SEVERAL ORGANIC ARSENICALS

A thesis submitted to the Graduate School of the University of Wisconsin in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

by

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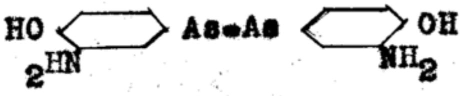
TABLE OF CONTENTS

PART I

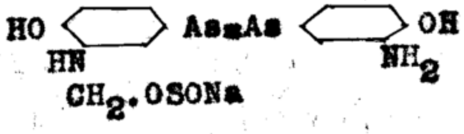
INTRODUCTION

In 1760 L. C. Cadet de Gassicourt distilled a mixture consisting of equal parts of arsenious oxide and potassium acetate and obtained two liquids which we now know to be cacodyl, $(CH_3)_2As-As(CH_3)_2$, and cacodyl oxide, $(CH_3)_2As-O-As(CH_3)_2$.(1 While naturally-occurring arsenic compounds, such as sulphides, were known to ancient peoples, this is the first recorded instance of an arsenic compound in which the arsenic occurred in organic combination, a so-called organic arsenical. In the early nineteenth century, when modern chemistry was first developing, the organic arsenicals became the subject of considerable investigation. Among the famous chemists whose names are associated with these compounds, might be mentioned such men as Bunsen, Dumas, Berzelius, Laurent, Gerhardt, Baeyer, Hofmann, and Michaelis. In the early part of the twentieth century, when already a large number of organic arsenicals had been prepared, the discovery by Thomas(2 and later by Breinl and Kinghorn(3 that the sodium salt of p-arsanilic acid or atoxyl, had a therapeutic action in trypanosomiasis furnished a tremendous impetus for the making of new arsenic compounds. It started Ehrlich on the track of an illusive compound that would be better than the dangerous atoxyl; resulted in the discovery of arsphenamine, which has saved innumerable lives; and still today encourages many research workers in their efforts to discover the most efficient arsenical for the treatment of those diseases caused by spirochetes and trypanosomes.

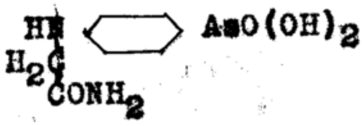
Of the many organic arsenicals which have been tested for therapeutic action only those containing certain groups seem to be effective. In addition to arsenic and the benzene ring one or more amino groups seem essential for therapeutic action. Thus the following compounds have proved to be among the most efficient in the treatment of syphilis:



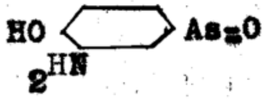
arsphenamine, and various coordination compounds of arsphenamine,



neoarsphenamine,



tryparsamide,



mapharsen.

While thousands of other arsenicals have been tried the above compounds are used almost exclusively today in medical practice. Yet none of these can be termed the ideal remedy for the treatment of syphilis. Arsphenamine is difficult to prepare, requires a skilled technician for its administration, and together with neoarsphenamine often produces toxic symptoms in the patient whom it is intended to cure. Tryparsamide is of value only in the last stages of the disease. Mapharsen, while comparatively new as a therapeutic agent, would seem to be the most efficient drug yet developed.(16, 129 The need for further study of arsenic compounds is apparent.

Practically all the organic arsenicals which have been prepared have the arsenic atom joined to carbon. The few exceptions to this, containing such linkages as arsenic to oxygen, arsenic to sulphur, and arsenic to nitrogen, have been so-little investigated that it is impossible to say whether any compounds containing such linkages will possess therapeutic value or not. It is with these compounds that the present thesis deals, more especially those containing the arsenic to nitrogen linkage. In that the most effective arsenicals contain a nitrogen atom in the form of an amine group, the hope that the compounds investigated and discussed here may possess some measure of therapeutic activity is not altogether without foundation.

While a few compounds with the As-N linkage have been prepared and investigated from the chemical standpoint, only one apparently has been tested in vivo. Leonard, whose chemical investigation of arsine-tri-1-piperidinium chloride was published in 1921,(4 reported the results of his therapeutic investigation of this same compound in 1926.(5 He found that it produced the same symptoms as quaternary ammonium salts (a result in harmony with the structure assigned to the compound by the author), showed no arsenical toxicity, and exhibited no trypanocidal activity in sublethal doses. It is of course impossible to condemn all compounds containing the As-N linkage because one compound fails to show therapeutic activity. Arsphenamine, 3,3'-diamino-4,4'-dihydroxyarsenobenzene, is extremely active, while 4,4'-diamino-3,3'-dihydroxyarsenobenzene, isomeric with arsphenamine, is entirely devoid of action. Thus the chemical investigation of compounds containing the As-N linkage was undertaken, and the results are given in the experimental portion of this thesis.

