and the methanol insoluble material was separated by filtration. This insoluble material was found to be unreacted N.D.C.D.

The methanol was evaporated at a reduced pressure and the residue, a greenish-white solid, weighed 11.5g. It was found very difficult to purify this compound to a white crystalline material. Many recrystallizations from water-charcoal, ethanol, methanol, ethanol-acetone, methanol-acetone, ethanol-ether, methanol-ether were necessary to obtain white crystals, m.p. 192°C. A mixture of this product with aniline hydrochloride gave a depression of the m.p. but the product gave a positive Runge's test for aniline hydrochloride.

Anal. Calcd. for $C_8H_{13}N_3Cl_2$: C, 43.2; H, 5.86; N, 18.9; Cl, 32.0.
Found: C, 45.6; H, 6.16; N, 18.5; Cl, 29.3

(i) The reaction was repeated but here the material, which separated upon cooling the reaction mixture to 50°C, was collected on a filter. This material was found to be N.D.C.D. (4.3g.).

(ii) The reaction was studied at 70°C, at which temperature most of the residue was unreacted N.D.C.D.

(e) With (i) toluidine hydrochloride, (ii) methylamine hydrochloride, (iii) butylamine hydrochloride in dilute hydrochloric acid.

This reaction was repeated with (i) toluidine hydrochloride, (ii) methylamine hydrochloride, (iii) butylamine hydrochloride instead of aniline hydrochloride. In all these studies the hydrochloride salts were recovered unreacted. In these experiments the N.D.C.D. had decomposed to guanidine hydrochloride which is the expected decomposition product of N.D.C.D. in hydrochloric acid.

34. Attempted structure proof of nitrodicyandiamidine.

(a) Reactions with cyanamide.

The cyanamide used in the following experiments was prepared following the procedure outlined by Blair and Braham (149).

(i) Reaction between cyanamide and nitrourea.

A suspension of 2.1g. of cyanamide (0.05M.) and 10.5g. nitrourea (0.1M.) was refluxed for seven hours in 50 mls. absolute ethanol. The insoluble material was collected on a filter. This product was soluble in water and thus was not N.D.C.D. The filtrate gave a positive test for cyanamide when tested with ammoniacal silver nitrate.

This reaction was repeated several times and in no case did the cyanamide react with the nitrourea.

(ii) Reaction between cyanamide and acetonesemicarbazone.

One tenth mole of acetonesemicarbazone (11.5g.)and 2.1g. cyanamide (0.05M.) were added to 50 mls. anhydrous ethanol and the suspension was refluxed for three hours. The mixture was then tested for the presence of cyanamide with ammoniacal silver nitrate with a positive result. As all of the semicarbazone had not dissolved, another 50 mls. of anhydrous ethanol was added (still not enough ethanol to dissolve all of the semicarbazone). The refluxing was continued for another six hours at which time a negative test for cyanamide was obtained. The mixture was then cooled and the insoluble portion was separated by filtration. This solid product weighed 7.5g. m.p. 186-88°C. This was shown to be unreacted acetonesemicarbazone.

The filtrate was distilled off at a reduced pressure and the residue was taken up in 30 mls. 12% hydrochloric acid. Three mls. of benzaldehyde was added to the solution and upon shaking a white gelatinous solid separated out of the solution. The mixture was allowed to stand overnight and the precipitate was collected on a filter and washed with ethanol.

The benzaldehyde derivative was decomposed in 10 mls. of hot concentrated hydrochloric acid and the benzaldehyde was extracted with boiling benzene. Upon cooling white crystals separated from the hydrochloric acid. This precipitate was collected on a filter and washed with methanol. The product weighed 0.8g. m.p. 179-80°C. Further recrystallizations from ethanol did not cause any raise in the m.p. and a mixture of this product and aminodicyandiamidine dihydrochloride gave a depression of the m.p.

The reaction was repeated under conditions where (i) equivalent amounts of acetonesemicarbazone and cyanamide (ii) an 100% excess of cyanamide were used. In no case was aminodicyandiamidine ever isolated.

(b) Reaction with S-methylisothiourea.

The S-methylisothiourea was prepared as the sulfate salt following the procedure outlined in "Organic Synthesis" (150).

(i) Reaction between S-methylisothiourea and acetonesemicarbazone.

Seven grams of S-methylisothiourea sulfate (0.025M.) was cooled in an ice bath and 50 mls. of aqueous dilute sodium hydroxide (2g. or 0.05M. sodium hydroxide) was added to it, the the temperature being kept at 10°C. After all of the S-methylisothiourea had dissolved in the sodium hydroxide, 5.7g. of acetonesemicarbazone (0.05M.)dissolved in 100mls. of hot water was added to it. The solution was cooled in the ice bath for one half hour, and then it was allowed to stand at room temperature for one hour during which white crystals started to separate out of the solution. It was then allowed to stand in the refrigerator, and the solid was collected on a filter and washed with water, m.p.187°C. A mixture of this product and acetonesemicarbazone showed no depression of the m.p. The product weighed 2.5g.

Ten mls. of concentrated hydrochloric acid was added to the filtrate. Upon standing for thirty minutes the filtrate became turbid. After standing overnight no solid separated out of it.. The water was therefore distilled off under reduced pressure, leaving a residue which did not exhibit the characteristic smell of the mercaptons. It was dissolved in 150 mls. of 5% hydrochloric acid and one ml. of benzaldehyde was added to it. Upon vigorous shaking a white precipitate separated out of the solution. This precipitate was collected on a filter and washed with ethanol. The weight of the precipitate was one gram.

The benzaldehyde derivative was decomposed in 2 mls. hot concentrated hydrochloric acidand the benzaldehyde extracted with 15 mls. boiling benzene. Upon cooling, white crystals separated out of the hydrochloric acid. These were collected on a filter and washed with methanol, m.p. 198-203°C. Further recrystallizations from dilute aqueous ethanol raised the m.p. to 210°C, and thus this compound was not aminodicyandiamidine dihydrochloride.

The reaction was repeated with (i) excess S-methylisothiourea (ii)excess acetonesemicarbazone and the only identifiable product was unreacted semicarbazide. The reaction was also attempted with nitrourea and the potassium salt of nitrourea and in no case was the product observed to be N.D.C.D.

(c] Reaction between cyanogen bromide and nitrourea.

The cyanogen bromide was prepared according to the procedure outlined in "Organic Synthesis" (151).

Equivalent amounts of nitrourea (5.3g. or 0.05M.) and cyanogen bromide (5.3g. or 0.05M.) were added to 600 mls. of anhydrous ether. Since no reaction appeared to take place the mixture was refluxed for twenty four hours. Then ammonia gas was passed through for thirty minutes. This caused the separation of a white solid. The mixture was then allowed to stand for one hour, after which the solid was collected on a filter. This solid was found to be unreacted nitrourea.

This reaction was repeated with potassium nitrourea with similar results.

(c) Reaction with guanidine.

The guanidine was prepared following the procedure outlined by Traube (152).

(i) Reaction between guanidine and ammonium nitrourethane.

The ammonium nitrourethane was prepared following the procedure given in "Inorganic Synthesis" (153).

A sample of ammonium nitrourethane (2.8g. or 0.02M.) was added to 50 mls. of absolute ethanol-guanidine solution (1.2g. or 0.02M. guanidine). The mixture was then allowed to stand for four days, during which time ammonia was evolved. Ten mls. of hydrochloric acid was then added to this mixture and the white insoluble material was collected on a filter. This material was soluble in water and thus was not N.D.C.D.

The above reaction was repeated with nitrourethane and potassium nitrourethane, and in no case was it possible to isolate N.D.C.D. as the product.

(ii) Reaction between guanidine and carbethoxy hydrazine.

The carbethoxy hydrazine was prepared following the procedure outlined by Diels((154).

To 50 mls. of an ethanol-guanidine solution (3g. or 0.05M. guanidine) an equivalent amount of carbethoxy hydrazine (5.2g. or 0.05M.) was added. The colour of the solution turned orange-redand the resulting solution did not exhibit the pungent odour of guanidine. It was then allowed to stand overnight during which a red precipitate separated out. This red precipitate was filtered off and was found to be insoluble in all common organic solvents and soluble in water. This material did not form any benzaldehyde derivative.

The filtrate was distilled off under reduced pressure leaving a red jelly-like residue. This residue was taken up in a small amount of water and the aqueous solution turned red litmus blue. It was then acidified with concentrated hydrochloric acid. Two mls. of benzaldehyde was added to it and upon shaking a mixture of white and yellow benzaldehyde derivatives separated out of the solution. These derivatives were collected on a filter. They were found to be soluble in ether and thus the white derivative was benzalcarbethoxy hydrazine and the yellow derivative was benzalhydrazone.

When the reaction occurred in completely anhydrous media no decomposition of the carbethoxy hydrazine occured and only benzalcarbethoxy hydrazine was obtained as the product. Also the colour of the reaction mixture did not turn red.

(iii) Reaction between guanidine and carbethoxy guanidine hydrochloride.

The carbethoxy hydrazine hydrochloride was prepared in the following manner:-

One tenth of a mole of carbethoxy hydrazine (10.4g.) was dissolved in 150 mls. of anhydrous ether. Dry hydrogen chloride gas was passed through the solution for three hours with mechanical stirring and a white solid separated out. This precipitate was collected on a filter and washed with ether. The white product weighed 13.6g. which corresponds to a yield of 93%. It exhibited the same m.p. as the hydrochloride salt reported in the literature (155) i.e. m.p. 129°C, and the same solubilities, i.e. soluble in water and in ethanol and methanol.

Seven grams of carbethoxy hydrazine hydrochloride (0.05M.) was added to an equivalent amount of guanidine (3g. or 0.05M.) in 15 mls. of absolute ethanol. After the exothermic reaction had ceased, the mixture was allowed to stand overnight. The ethanol was distilled off under reduced pressure and the residue was dissolved in dilute hydrochloric acid. Two mls. of benzaldehyde was added and upon vigorous shaking a white solid separated out. This precipitate was collected on a filter, and was washed repeatedly with ether. The product weighed one gram, and it gave a Beilstein test.

This material was decomposed in concentrated hydrochloric acid in the same manner described in previous experiments. The material which crystallized out of the concentrated hydrochloric acid was collected on a filter. After recrystallizations from ethanol the m.p. was 138°C and no Beilstein test was obtained.

This reaction was repeated. In different experiments the reaction mixture was refluxed for thirty minutes, and for two hours, but again the product was not aminodicyandiamidine dihydrochloride.

(d) Reaction with hydrazine hydrate.

(i) Reaction between hydrazine hydrate and carbethoxy guanidine.

The carbethoxy guanidine was prepared by the following procedure (101).

Ten grams of N.D.C.D. (0.068M.) was refluxed in a solution of 250mls. of 95% ethanol and 100mls. of water until all of the N.D.C.D. had dissolved. The solution was then evaporated on the steam cone. The residue was taken up in 60 mls. of hot water and the insoluble material (ammeline and ammelide) was separated by filtration.

The filtrate was evaporated to dryness and treated with warm ethanol. The insoluble portion (guanidine carbonate) was separated by filtration. The alcohol solution yielded a solid which weighed 5g. corresponding to a 56% yield of carbethoxy guanidine. The material was recrystallized from sodium bicarbonate and it gave colourless crystals of carbethoxy guanidine, m.p.100°C.

A sample of carbethoxy guanidine (1.5g. or 0.011M.) was dissolved in an 100% excess of 100% hydrazine hydrate (1.1g. or 0.02M.). The reaction mixture was then allowed to stand for three hours and the hydrazine hydrate was distilled off under reduced pressure at 30°C. The residue was taken up in a small amount of water and acidified with concentrated hydrochloric acid. Two mls. of benzaldehyde was added to it and upon vigorous shaking a yellow benzaldehyde derivative separated out. This was collected on a filter and was found to be soluble in ether. Hence this product this product was benzalhydrazone.

The reaction was repeated under the following conditions:-

(i)The reaction mixture was composed of 3g. carbethoxy guanidine (0.02M.), a 300% excess of 100% hydrazine hydrate (6.6g. Or 0.06M.) and 10 mls. of absolute ethanol. This solution was refluxed for four hours and was then allowed to stand overnight. The reaction mixture was worked up in a similar manner as outlined in (i), and 0.3g. of a product of m.p. 212°C was obtained. This product gave a positive Beilstein test.

(ii) Reactionbetween hydrazine and carbethoxy guanidine hydrochloride.

The carbethoxy guanidine hydrochloride was prepared in the following manner:-

A sample of carbethoxy guanidine was dissolved in a minimum amount of water. This solution was acidified with concentrated hydrochloric acid. Upon cooling long white needles separated out of the solution, m.p.133°C.

This salt can also be prepared by dissolving the guanidine derivative in methanol, acidifying with concentrated hydrochloric acid, and precipitating the hydrochloride salt with ether.

To 1.67g. of carbethoxy guanidine hydrochloride (0.01M.) a five fold excess of 100% hydrazine hydrate (2.5 mls. or 0.05m.) was added. During the addition of the hydrazine hydrate a small amount of heat was given off. The mixture was allowed to stand for five hours during which the guanidine derivative dissolved in the hydrazine hydrate and the colour of the solution changed to a purple-pink colour. The hydrazine hydrate was then distilled off at 25°C under reduced pressure. The crystalline residue had no sharp m.p. but melted over a range 135-75°C. This compound gave a positive Beilstein test, and formed an ether insoluble benzaldehyde derivative. Since the benzaldehyde decomposition product was soluble in methanol, it was not aminodicyandiamidine dihydrochloride.

(e) Fusion reactions.

(i) Reaction between guanidine hydrochloride and semicarbazide hydrochloride.

A mixture of 9.5g. (0.1M.) of guanidine hydrochloride and 11.1g. of semicarbazide hydrochloride (0.1M.) was fused together at 175°C for three hours. During the course of the fusion white fumes of ammonium chloride were given off. The fusion mixture was then cooled and the product was taken up in hot water. Five mls. of benzaldehyde was added and upon vigorous shaking a white solid separated out of the solution. This product was collected on a filter, washed with ether and dried in a vacuum desiccator, m.p. 248-50°C.

The benzaldehyde derivative was decomposed with concentrated hydrochloric acid. Since no crystalline material separated out of the concentrated hydrochloric acid, the acid was evaporated off and the residue was recrystallized from dilute aqueous ethanol. The final product was a white crystalline material, m.p. 266-68°C.

This fusion reaction was repeated with guanidine hydrochloride and acetonesemicarbazone.

(ii) Fusion of nitrourea and guanidine hydrochloride.

One tenth mole of nitrourea (10.5g.), mixed with 9.5g. of guanidine hydrochloride (0.1M.) gave off hydrogen chloride. As this mixture was heated to 80°, white fumes were given off and the temperature rose to 160°C, at which temperature the reaction mixture decomposed to gaseous products.

(iii) Fusion of nitroguanidine and urea.

A mixture of 10.4g. of nitroguanidine (0.1M.) and 6g. of urea (0.1M.) was immersed in an oil bath at 140°C. As the temperature of the reaction mixture rose to 110°C, ammonia was given off, as it rose to 150°C larger amounts of ammonia continued to be given off and the whole reaction mixture appeared to boil depositing a white solid on the side of the reaction flask. When the reaction had subsided, hot water was added to the reaction mixture. The product was scraped off from the side and the water insoluble material was collected on a filter.

This solid was soluble in aqueous alkali from which it could be recrystallized by either acidifying with mineral acids or by passing through carbon dioxide. The compound did not melt even when heated to 340°C. It analysed for C, 41.8; H, 5.75; N, 25.3.

35. Preparation of Nphenyl N^1nitrodicyandiamidine sulfate.

The phenylazodicyandiamide, and phenyldicyandiamidine hydrochloride were prepared following the procedure outlined by Walther and Greishammer (67).

(i) Preparation of phenyldicyandiamidine nitrate.

A sample of phenyldicyandiamidine hydrochloride (8.6g. or 0.04M.) was dissolved in a small amount of hot water. To it was added an equivalent amount of aqueous silver nitrate (6.8g. or 0.04M.). The silver chloride was separated by filtration and the filtrate was evaporated by an air stream at 50°C. The residue was taken up in a small amount of boiling ethanol, and the solid residual silver nitrate was separated by filtration. The filtrate was allowed to stand overnight in a refrigerator and the white crystals which had separated out were separated by filtration, and dried in a vacuum desiccator. The product was composed of white crystals, the bulkiness of which gave the appearance of guanidine nitrate. The compound gave the characteristic brown ring test of a nitrate when treated with concentrated sulfuric acid, m.p. 147-48°C (uncorr).

Anal. Calcd. for $C_8H_{11}N_5O_4$: C, 39.8; H, 4.56; N, 29.1.
Found: C, 39.8; H, 4.65; N, 29.2.

An attempt was made to prepare the nitrate salt from an aqueous solution of phenyldicyandiamidine and ammonium nitrate. Here, no ammonia was evolved and no reaction appeared to take place. Since when phenylazodicyandiamidine is treated with an ethanol-hydrogen chloride solution, phenyldicyandiamidine hydrochloride is obtained, it was thought that if an ethanol-nitric acid solution was used, the nitrate salt would be obtained. This was not the case, since on the evaporation of the alcohol, a dark brown oil was obtained.

(ii) A sample of phenyldicyandiamidine nitrate (7.23g. or 0.03M.) was added to 25 mls. of concentrated sulfuric acid which had been cooled to -5°C. The nitrate salt was added at a rate such that the temperature did not rise above 0°C. After all the nitrate had been added the mixture was stirred until the salt went completely into solution. It was then added to 500g. chopped ice and a white solid separated out of the solution. This product was collected on a filter and washed with water. The product, which was composed of white crystals, weiged 6g. This corresponds to a 75% yield of the sulfate salt. It was then recrystallized from boiling water, m.p.194°C(uncorr).

It is insoluble in methanol, ethanol, acetone, ether, nitromethane, chloroform, cold water, and sodium hydroxide solutions. It is soluble in concentrated sulfuric acid, formamide, glacial acetic acid and in hot water. When this salt is added to either aqueous sodium hydroxide, formamide, glacial acetic acid and ethanol it imparts a yellow-orange colour to these solvents. The compound cannot be reprecipitated from the formamide and the glacial acetic acid by the addition of either ethanol or water.

Anal. Calcd. for $C_{16}H_{20}N_{10}O_{10}S$: C, 35.3; H, 3.68; N, 25.7; S, 5.88
Found: C, 35.4; H, 3.90; N, 25.8; S, 6.1

The compound can be purified by recrystalling from 5% sulfuric acid solution, avoiding any prolonged heating. It can also be purified by dissolving in cold concentrated sulfuric acid, and reprecipitating by diluting the acid with chopped ice.

When the salt was recrystallized several times from either boiling water, or 12% hydrochloric acid, or 5% sulfuric acid, yellow green crystals separated out of the solution, m.p. 177°C. The compound exhibited the same solubilities as the initial sulfate salt, but it did not impart a yellow-orange colour to ethanol, formamide, glacial acetic acid or aqueous sodium hydroxide. The compound has the composition of the hydrate salt of N phenyl N^1 nitrodicyandiamidine sulfate.

Anal. Calcd. for $C_{16}H_{22}N_{10}O_{11}S$: C, 34.2; H, 3.92; N, 24.9; S, 5.7.

Found: C, 34.2; H, 3.95; N, 24.7; S, 5.98.

Summary

1. The properties of the silver salt of nitrodicyandiamidine (N.D.C.D.) were investigated as a basis for the quantitative estimation of N.D.C.D.

2. The mercury, nickel and copper salts of N.D.C.D. were prepared by adding mercuric chloride, nickel nitrate and copper nitrate to an aqueous alkaline solution of N.D.C.D. These salts separate out of the solution as colloids and adsorb other ions. Due to this contamination, complete analysis of the precipitated salts did not correspond to the calculated values.

3. A method was developed for the quantitative estimation of N.D.C.D. The method consists of dissolving the N.D.C.D. in a standard solution of sodium hydroxide, and back-titrating the solution with standard hydrochloric acid, to the point where the N.D.C.D. begins to precipitate out of the solution. From the amount of the sodium hydroxide consumed, the amount of N.D.C.D. can be estimated to within 0.5%.

4. A theoretical explanation for the behaviour of N.D.C.D. in alkaline solutions has been proposed.

5. The sodium and potassium salts of N.D.C.D. were isolated by adding excess acetone and/or methanol to an aqueous alkaline solution of N.D.C.D., and the behaviour of the aqueous solutions of these salts to acid was studied.

6. Nitrosodicyandiamidine was shown to exist for a short period of time during the reduction of N.D.C.D. with zinc and sodium

hydroxide. Other reduction products could not be isolated, the compound undergoing decomposition.

7. N phenylazo N^1 nitrodicyandiamidine was prepared by treating a dilute aqueous solution of N.D.C.D. in sodium hydroxide with sodium phenyldiazotate, followed by acidification with hydrochloric acid. The product decomposes in ethanol solutions of hydrochloric acid, nitric acid or sulfuric acid to yield N.D.C.D.; it decomposes to carbethoxy guanidine hydrochloride in absolute ethanol hydrogen chloride solution.

8. The tolylazo and the o-carbonicbenzeneazo derivatives of N.D.C.D. were prepared in the same manner as the benzeneazo derivative. However these derivatives separate out of solution contaminated with N.D.C.D. Since N.D.C.D. and these derivatives have similar solubilities the analytical results do not agree with the calculated values.

9. Sodium and potassium N.D.C.D. undergo decomposition to sodium or potassium carbonate when an equivalent amount of formaldehyde is added to aqueous alkaline solutions of these salts.

10. When N.D.C.D. is added to an excess of 100% hydrazine hydrate the N.D.C.D. immediately decomposes to form N(1,1 bishydrazino) methyl N^1 nitrourea. This compound is formed in good yields, has a characteristic melting point, is a "zwitterion", and forms recognizable derivatives with acetone, benzaldehyde and hydrochloric acid. All these properties make it an ideal derivative for the identification of N.D.C.D.

11. N.D.C.D. decomposes in a solution of aniline hydrochloride

in dilute hydrochloric acid to yield a compound which is assumed to be N methyl N^1 phenylguanidine. When this reaction takes place in dilute solutions containing toluidine hydrochloride, methylamine hydrochloride, or butylamine hydrochloride the N.D.C.D. dearranges to guanidine hydrochloride, and the amine salts are recovered unchanged.

12. When N.D.C.D. is decomposed in absolute ethanol or ethanol hydrogen chloride solution, carbethoxy guanidine and carbethoxy guanidine hydrochloride are the products.

13. Attempts to prove conclusively by synthetic methods on which side of the molecule the nitro group is located did not yield conclusive results.