PART II

HISTORICAL

The reaction between metal or metalloid halides and ammonia or amines may be expressed by the following equation where M represents the metal or metalloid and X the halogen:

$$nNH_3 + MX_m \longrightarrow M(NH_3)_nX_m.$$

The resulting complexes thus formed may be divided into two classes:

1. Where one mole of ammonia or an amine enters the complex for each halogen atom present in the original halide. Such a reaction takes place for example between arsenious chloride or bromide and aniline,(6,7,8

$$AsCl_3 + 3C_6H_5NH_2 \longrightarrow (C_6H_5NH.HCl)_3As,$$

or between piperidine and arsenious chloride or antimony trichloride,

$$SbCl_3 + 3C_5H_{10}NH \longrightarrow (C_5H_{10}N.HCl)_3Sb.$$

2. Where more than one mole of ammonia or an amine enters the complex for each halogen atom present in the original halide. An example of this type is the reaction between ammonia or amines and lithium chloride and bromide to give four different types of complex ammines:(9,10,11 $LiCl.NH_3$, $LiCl.2NH_3$, $LiCl.3NH_3$, and $LiCl.4NH_3$. To this class also belong the complex ammines of cobalt, platinum and other metals, such as $[Co(NH_3)_6]Cl_3$ and $[Pt(NH_3)_6]Cl_4$, whose structure was elucidated by Werner.(12 While there is no essential difference between

the reactions involved in the formation of the two classes, halides of phosphorus, arsenic, antimony, and bismuth usually react to form complexes of the first class and as it is with these elements in particular that this paper is dealing, they will be dealt with more fully than those of the second class.

1) <u>The reaction between arsenious halides and amines</u>

Persoz, in 1830, was the first worker to observe the action of arsenious halides on ammonia.(13 He obtained a compound to which he assigned the formula $AsCl_3.4NH_3$ and observed that it was decomposed by water. In 1841 Rose, by treating arsenious chloride with dry ammonia, obtained a white powder which he formulated as $2AsCl_3.7NH_3$.(14 Pasteur in 1848 repeated Rose's work and observed that the resulting mixture contained two types of crystals, one being ammonium chloride and the other an arsenic complex.(15 He expressed the reaction thus:

$$2AsCl_3 + 7NH_3 \longrightarrow 2(Cl.AsNH) + 4NH_4Cl + NH_3.$$

Schiff in 1863 was the first worker to definitely assign a structure to this type of compound.(6 Using arsenious, antimony, and bismuth halides and aniline he obtained compounds $AsCl_3.3C_6H_6NH_2$, $SbCl_3.3C_6H_5NH_2$, and $BiCl_3.3C_6H_5NH_2$. He expressed them structurally thus:

$$N_3\left\{\begin{matrix}As\\3C_6H_5.3HCl.\\H_3\end{matrix}\right.$$

The arsenic compound melted at 90° and was decomposed by water. Leeds in 1881 obtained similar compounds from arsenious and antimony chlorides and aniline.(17 He also obtained compounds with aniline and a number of halides such as those of cadmium, ferrous iron, manganese, stannous and stannic tin, titanium, uranium, zinc, and mercury. He also used other amines including p- and o-toluidine and xylidine.

Bamberger and Philipp in 1881 obtained a compound by the action of ammonia gas on arsenious iodide in benzene solution to which they assigned the formula $2AsI_3.9NH_3$.(18 Landau in 1888, using arsenious bromide and a large number of amines, obtained compounds containing different numbers of amine molecules depending upon the amine used.(7 Thus with ammonia $2AsBr_3.7NH_3$ was formed, with aniline $AsBr_3.3C_6H_5NH_2.H_2O$ which was changed into $AsBr_3.4C_6H_5NH_2.H_2O$ by treatment with absolute alcohol or glacial acetic acid. Other amines used were ethylamine, dipropylamine, trimethylamine, triethylamine, diphenylamine, and quinoline.