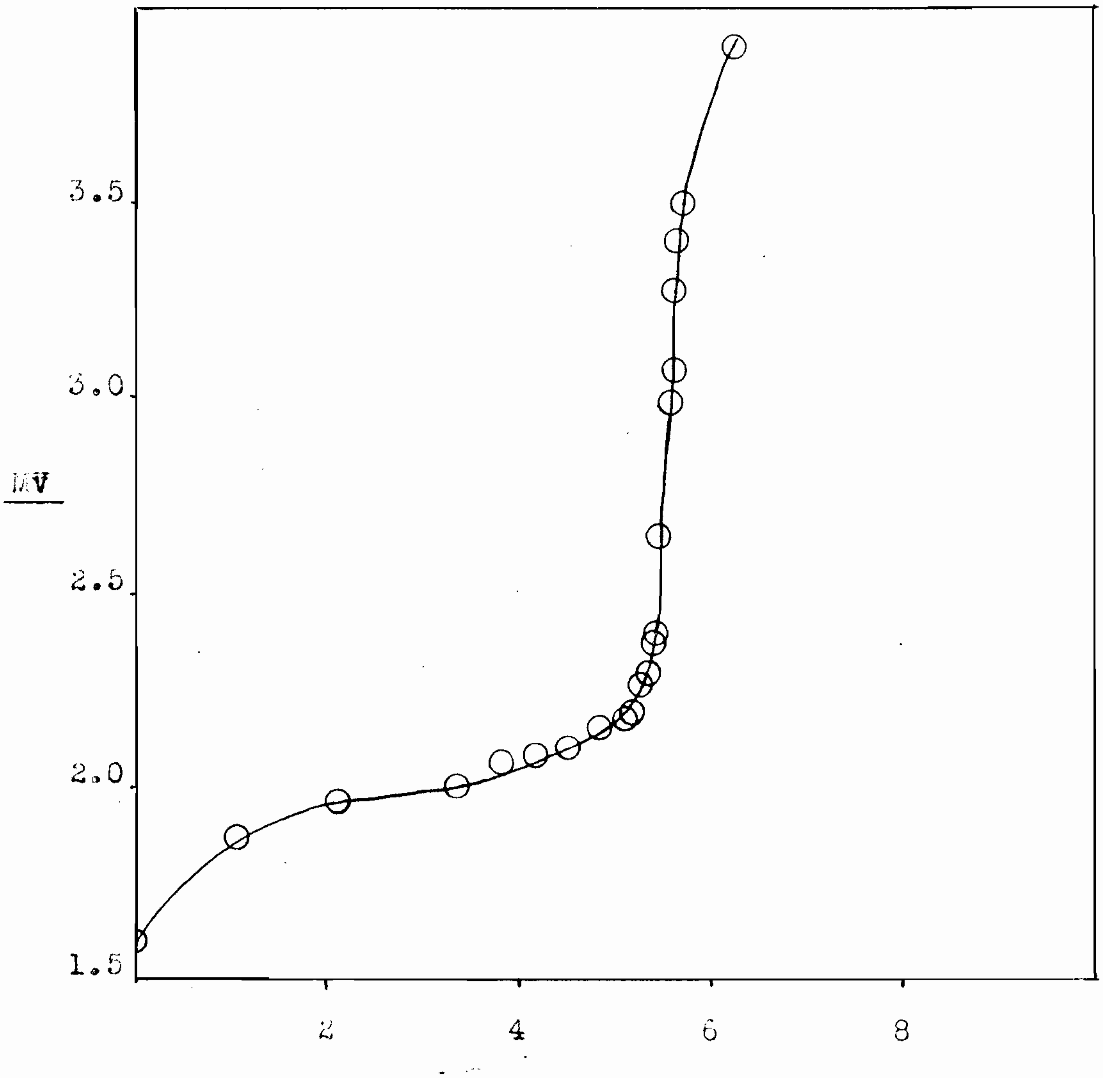
14. N phenyl N^1 nitrodicyandiamidine sulfate was prepared by first treating phenyldicyandiamidine hydrochloride with silver nitrate to form the nitrate salt, and then dehydrating the salt with concentrated sulfuric acid. The sulfate salt is converted to the hydrate sulfate salt on heating in aqueous medium.

Claims to Original Research

1. The following compounds were prepared for the first time:- the sodium, potassium, mercury, nickel and copper salts of nitrodicyandiamidine; N phenylazo N^1 nitrodicyandiamidine, N tolylazo N^1 nitrodicyandiamidine, N o-carbonic benzeneazo N^1 nitrodicyandiamidine; N (1,1 bishydrazino) methyl N^1 nitrourea, and the acetone, benzaldehyde and hydrochloric acid derivatives of N (1,1 bishydrazino) methyl N^1 nitrourea; N phenyl N^1 methylguanidine; phenyldicyandiamidine nitrate, N phenyl N^1 nitrodicyandiamidine sulfate, and the hydrate salt of N phenyl N^1 nitrodicyandiamidine sulfate.
2. Carbethoxy guanidine and carbethoxy guanidine hydrochloride were prepared by new methods.
3. Nitrosodicyandiamidine was shown to exist in solution for a short period of time.
4. A method, with an accuracy of 0.5% has been developed for the quantitative estimation of nitrodicyandiamidine.
5. A convenient method for the identification of nitrodicyandiamidine has been developed.

Figure 1

Addition of Silver Nitrate to Sodium Hydroxide-N.D.C.D. Solution



Mls. of 0.2584N Silver Nitrate

Figure 2

Addition of Silver Nitrate to Sodium Hydroxide-N.D.C.D. Solution

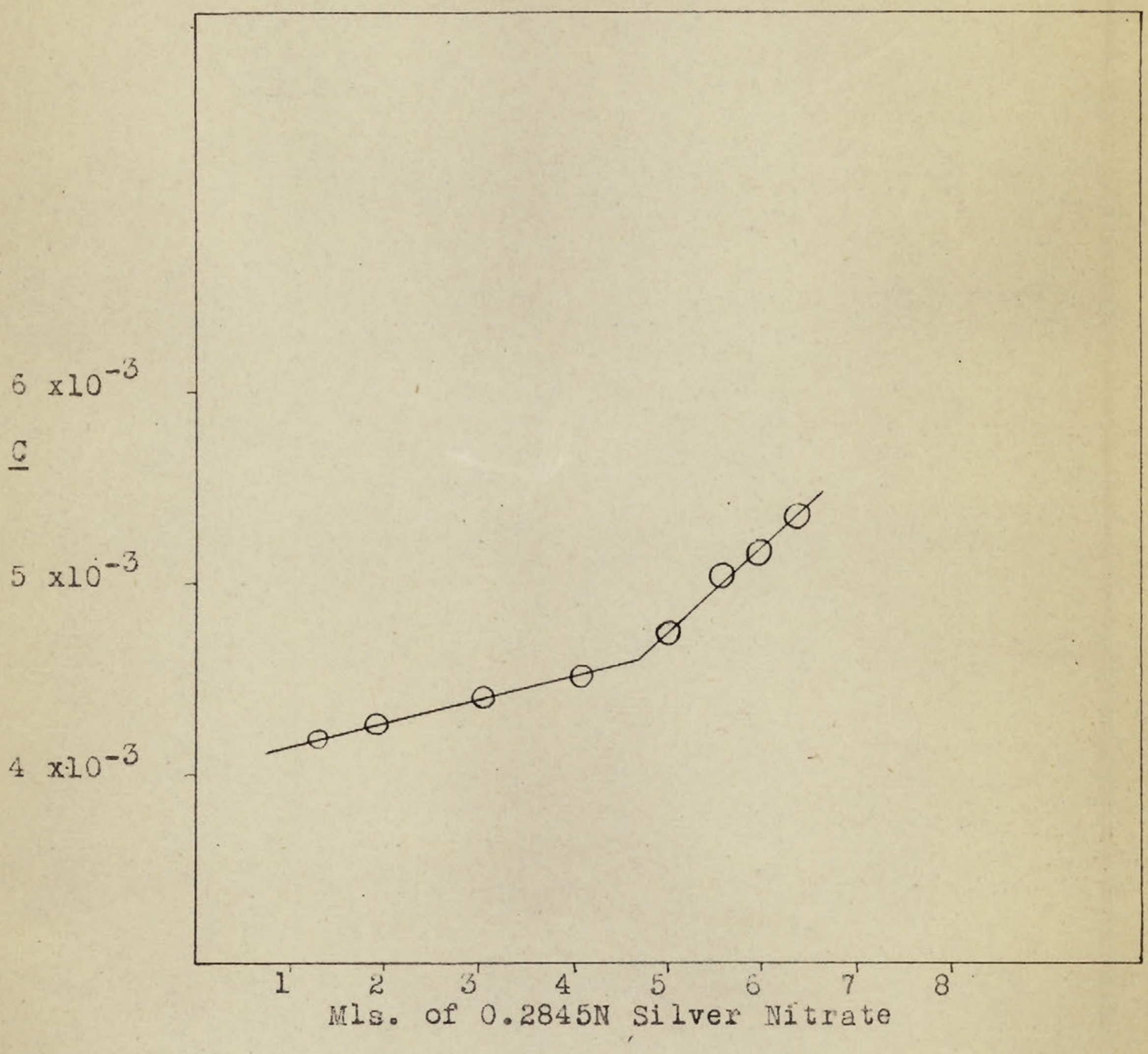


Figure 3

Addition of Sodium Hydroxide to a Suspension of N.D.C.D. in Water

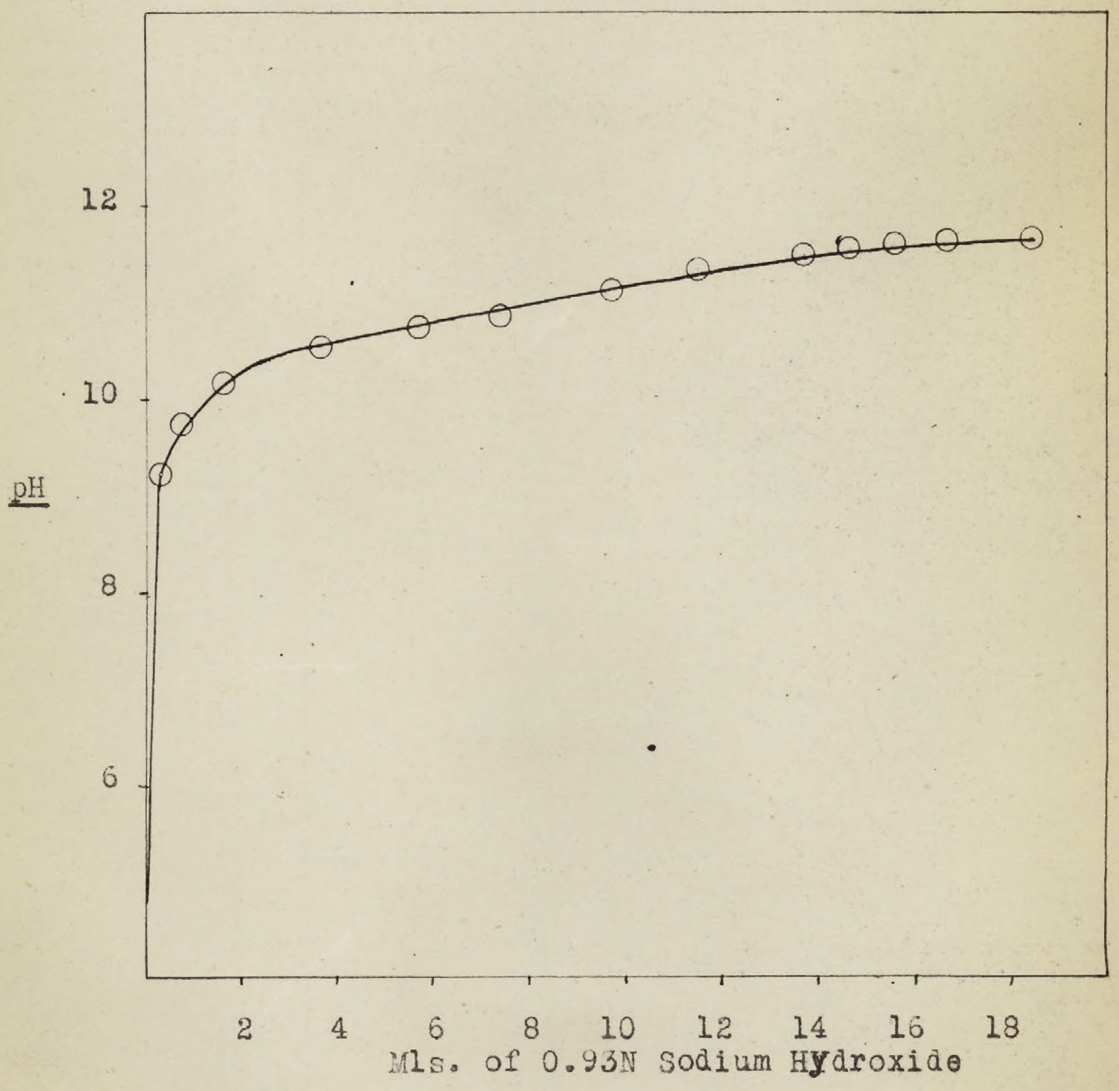


Figure 4

Addition of Sodium Hydroxide to a Suspension of N.D.C.D. in Water

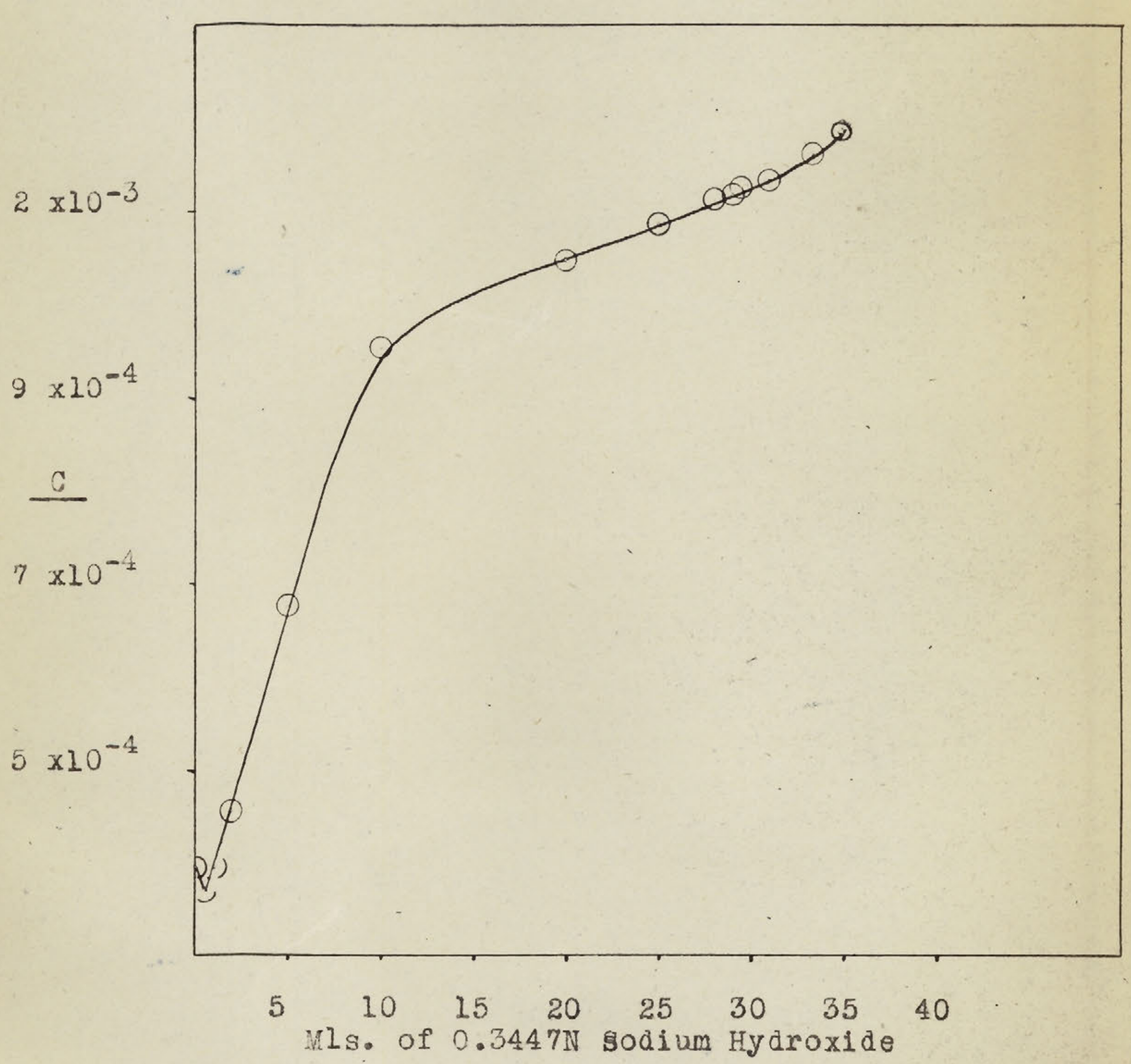


Figure 5

Addition of Hydrochloric Acid to the Sodium Salt of N.D.C.D. in Sodium Hydroxide

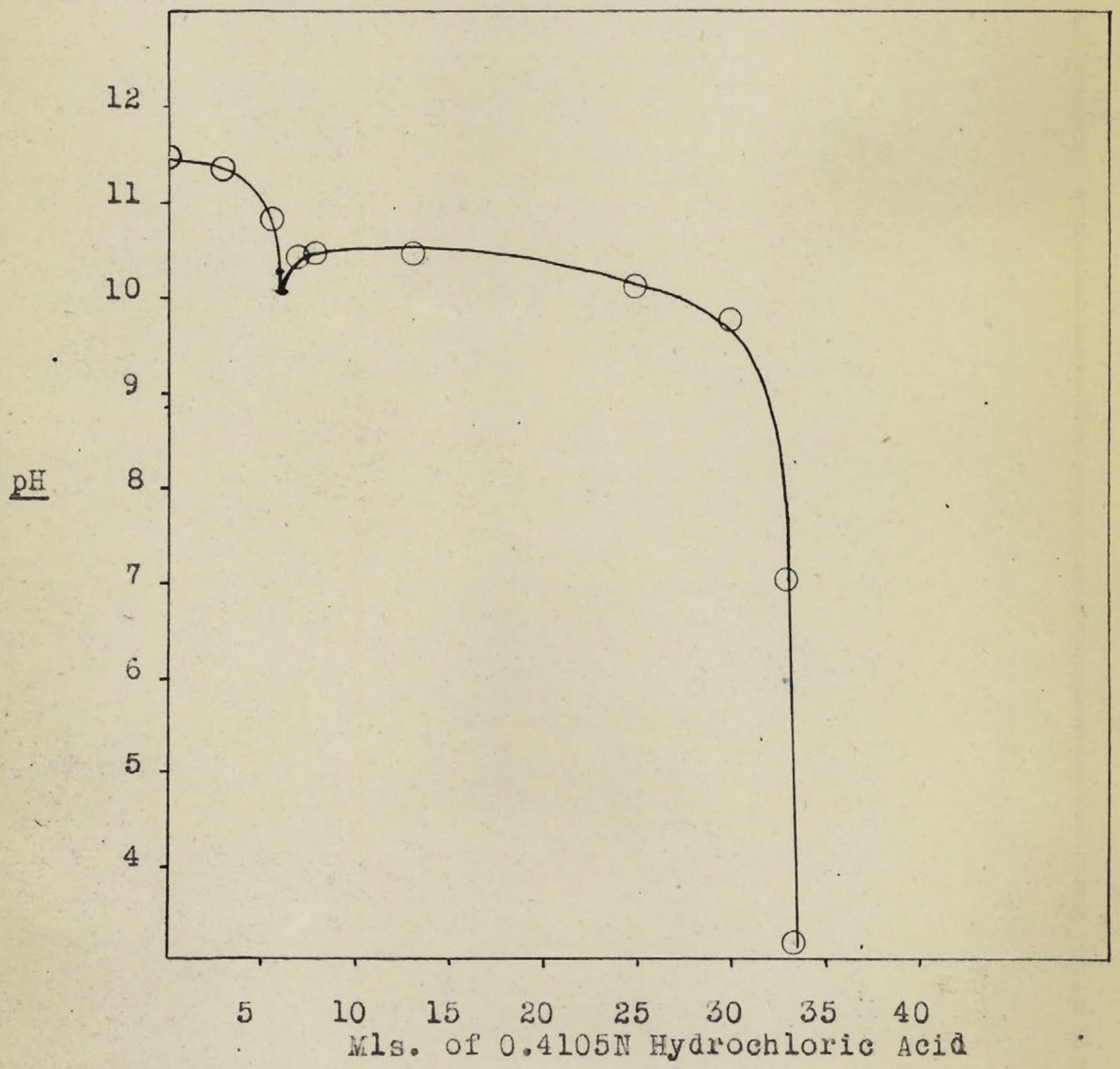


Figure 6

Addition of Hydrochloric Acid to the Sodium Salt of N.D.C.D.