In 1890 Anschütz and Weyer made a very thorough investigation of the reaction between arsenious bromide and chloride and aniline.(19 These reactions were performed in dry ether solution. With an excess of $AsCl_3$ or $AsBr_3$ the compounds $Cl_2As.NHC_6H_5$ and $Br_2As.NHC_6H_5$ were obtained. The chlorine compound was a yellow crystalline product, m.p. 87-88°, and decomposed in moist air. The yield was extremely small. However if an excess of aniline was used, the compound $ClAs(NHC_6H_5)_2$ was obtained, together with a large amount of ammonium chloride. A similar compound was obtained with arsenious bromide. These investigators were unable to obtain the compound $AsCl_3.3C_6H_5NH_2$, prepared by Schiff and Landau, and believed that the latter had been dealing with a mixture of ammonium chloride and the above arsenic compounds. Besson in 1890 by placing arsenious chloride, bromide, or iodide in an atmosphere of ammonia gas obtained compounds $AsCl_3.4NH_3$, $AsBr_3.3NH_3$, and $AsI_3.4NH_3$.(20 He noted that at 300° both the bromide and iodide compounds were decomposed into the nitride, AsN.

Michaelis and Rabinerson in 1890, by mixing arsenious chloride and dimethylaniline at ordinary temperatures, obtained a compound melting at 240° to which they gave the formula $(C_6H_4N(CH_3)_2)_3As$. When treated with sodium hydroxide it formed $C_6H_4N(CH_3)_2AsO$.(21 In 1896 Michaelis and Luxembourg obtained $(i\text{-}C_4H_9)_2NAsCl_2$ from diisobutylamine and arsenious chloride.(27 It was a crystalline substance, b.p. 125°/15 mms.

Hugot in 1904 was the first to thoroughly investigate the reaction between arsenious halides and ammonia.(22 When arsenious chloride was saturated with dry ammonia gas at -40 to -30°, the following reaction took place:

$$AsCl_3 + 6NH_3 \longrightarrow As(NH_2)_3 + 3NH_4Cl.$$

The amide was a gray amorphous powder, stable below 0° and decomposed by water. Arsenious bromide and iodide reacted similarily. Between 0 and 60° the amide was decomposed into the imide,

$$2As(NH_2)_3 \longrightarrow As_2(NH)_3 + 3NH_3.$$

The imide was a yellow amorphous powder. At 250° the imide decomposed into the nitride, which itself decomposed into the elements a few degrees above its temperature of formation:

$$As_2(NH)_3 \longrightarrow 2AsN + NH_3.$$

The nitride was an orange powder.

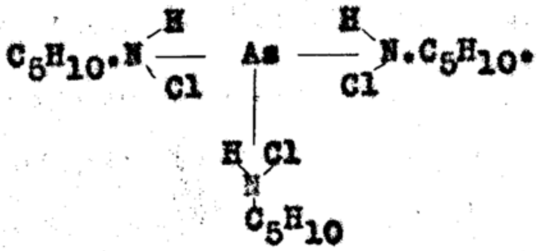
In 1908 Besson and Rosset repeated the experiments of Besson and believed that they had confirmed the fact that $AsCl_3.4NH_3$ is formed by the interaction of arsenious chloride and ammonia. The reaction was carried out in liquid ammonia.(23 In 1909 Morgan and Micklethwait obtained a compound which they believed to be either $C_6H_5NH.C_6H_4As(C_6H_4NH_2)_2$ or $C_6H_5NH.C_6H_4As(NHC_6H_5)(C_6H_4NH_2)$, by the action of arsenious chloride on aniline in boiling benzene or toluene solution.(24 However as the product was treated with sodium carbonate solution and the excess aniline removed by steam distillation, it is probable that their original product was not isolated, but changed by the action of the alkali and steam. Mrooszkowski, a pupil of Michaelis, in 1910 obtained a number of compounds by the interaction of arsenious chloride and various substituted anilines.(25 He gives the following reaction between dimethylaniline and arsenious chloride:

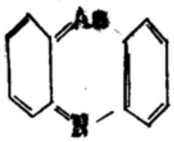
$$C_6H_5N(CH_3)_2 + AsCl_3 \longrightarrow AsCl_2.C_6H_4N(CH_3)_2HCl$$

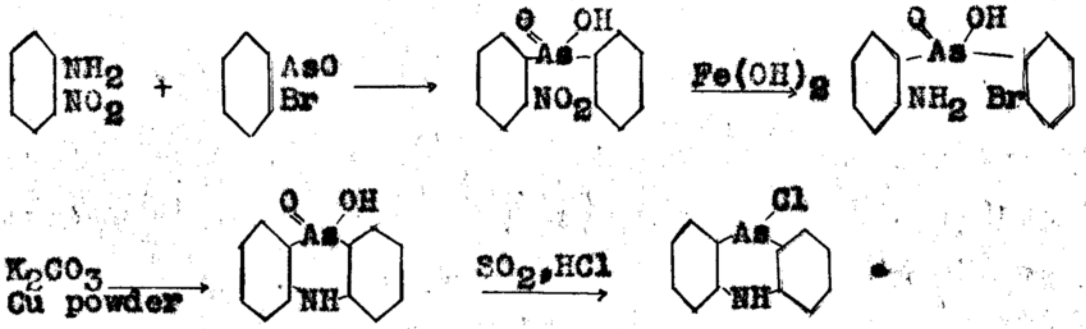
$$AsCl_2.C_6H_4N(CH_3)_2HCl + 3NaOH \longrightarrow OAsC_6H_4N(CH_3)_2 + 2H_2O + 3NaCl.$$

Using monomethylaniline he obtained $O{=}As.C_6H_4NH.CH_3$ and proved the presence of the free imino group by acetylation. Again the action of alkali would decompose any substance formed containing the As-N linkage, and Mrooszkowski's work does not prove that a compound $(C_6H_5N(CH_3).HCl)_3As$, similar to that obtained by Schiff from aniline, was not formed between dimethyl and monomethylaniline and arsenious chloride. In 1913 Fränkel and Löwy obtained a compound $AsCl_3.C_9H_7N$ by adding an ethyl acetate solution of arsenious chloride to quinoline.(26

At the University of Wisconsin the action of arsenious chloride on aniline and on piperidine was investigated by two workers. Leonard obtained the compound $(C_5H_{10}N.HCl)_3As$ by the interaction of piperidine and arsenious chloride in dry heptane solution.(4 He named this arsine-tri-l-piperidinium chloride and assigned to it the following structure:



The substance was recrystallized from alcohol and was but slightly decomposed by water. It formed double compounds with mercuric and lead iodides similar to those formed by ammonium chloride. Leonard obtained similar compounds with piperidine and antimony, silicon, stannic, titanium, and phosphorus chlorides. Schmidt obtained $(C_6H_5NH.HCl)_3As$ from aniline and arsenious chloride in dry heptane solution.(8 In 1921 Wieland and Rheinheimer, by the interaction of arsenious chloride and diphenylamine, obtained 10-chloro-5:10-dihydrophenarsazine, the same substance which Schmidt had obtained by heating his trianilidoarsine hydrochloride.(29 They also obtained the parent substance, phenarsazine,  by heating 10-methoxy-5:10-dihydrophenarsazine. Lewis and Hamilton used phenyl-α-naphthylamine instead of diphenylamine and obtained the corresponding 7-chloro-7:12-dihydro-γ-benzophenarsazine.(30 In 1926 Gibson and his fellow workers commenced a series of investigations on phenarsazine and its substitution products, which throw considerable light on these interesting compounds. The structure of 10-chloro-5:10-dihydrophenarsazine was proved by the following synthesis:(31



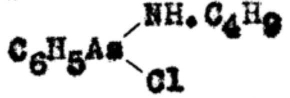
Schmidt's work was repeated and by heating $(C_6H_5NH.HCl)_3As$ some diphenylamine was isolated, and the authors believe that it is this diphenylamine that gives the 10-chloro-5:10-dihydrophenarsazine. Other amines used to give substitution products of phenarsazine were β-naphthylamine, di-β-naphthylamine, di-α-naphthylamine, p-tolyl-β-naphthylamine, p-tolyl-α-naphthylamine, m- and p-chlodiphenylamine, and p,p'-dichlorodiphenylamine.(32 A great deal more work on 10-chloro-5:10-dihydrophenarsazine was done by Gibson and his fellow workers, but the majority of the compounds were made by the indirect synthesis given above, and no further investigations into the action of arsenious chloride on the amines themselves were made. Also in 1926 Dafert and Melinski obtained stable addition compounds by the interaction of arsenious halides and pyridine.(33 They obtained $AsCl_3.C_5H_5N$, a white crystalline substance, m.p. 145.5°; $AsBr_3.(C_5H_5N)_2$, a white crystalline substance, m.p. 195°; and $AsI_3.(C_5H_5N)_2$ which decomposed without melting. It seems remarkable that the three arsenious halides should give different types of compounds by their reaction on pyridine under the same conditions. Puschin and Löwy in the same year, by a study of phase rule diagrams showed that arsenious bromide formed only a mechanical mixture with -naphthylamine.(34 Vournasos in 1927 obtained compounds $Na_8[AsBr_3(N_3)_8]$ and $Na_8[AsI_3(N_3)_8]$ by the reaction between sodium azide and arsenious bromide and iodide.(35 Nitrogen in azides of course is in an entirely different state than in amines. Raudnitz obtained $(CH_3)_2N.C_6H_4AsO$ by the interaction of arsenious chloride and dimethylaniline, but again the reaction mixture was treated with water and no compound containing the As-N linkage could thus be expected.(36 In 1930 Shirey obtained a compound $AsCl_3.2C_5H_5N$, melting at 64°, by the interaction of arsenious chloride and pyridine.(37 Gibson, Johnson, and Vining in the same year obtained a compound from the same substances of the formula $AsCl_3.C_5H_5N$, melting at 138-139° which is 6-7° lower than the melting point of Dafert and Melinskis' compound of the same formula.(38 When treated with water the compound decomposed to give pryidine hydrochloride and arsenious oxide. In 1932 the compound 