in Sodium Hydroxide

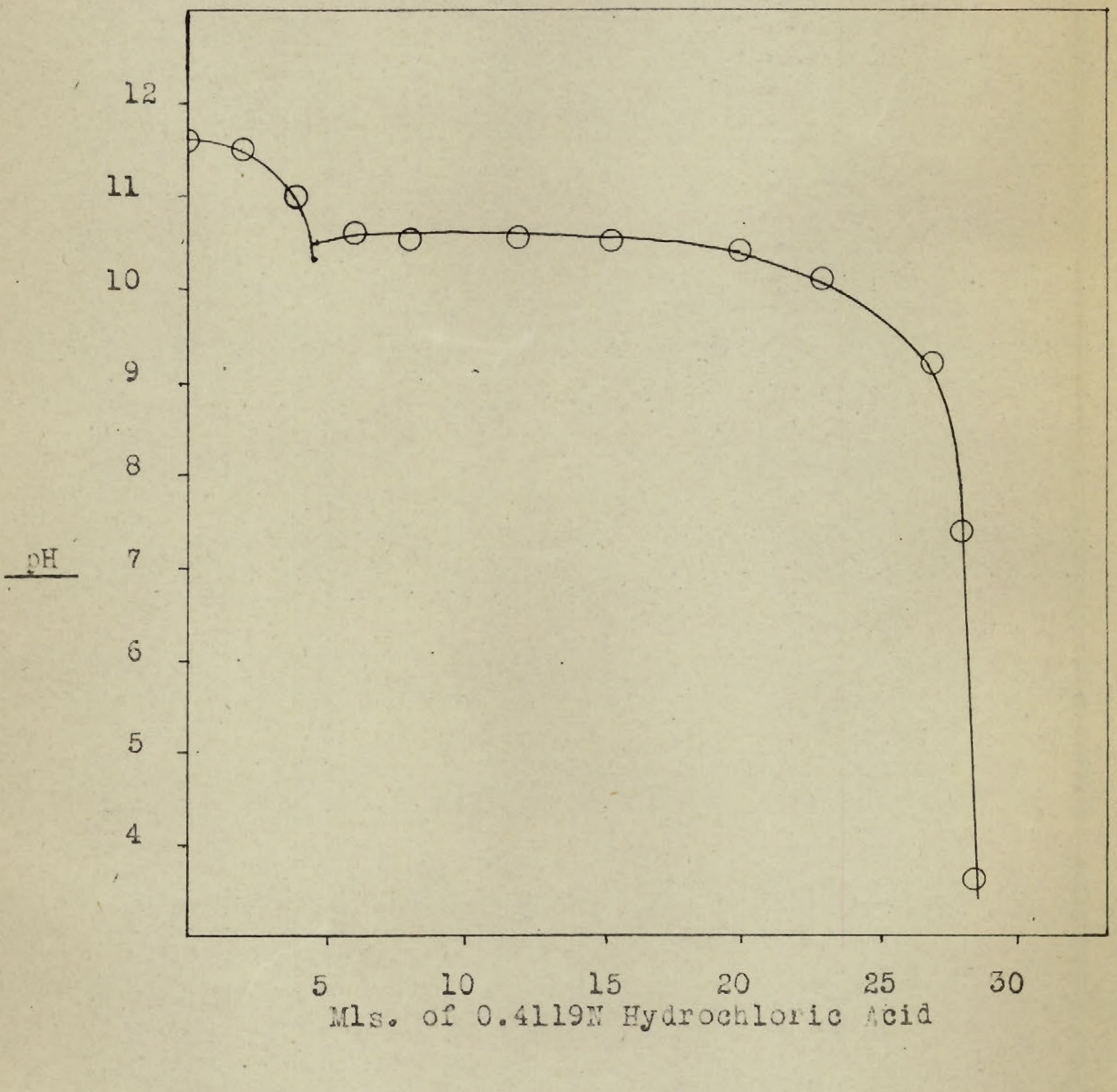


Figure 7

Addition of Hydrochloric Acid to the Sodium Salt of N.D.C.D. in Sodium Hydroxide

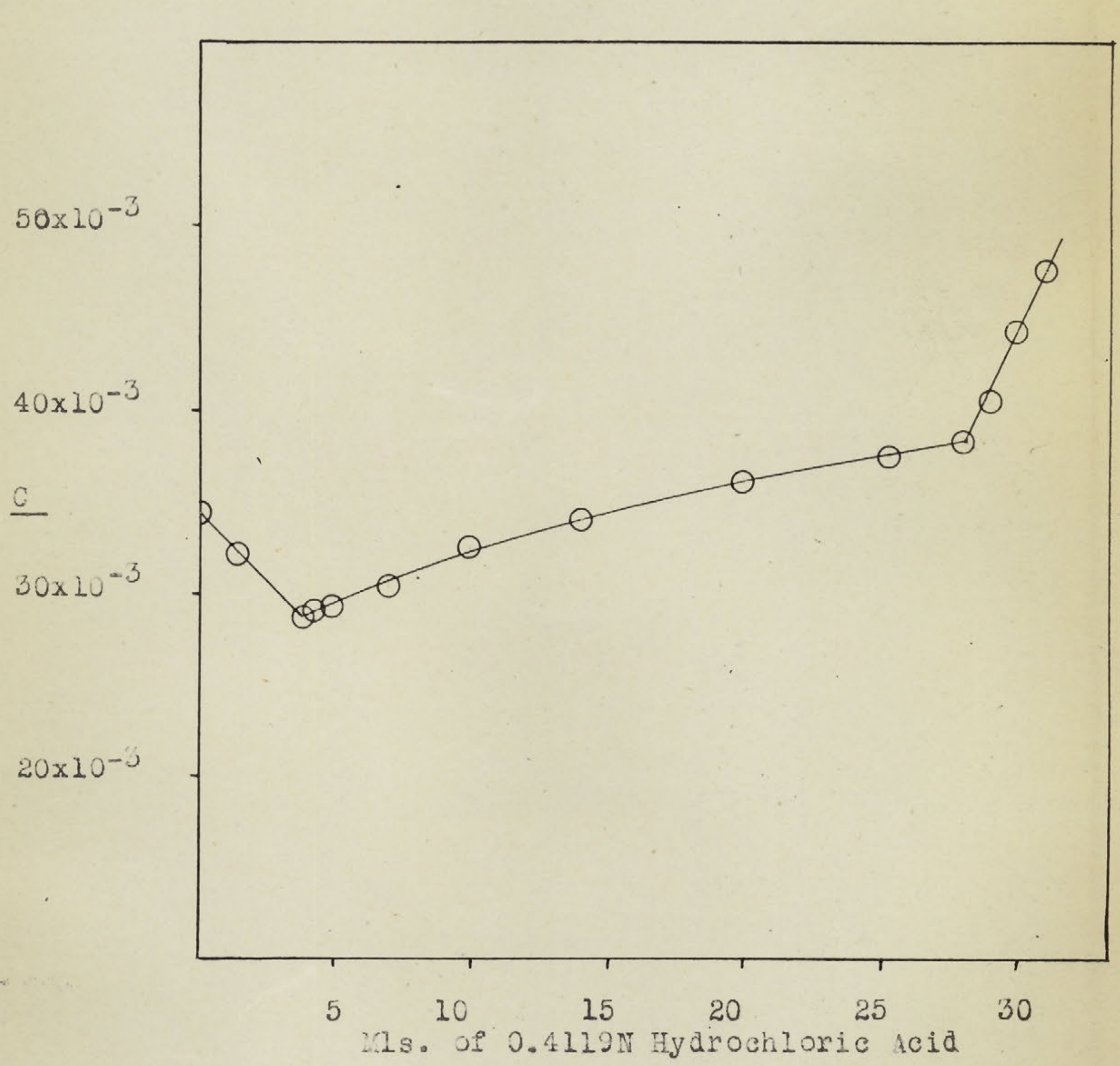


Figure 8

Addition of Hydrochloric Acid to the Sodium Salt of N.D.C.D. in Sodium Hydroxide

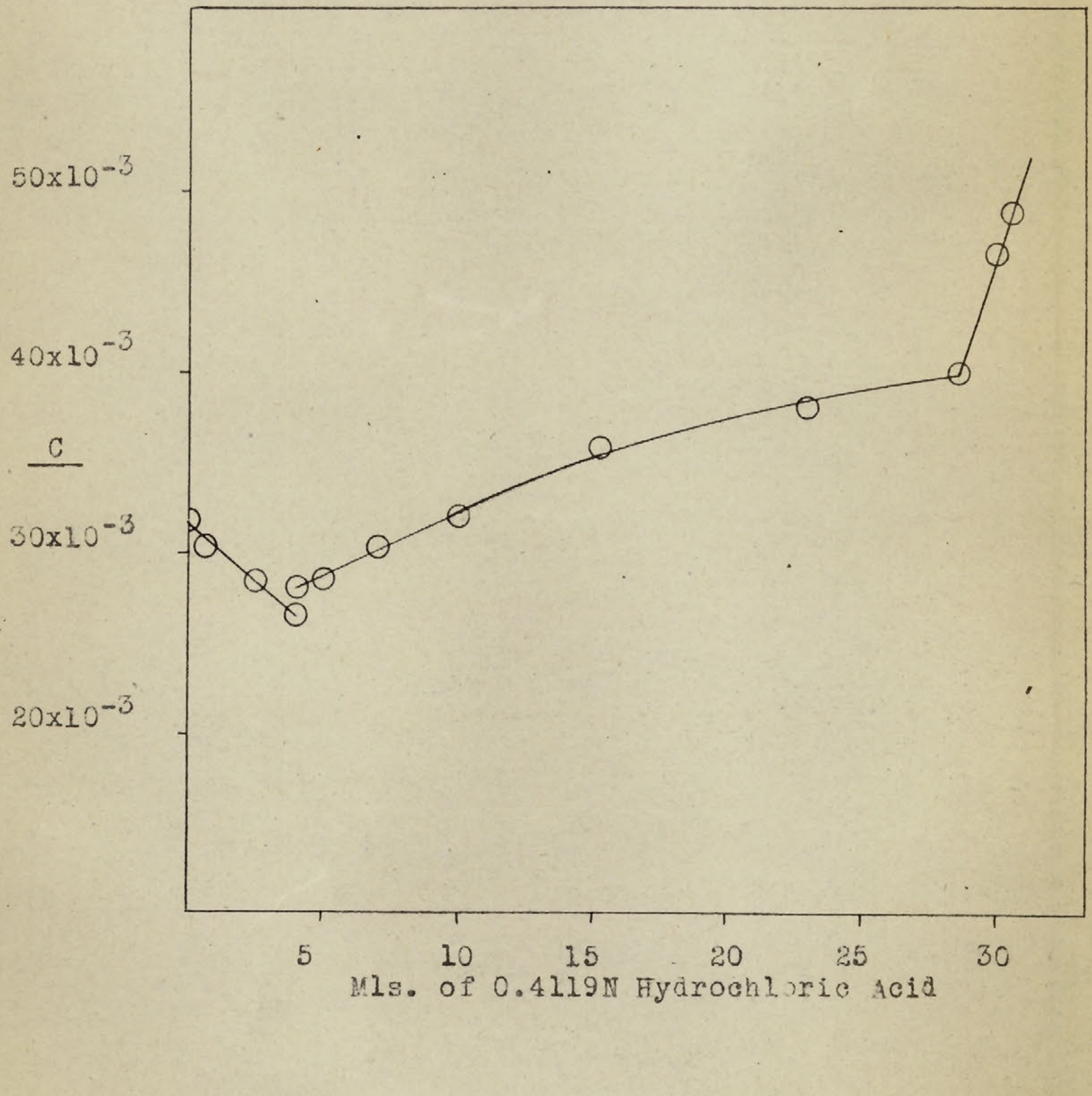


Figure 9

Addition of Hydrochloric Acid to Aqueous Sodium N.D.C.D.

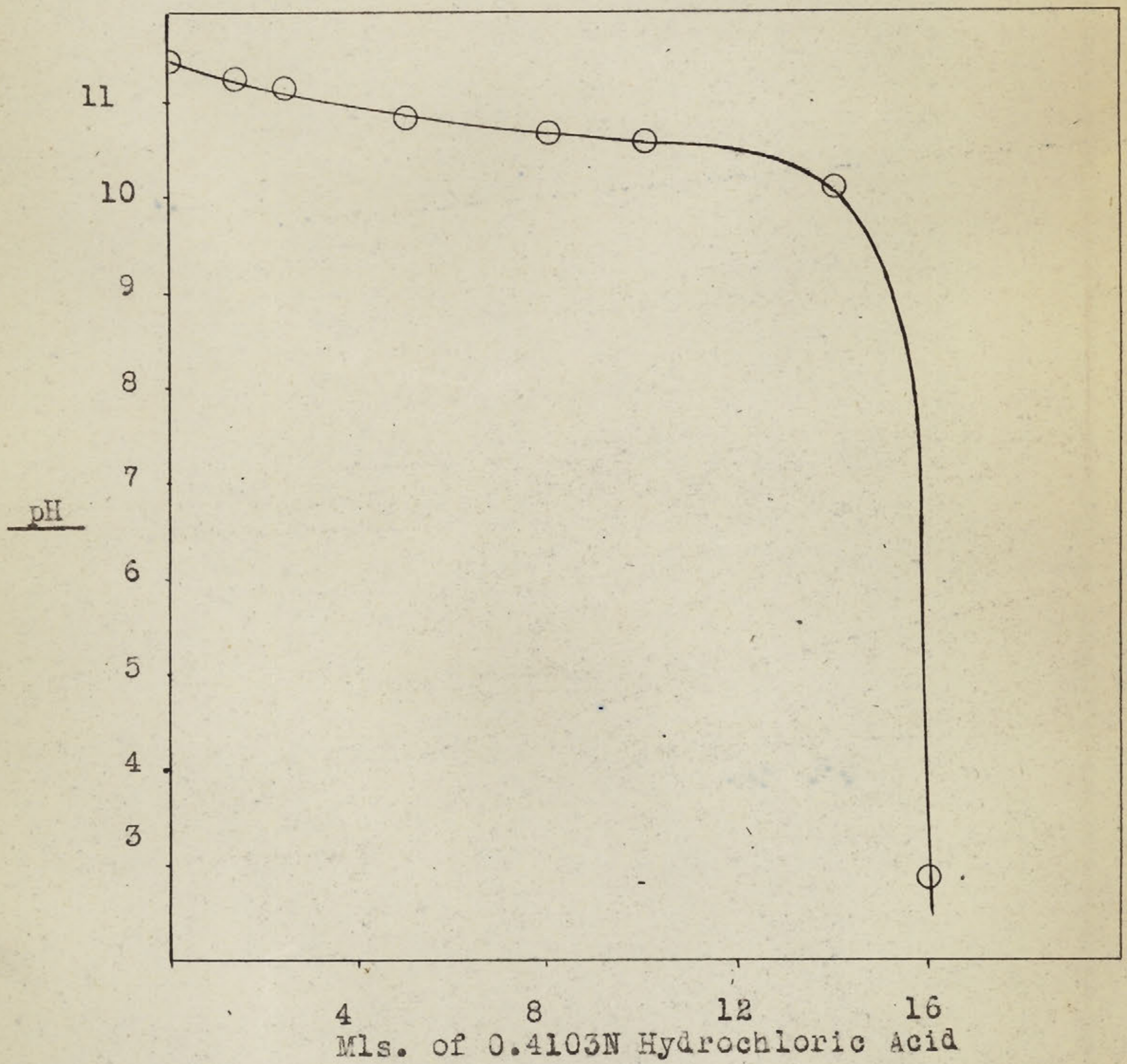


Figure 10

Addition of Hydrochloric Acid to Aqueous Sodium N.D.C.D.