was obtained by McCleland and Wilson by the action of 3-chloromercuripyridine and arsenious chloride and passing hydrogen chloride into an aqueous solution of the crude product.(39

The author in 1932 obtained compounds similar to those obtained by Schmidt and Leonard by the interaction of arsenious chloride and benzylamine, dibenzylamine, and tribenzylamine in dry heptane solution.(40 In addition to

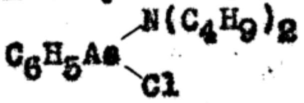
$(C_6H_5CH_2NH.HCl)_3As$, formed by the interaction of benzylamine and arsenious chloride, a small amount of the di-substituted compound, $(C_6H_5CH_2NH.HCl)_2AsCl$, was formed. There was also formed a light yellow, very unstable liquid which was not purified, but the compound $C_6H_5CH_2NH.AsCl_2$ was indicated by analyses of the crude product.

In addition to using arsenious halides some work has been done in which substituted arsenious halides were used. Thus Michaelis in 1902 reacted $C_6H_5AsCl_2$, phenyldichlorarsine, with ammonia and various amines.(41 When dry ammonia gas was passed into a dry benzene solution of phenyldichlorarsine, ammonium chloride precipitated and was filtered off. A yellow oil was obtained from the benzene solution which crystallized into a white compound, m.p. 270°. This was identified as the imide, $C_6H_5As{=}NH$, and probably was formed by deamonization of the diamide, $C_6H_5As(NH_2)_2$. The imide was decomposed by water. Using primary or secondary amines Michaelis obtained mono-substitution products. Thus with butylamine and dibutylamine the compounds



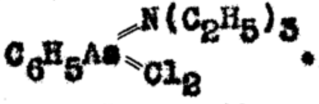
$C_6H_5As\begin{smallmatrix}\diagup NH.C_4H_9\\ \diagdown Cl\end{smallmatrix}$

and



$C_6H_5As\begin{smallmatrix}\diagup N(C_4H_9)_2\\ \diagdown Cl\end{smallmatrix}$

were obtained. With tertiary amines Michaelis claimed to have obtained addition compounds. Thus with triethylamine he obtained a white compound to which he assigned the formula



$C_6H_5As\begin{smallmatrix}= N(C_2H_5)_3\\ = Cl_2\end{smallmatrix}$

. Such a structure is incompatible with modern valency theories as the nitrogen is given a covalency of five which we now believe nitrogen can never possess. In the light of work described in the experimental portion of this thesis it is extremely unlikely that the compounds obtained by the interaction of phenyldichlorarsine and tertiary amines possess the structure assigned to them by Michaelis. Ipatiew, Rasuwajew, and Stromski in 1929 reacted ammonia with several halogen arsines, both aromatic and aliphatic.(42 With diphenylchlorarsine, $(C_6H_5)_2AsCl$, and ammonia they obtained ammonium chloride and the amide $(C_6H_5)_2As.NH_2$, a crystalline substance, m.p. 53°. With methyldichlorarsine they obtained $CH_3As=NH$, which polymerized in aggregates of four or six molecules. With phenyldichlorarsine they obtained $C_6H_5As=NH$, the same compound obtained by Michaelis but melting five degrees lower. In all these reactions ammonium chloride was also found, and the compounds were all decomposed by water with the formation of the corresponding arsineoxide. Blicke and Smith in 1930, repeating the work of Ipatiew, Rasuwajew, and Stromski with phenyldichlorarsine and ammonia, also found that the imide $C_6H_5As=NH$ polymerized to $(C_6H_5As=NH)_4$.(43

2) <u>The reaction between arsenious halides and ammonium salts and salts of the amines.</u>

There has also been considerable work done on the interaction of arsenious halides and ammonium salts and salts of the amines. In these cases however the reaction is entirely different from that in which an amine or ammonia is used, and the double compounds thus formed are not decomposed by water. Thus Dehn in 1926 obtained $C_9H_7NH.Cl.AsCl_3.2H_2O$ by the interaction of quinoline hydrochloride and arsenious chloride.(44

3) <u>Compounds containing the As-N linkage prepared by other methods.</u>

From the later work on the interaction of arsenious halides and amines it is evident that the resultant arsenic compounds contain the As-N linkage. There have been several attempts to prepare compounds containing this linkage by methods other than the interaction of arsenious halides and amines. Mann and Pope investigated the oxidation of organic sulphides with chloramine-T and obtained compounds of the type S=NH which they termed "sulphimines".(45 They also showed that triphenylarsine was oxidised by chloramine-T to

$2C_6H_4CH_3.SO_2.N{=}As(C_6H_5)_3,C_6H_4CH_3.SO_2.NH_2$. A compound containing this type of As=N linkage was also formed by oxidising β,β',β''-trichlorotrivinylarsine with chloramine-T.(46 By analogy to the sulphur compounds this linkage is termed the "arsylimine" and the compound thus obtained, $(CHCl{:}CH)_3As{=}N.SO_2.C_6H_4CH_3$, is named β,β',β''-trichlorotrivinylarsine-p-toluenesulphonylimine. Steinkopf and Dudek in 1929 attempted to obtain compounds of the type RAs=NR by a process similar to diazotization.(47 They reacted nitrosobenzene and phenylarsine in a carbon dioxide atmosphere at 0°. Colour changes were noted but the products of the reaction were arsenobenzene, diazobenzene, aniline, and phenylarsineoxide. They represented the reactions as follows:

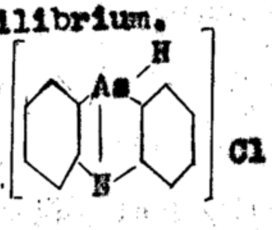
$$2C_6H_5AsH_2 + 2ONC_6H_5 \longrightarrow 2C_6H_5As{=}NC_6H_5 + H_2O$$

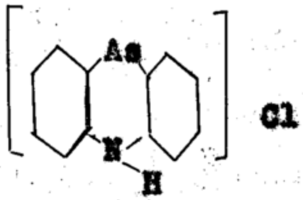
$$2C_6H_5As{=}NC_6H_5 + H_2O \longrightarrow (C_6H_5As{=})_2 + (C_6H_5N{=})_2$$

$$C_6H_5As{=}NC_6H_5 + H_2O \longrightarrow C_6H_5AsO + C_6H_5NH_2$$

$$C_6H_5AsH_2 + C_6H_5NO \longrightarrow C_6H_5AsO + C_6H_5NH_2.$$

Gibson has proposed a structure for 10-chloro-5:10-dihydrophenarsazine and certain of its derivatives involving an As-N linkage as a part of a ring(48,49 in which the two may be in equilibrium.





There is considerable evidence for the above structures, both from the physical properties of the compounds and absorption spectra.(50

4) <u>The reaction between phosphorus halides and amines</u>

While the interaction of arsenious halides and amines has been more thoroughly investigated, halides of the three related elements, phosphorus, antimony, and bismuth, react similarily with amines. Phosphorus halides have not been investigated very extensively, and the resulting compounds appear to be less stable than the corresponding arsenic compounds. Sir Humphrey Davy in 1810 and 1811 reacted phosphorus trichloride with ammonia and obtained a "triple compound" from which the phosphorus could be expelled by a gentle heat.(51,52 In 1832 Rose obtained compounds which he believed to be $PCl_3 \cdot 5NH_3$ and $PCl_5 \cdot 5NH_3$ by passing dry ammonia into the two chlorides of phosphorus.(53 Using ammonia, aniline, and phosphorus oxychloride Schiff in 1857 obtained compounds $OP(NH_2)_3$ and $OP(NHC_6H_5)_3$. With $PSCl_3$, the compounds $SP(NH_2)_3$ and $SP(NHC_6H_5)_3$ were obtained.(54 On heating $OP(NH_2)_3$, phosphorus oxynitride, $OP\equiv N$, was obtained.