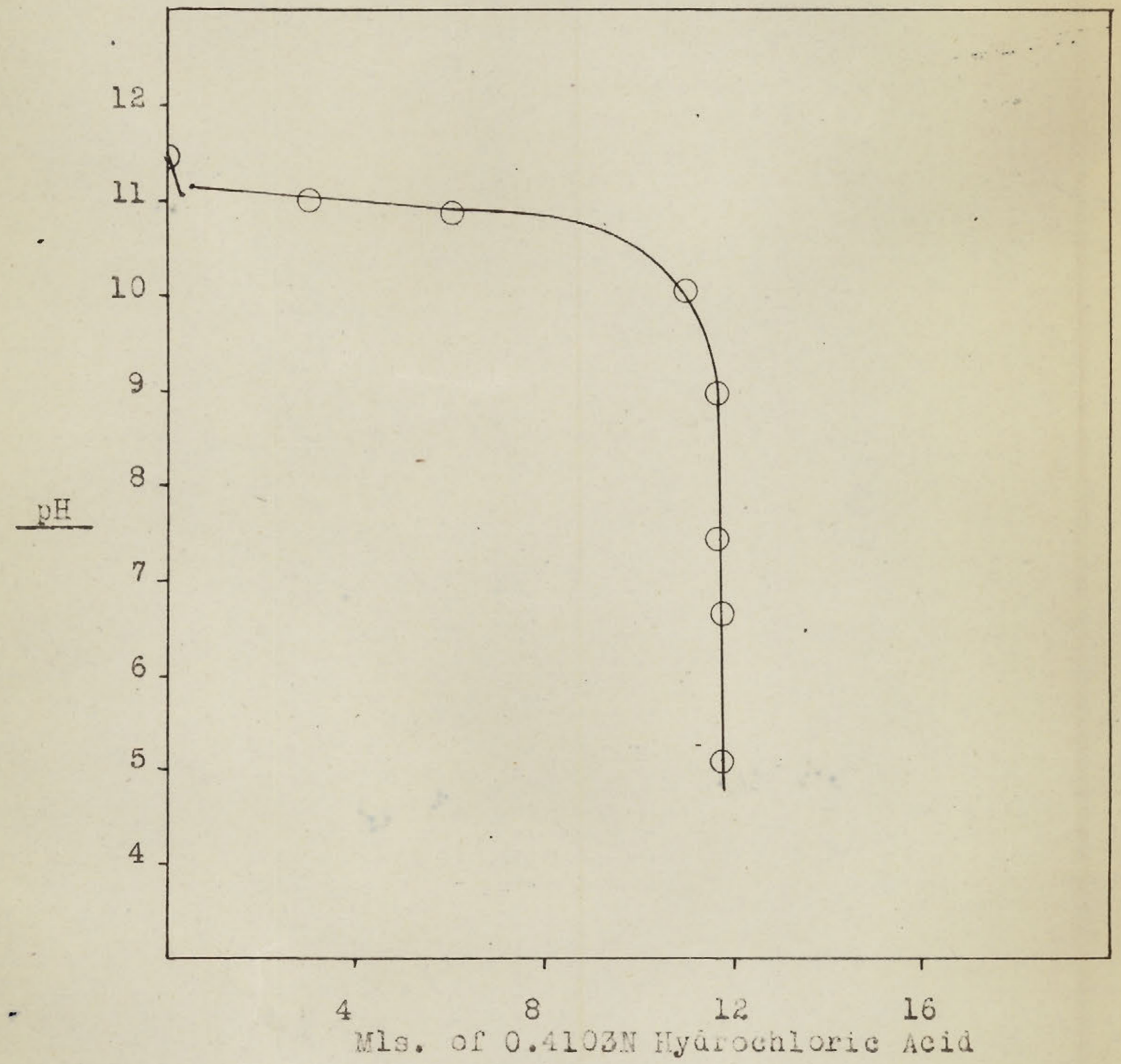


Figure 11

Addition of Hydrochloric Acid to Aqueous Sodium N.D.C.D.

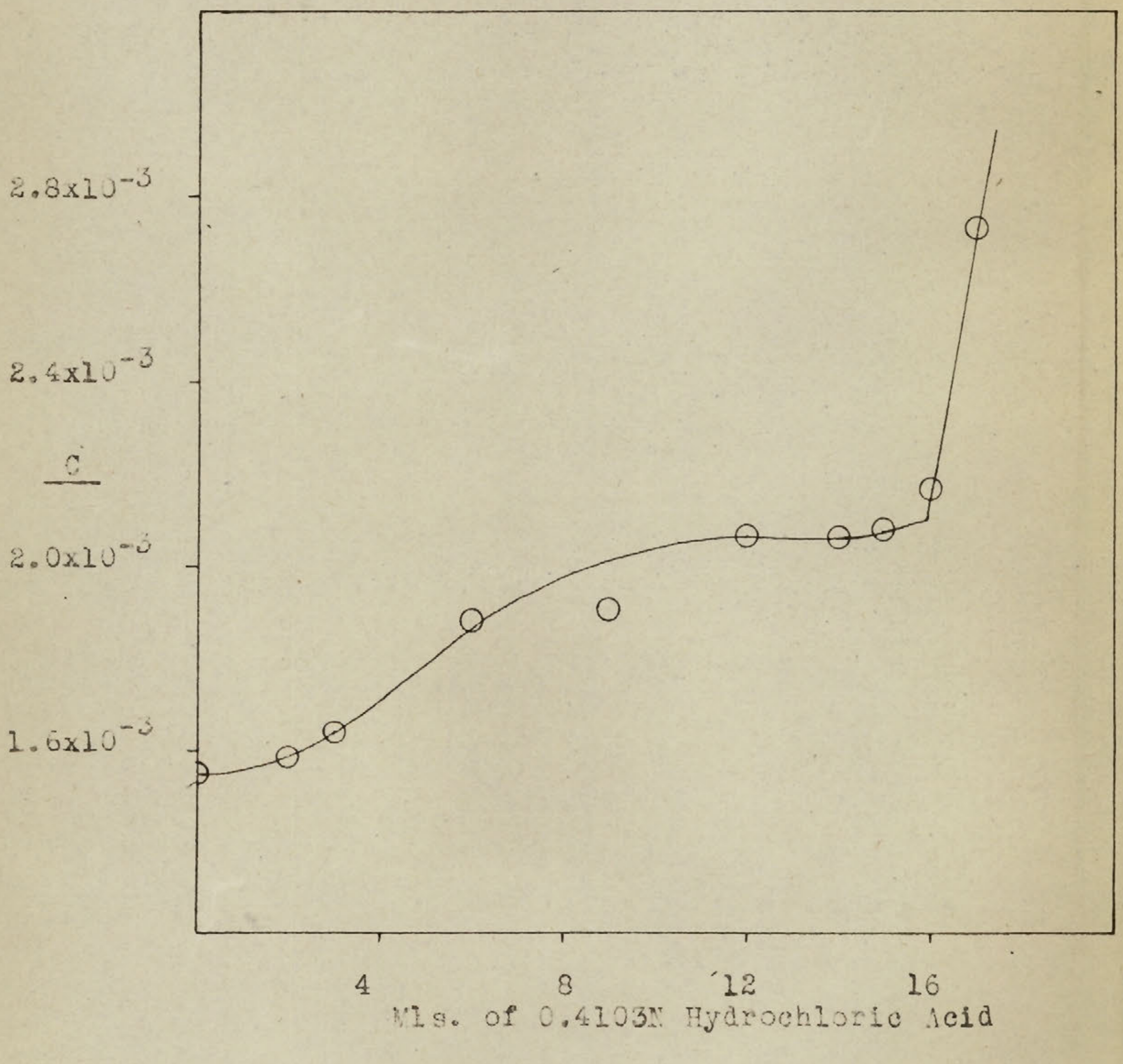


Figure 12

Addition of Hydrochloric Acid to Aqueous Sodium-N.D.C.D.

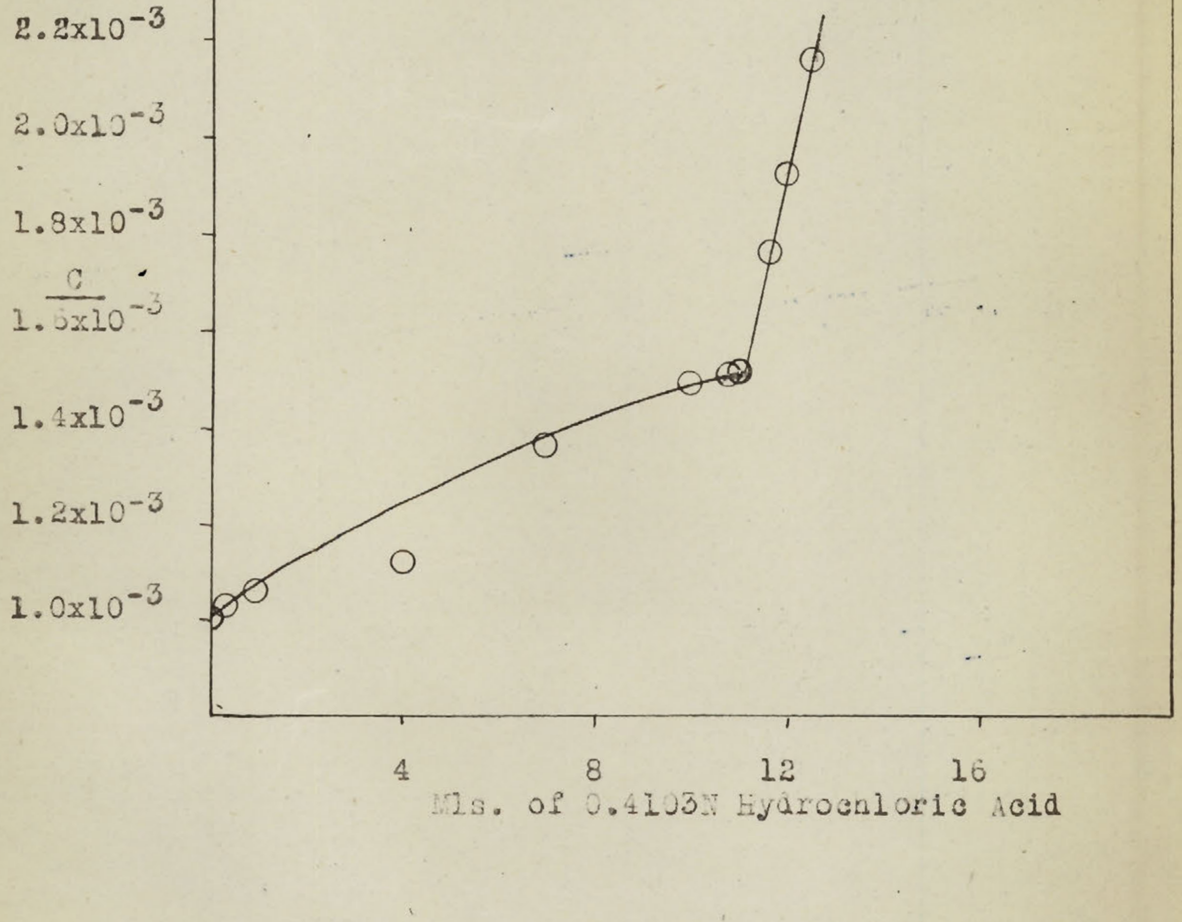


Figure 13

Addition of Hydrochloric Acid to Aqueous Potassium N.D.C.D.