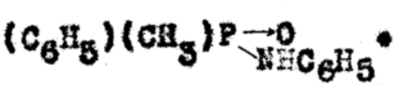
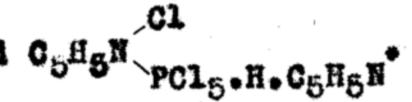
In 1890 Besson found that phosphorus trichloride absorbed dry ammonia to give a compound, to which, from phosphorus and chlorine analyses, he assigned the formula $PCl_3.5NH_3$.(55) Using PCl_5 without a solvent he states that the following reaction takes place:

$$PCl_5 + 4NH_3 \longrightarrow Cl_3P(NH_2)_2 + 2NH_4Cl.$$

In carbon tetrachloride solution however he obtained $PCl_5.8NH_3$, and with phosphorus pentabromide he isolated $PBr_5.9NH_3$. Michaelis and Schenk in the same year condensed various tertiary amines and phosphorus trichloride, using dry aluminum chloride as a catalyst.(56) In this case however the investigators believed that the phosphorus was joined to carbon. Thus from dimethylaniline they obtained a compound which they believed to be $(CH_3)_2NC_6H_4.PCl_2$. Other amines used were methylbenzylaniline, ethylbenzylaniline, and diethylaniline. In 1895 Michaelis using phosphorus oxychloride and piperidine obtained $OP(NC_5H_{10})_3$ which formed a hydrochloride with HCl and double salts with chloroplatinic acid and mercuric chloride.(57) In 1896 compounds of the type R_2NPCl_2 and R_2NPOCl_2 were obtained by Michaelis from secondary amines and phosphorus trichloride or oxychloride.(27) Thus from diethylamine and phosphorus trichloride he obtained $(C_2H_5)_2N.PCl_2$ and from phosphorus oxychloride $(C_2H_5)_2N.POCl_2$. Moissan, in his classic investigations on fluorine and its compounds, observed that phosphorus trifluoride absorbed dry ammonia to give a white compound which was instantaneously decomposed by water.(58) In 1905 Hugot, who had isolated $As(NH_2)_3$, $As_2(NH)_3$ and AsN, repeated his work using phosphorus trichloride and tribromide and ammonia at -70°.(59) He isolated the amide according to the following equation:

$$15NH_3 + PBr_3 \longrightarrow 3(NH_4Br.3NH_3) + P(NH_2)_3.$$

Like the arsenic amide at 0° it decomposes into the imide $P_2(NH)_3$, but the nitride, P≡N, was not isolated in a pure state, probably due to its rapid decomposition into the elements. Leonard in his investigations of the reaction between piperidine and metal or metalloid halides obtained a compound which he believed to be $(C_5H_{10}N.HCl)_3P$ by the action of phosphorus trichloride on piperidine in dry heptane solution. The substance deteriorated too rapidly for accurate analysis.(4) Bourneuf in 1923 obtained $[(CH_3)_2N.C_6H_4]_2POH$ from phosphorus trichloride and dimethylaniline, but again the reaction was treated with aqueous sodium carbonate which undoubtedly influenced the resulting product.(60) Perperot in 1925 obtained a compound $PCl_5.10NH_3$ by mixing phosphorus pentachloride in carbon tetrachloride with a carbon tetrachloride solution of ammonia.(61)

Gibson and Johnson in 1928, investigating the properties of phenylmethylphosphinyl chloride, $(C_6H_5)(CH_3)POCl$, formed the anilide,  $(C_6H_5)(CH_3)P\begin{matrix}\rightarrow O\\ \searrow NHC_6H_5\end{matrix}$.(62) Hutton and Webb in 1931 by the action of phosphorus pentachloride on dry pyridine obtained an addition compound in which they believe phosphorus to have a coordination number of seven.(63) They write the formula of the compound  $C_5H_5N\begin{matrix}\nearrow Cl\\ \searrow PCl_5.H.C_5H_5N\end{matrix}$. It is difficult to understand how phosphorus could form a compound of the structure assigned to it by these investigators.