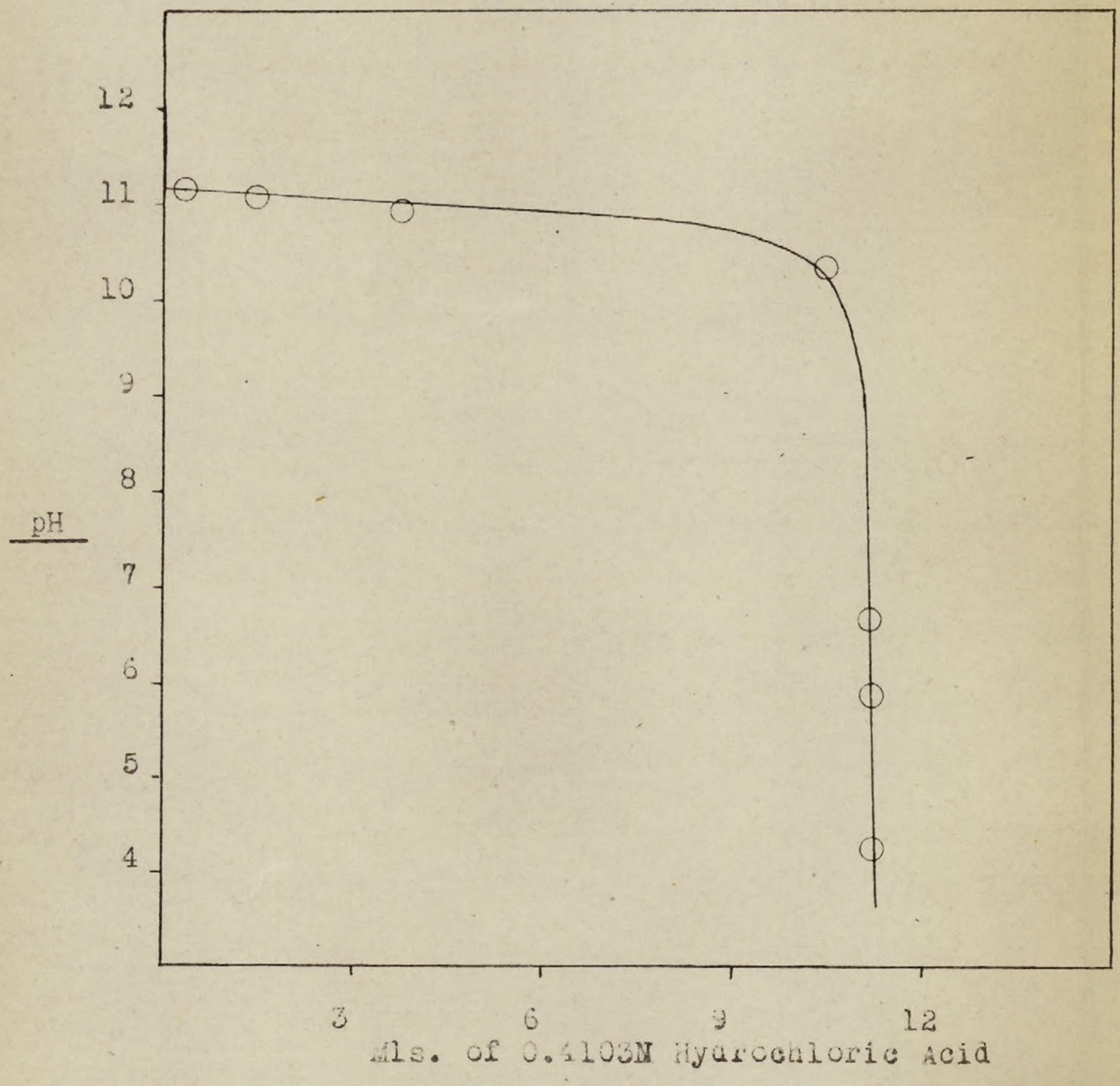


Figure 14

Addition of Hydrochloric Acid to Potassium N.D.C.D.

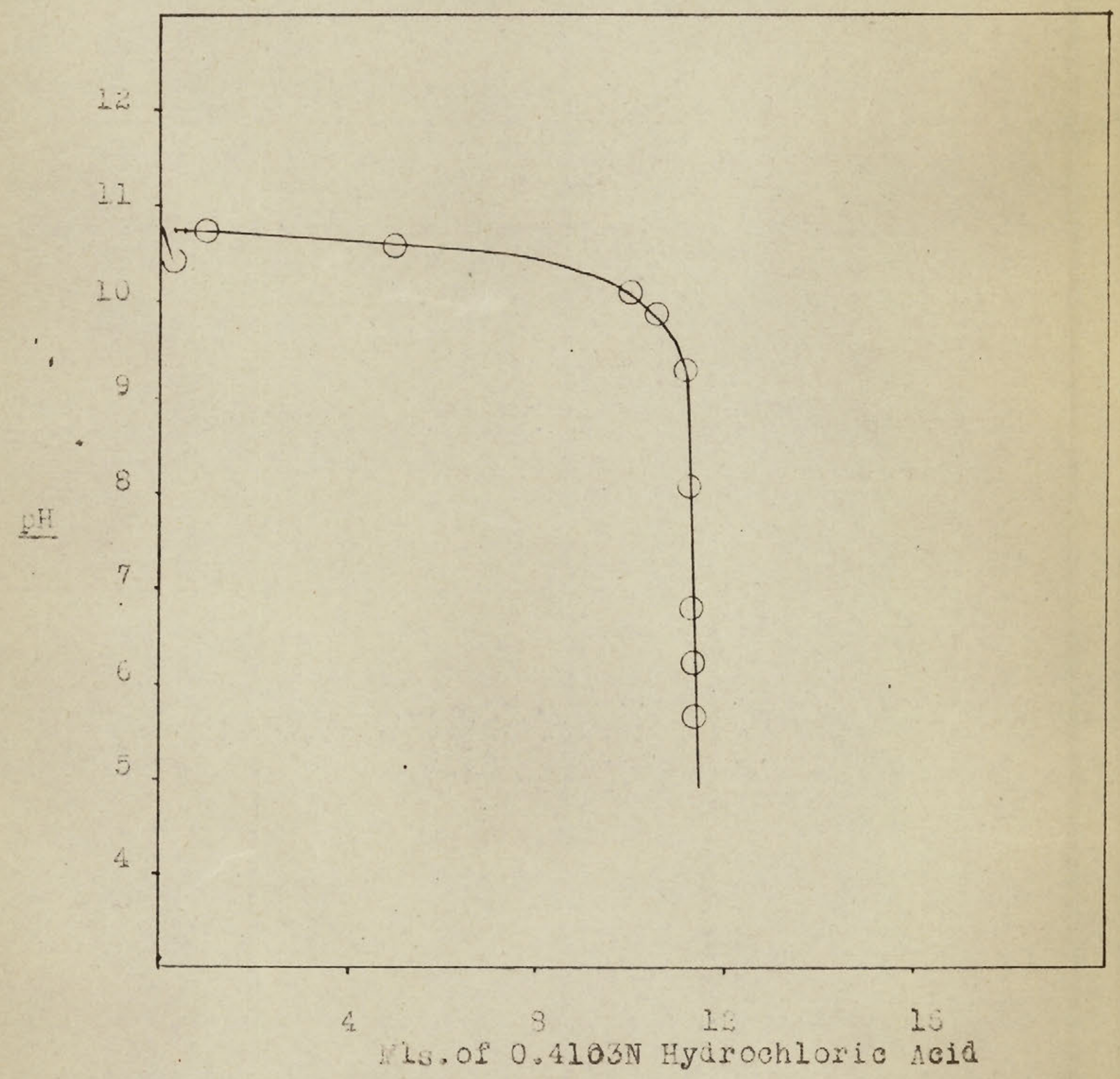


Figure 15

Addition of Hydrochloric Acid to Aqueous Potassium N.D.C.D.

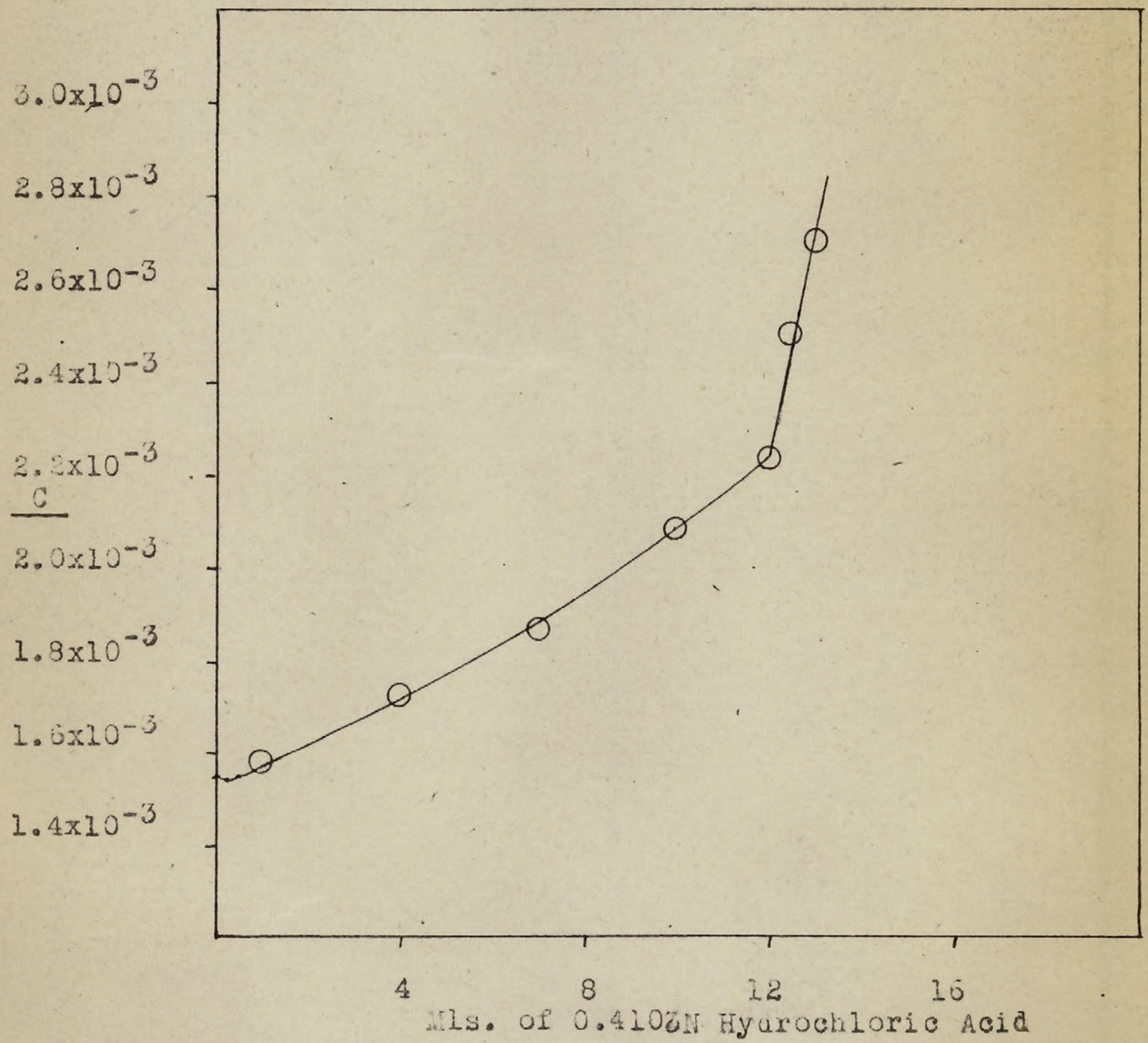
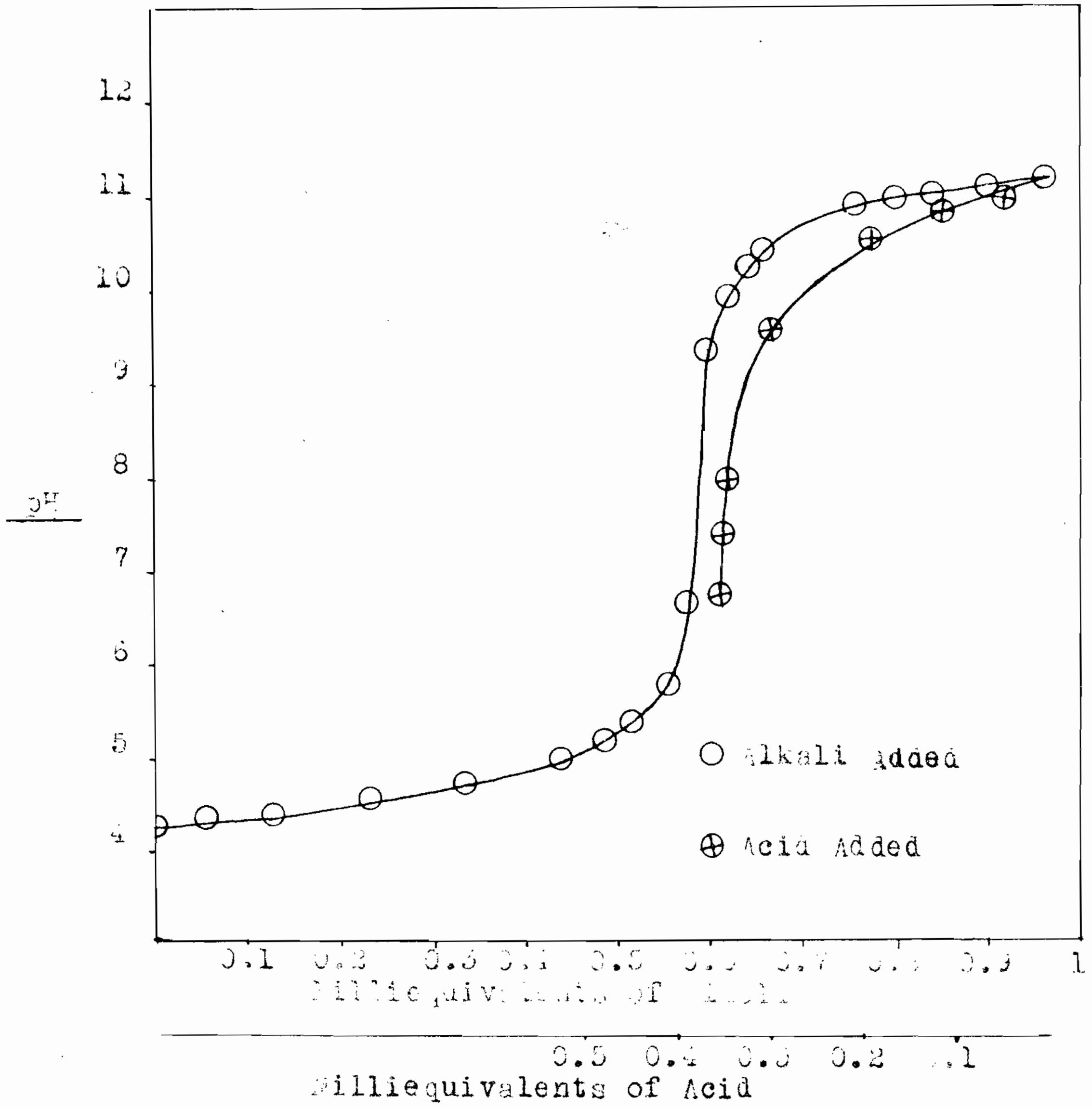


Figure 16

Titration of N (1,1 bishydrazino) Methyl N^1 Nitrourea



BIBLIOGRAPHY

1. Davis, Army Ordinance, 3, 193(1923).
2. Thiele and Uhlfelder, Ann. 303, 108 (1898).
3. Caro, Z. Angew. Chem. 23, 2414 (1910).
4. Davis, Proc. Am. Acad. Arts Sc., 11, 68 (1925).
5. Meyer, Ann., 171, 28, 48 (1874).
6. Meyer and Tscherniak, Ann. 180, 126 (1876).
7. Nef, Ann. 280, 263 (1894).
8. Meyer, Ber. 27, 3156 (1894).
9. Holleman, Rec. trav. chim. 14, 121 (1895).
10. Hantzsch and Schultze, Ber. 29, 699, 2253 (1896).
11. Hantzsch and Kissel, Ber. 32, 3137 (1899).
12. Hantzsch, Ber. 32, 576 - 600 (1899).
13. Hantzsch, Ber. 45, 89 (1912) footnote 1.
14. Michaels, J. pr. chem. 37, 507 (1888).
15. Meyer and Wertheimer, Ber. 47, 2374 (1914).
16. van't Hoff and Dimroth, Ann. 377, 127 (1910).
17. Arndt and Rose, J.C.S. 1, (1935).
18. Lowry, J.C.S. 75, 220 (1899).
19. Lowry and Magson, J.C.S. 93, 107, 119 (1908).
20. Junell, Svensk. Kemisk. Tidshrift, 46, 125 - 36 (1934).
21. Hantzsch, Ber. 32, 607 (1899).
22. Branch and Jaxon-Deelman, J.A.C.S. 49, 1765 (1927).
23. Hantzsch and Ley, Ber. 39, 3146 - 9 (1906).
24. Pedersen, Det. Kgl. Widensk. Selskab. math.-fys. Medd. 12, 1 - 16 (1932).
25. Bronsted, Chem. Rev. 5, 231 (1928).

26. Junell, Arkiv. Kemi. 11B, No. 34 (1934).

27. Junell, Svensk. Kemi. 46, 125 - 36 (1934).

28. Wynne-Jones, J. Chem. Phys. 2, 381 - 5 (1934).

29. Reitz, Z. physik. chem. A176, 363 - 87 (1936).

30. Maron and La Mer, J.A.C.S. 60, 2588 (1938).

31. Maron and La Mer, J.A.C.S. 61, 692 (1939).

32. Kuhn and Albrecht, Ber. 60, 1297 (1927).

33. Schriner and Young, J.A.C.S. 52, 3332 (1930).

34. Mills, J. Soc. Chem. Ind. 51, 750 (1932).

35. Franchimont and Klobbie, Rec. trav. chim. 7, 355 (1888).

36. Franchimont and Umgrove, Rec. trav. chim. 16, 362 (1897).

37. Davis and Luce, J.A.C.S. 49, 2303 (1927).

38. Davis, J.A.C.S. 55, 731 (1933).

39. Davis, J.A.C.S. 58, 1800 (1936).

40. Degner and von Pechman, Ber. 30, 652 (1897).

41. Pauling, Nature of the Chemical Bond, Cornell University Press, p. 214 (1940).

42. Thiele and Lachman, Ann. 288, 270 - 305 (1895).

43. Baeker, Rec. trav. chim. 31, 21 (1912).

44. Willstatter and Pfannesteil, Ber. 59B, 1870 (1926).

45. Davis and Blanchard, J.A.C.S. 51, 1790 (1921).

46. Gillman, "Organic Synthesis", Coll. Vol. 1, John Wiley and Sons Inc., New York City, 1st ed. 1932, p. 472.

47. Tokagi, Ueda and Sakaguti, J. Pharm. Soc. Japan 58, 938-45 (1938)

48. Thiele and Heuser, Ann. 288, 312 (1895).

49. Bruning, Ber. 21, 1809 (1888).

50. Jousselin, Compt. rend. 88, 1087 (1879).

51. Pellizari, Gazz.chim. ital. (2)21, 406 (1891).

52. Franchimont, Rec. trav. chim. 10, 231 (1891).

53. Thiele, Ann. 270, 1 - 17 (1892).

54. Evan and Young, J. Soc. Chem. Ind. 40, 109T (1921).

55. Davis, J.A.C.S. 47, 1063 (1925).

56. Smith, Sabetta and Steinbach, Ind. Eng. Chem. 23, 1124 (1931).

57. Gillman "Organic Synthesis", Coll. Vol. 1, John Wiley and Sons Inc., New York City, 1st ed., 1932, p. 392.

58. Sabetta, Himmelfarb and Smith, J.A.C.S. 57, 2478 (1935).

59. Gillman, "Organic Synthesis", Coll. Vol. 1, John Wiley and Sons Inc., New York City, 1st ed., 1932, p. 53.

60. Cavert and Atkins, J.A.C.S. 54, 4116 (1932).

61. Thiele, Ann. 302, 332 (1898).

62. Conard and Schriner, J.A.C.S. 55, 2867 (1933).

63. Soll and Stutzer, Ber. 42, 4538 (1909).

64. Cheetam, Dept. of Munitions and Supplies, Private Communications

65. Savard, M.Sc. Thesis, McGill University 1942.

66. Jona, Gazz. chim ital. (3)37, 558 (1908).

67. Walther and Greishammer, J. pr. chem. (2)92, 209 - 55 (1915).

68. Wheeler and Jamieson, J.A.C.S. 25, 720 (1903).

69. Curtius and Heidenrech, Ber. 27, 56 (1894).

70. Mistry and Guha, J. Ind. C. S. 7, 793 (1930).

71. Pellizari and Gaiter, Gazz. chim.ital. (2)44, 79 (1914).

72. Stolle and Krauch, J. pr. chem. (2)88, 312 (1913).

73. Hoffman and Ehrhart, Ber. 45, 2731 (1912).

74. Ellis, "The Chemistry of Synthetic Resins" Vol. 1, Reinhold Publishing Corp., New York, N.Y., 1935, p. 686.

75. Scheihler, Trastler and Schalz, Z. angew. chem. 41, 1305 (1928).

76. Halzer, Ber. 17, 659 (1884).

77. Ludy, J. Chem. Soc. 56, 1059 (1889).

78. Ludy, Monatshifte, 10, 295 (1889).

79. Bowen, Ph.D. Thesis, McGill University 1945.

80. Phillips and William, J.A.C.S. 50, 2465 (1928).

81. Pohl, J. pr. chem. (2)77, 537(1908).

82. Bishoff, Sohyum and Long, J. Biol. Chem. 81, 347 (1929).

83. Wohler, Pogg. Ann. Physik. 12, 253 (1828).

84. Emil Werner, Numerous Papers on Carbamides, J. Chem. Soc.1915-2
Chemistry of Urea, Longnans and Green & Co., London, 1923.

85. Gobian, Ber. 68B, 895 (1935).

86. Linhard and Betz, Ber. 73B, 177 (1940).

87. Wurtz, Ann. Chim. (3)30, 460 (1850).

88. Wurtz, Compt. rend. 27, 242 (1848).

89. Volhard, J. pr. chem. (2)9, 21 (1874).

90. Fleisher, Ber. 9, 955 (1876).

91. Wohler and Leibeg, Ann. 26, 301 (1838).

92. Walker and Hambly, J. Chem. Soc. 67, 749 (1895).

93. Wohler, Pogg Ann. Physik. 15, 622 (1829).

94. Wohler, Ann. Chim. (2)43, 67 (1830).

95. Davis, J.A.C.S. 44, 2595 (1923).

96. Davis, Proc. Am. Acad. Arts Sci. 11, 68 (1925).

97. Davis, J.A.C.S. 44, 2595 (1923).

98. Davis, Proc. Am. Acad. Arts Sci. 61, 437 (1926).

99. Davis, J.A.C.S. 51, 1790 (1929).

100. Davis, J.A.C.S. 51, 1801 (1929).

101. Savard, Private Communications.

102. Hetherington and Braham, J.A.C.S. 56, 907 (1934).

103. Buchanan and Barsky, J.A.C.S. 52, 195 (1936).

104. Winkler, Gilpin and Papineau-Couture, Project XR-51, McGill University, July 15th, 1943.