5) <u>The reaction between antimony halides and amines</u>

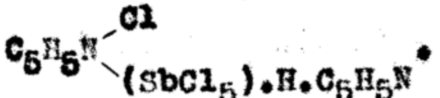
Compounds of antimony halides with amines have been more thoroughly investigated than those of phosphorus, especially by means of phase rule diagrams. In 1861 Deherain obtained $SbCl_3.NH_3$ and $SbCl_3.2NH_3$ with antimony trichloride and ammonia.(131 Both compounds reacted with HCl to form hydrochlorides. With antimony pentachloride and ammonia, $SbCl_5.3NH_3$ and $SbCl_5.4NH_3$ were obtained. Schiff investigated the reaction between antimony trichloride and triiodide and aniline simultaneously with his investigations with arsenious halides and aniline.(6 The structure of the resulting compound he wrote as $N_3\left\{\begin{matrix}Sb\\3C_6H_5.3HCl\\H_3\end{matrix}\right.$ which in modern terms would be the same as that proposed by Schmidt and Leonard for the arsenic compounds of aniline and piperidine; namely, $(C_6H_5NH.HCl)_3Sb$ in which the antimony is linked directly to the nitrogen. Leeds also obtained $SbCl_3.3C_6H_5NH_2$ and a compound of antimony pentachloride $SbCl_5.3C_6H_5NH_2$.(17 Schiff in 1901 obtained $SbCl_3.3C_6H_5NH_2$ and $SbI_3.3C_6H_5NH_2$.(64 Naumann in 1904 obtained with antimony trichloride and ammonia in acetone solution the compound $SbCl_3.3NH_3$.(65

Franklin, whose classical investigations on liquid ammonia as a solvent opened up a new field of chemical investigations, obtained many metal-amides by ammonolysis, a reaction comparable to hydrolysis, with ammonia instead of water. With antimony iodide and ammonia gas he obtained a white addition product, which in liquid ammonia was converted into a pure yellow, pulverent solid.(76 Analysis gave a compound of the formula Sb_5N_6I. Franklin states this may be a basic compound, $(NH_2)_2SbI.4SbN$, but more probably is a mixture of antimony nitride and unchanged antimony iodide. In 1910 Naumann, while investigating the reaction between ammonia and metallic halides in thoroughly dried non-hydrolytic solvents again obtained $SbCl_3.3NH_3$.(65 The reaction was conducted in ethyl acetate solution.

Menshutkin, a Russian physical chemist, made a series of studies of metal and metalloid halide reactions by means of phase rule diagrams. Four different compounds of antimony trichloride and aniline were indicated:(67

$SbCl_3.6C_6H_5NH_2$	m.p. 76.7°
$SbCl_3.4C_6H_5NH_2$	m.p. 80°
$SbCl_3.3C_6H_5NH_2$	m.p. 88°
$SbCl_3.2C_6H_5NH_2$	m.p. 95°.

Vanino and Mussgnug in 1917 obtained $SbCl_3.3CS(NH_2)_2$ from antimony trichloride and thiourea.(28 Leonard, whose work with piperidine and arsenic and phosphorus halides has already been referred to, also obtained a compound $(C_5H_{10}N.HCl)_3Sb$ by combining antimony trichloride and piperidine in dry heptane solution.(4 Kurnakow in 1924, studying the application of viscosity measurements to phase rule diagrams, obtained evidence of four compounds between antimony trichloride and aniline.(68 These were $SbCl_3.C_6H_5NH_2$, $SbCl_3.2C_6H_5NH_2$, $SbCl_3.3C_6H_5NH_2$, and $SbCl_3.4C_6H_5NH_2$. He did not obtain the compound $SbCl_3.6C_6H_5NH_2$ found by Menshutkin by phase rule diagrams. Vanstone also studied antimony trichloride compounds from the point of view of phase rule diagrams. Many of these compounds however were between amides and antimony halides, and due to the very slight basicity of the NH_2 group in amides it is probable that the linkage is Sb-O rather than Sb-N. He obtained compounds $C_6H_5CH_2NHC_6H_5 \cdot SbBr_3$ and $C_6H_5CH_2NHC_6H_5 \cdot SbCl_3$ with benzylaniline and antimony tribromide and trichloride. Both these compounds were unstable, but he noted that benzylaniline was more reactive than the amides investigated.(69 Harden and Dunning in 1927 obtained a crystalline compound $Sb(SCH_2 \cdot CONH_2)_3$ from antimony trichloride and thioglycolamide.(70 Again due to the decreased basicity of the NH_2 group it is unlikely that the linkage is Sb-N. Biltz and Rahlfs found five compounds of antimony trifluoride and ammonia by means of phase rule diagrams.(71 These were $SbF_3 \cdot NH_3$, $SbF_3 \cdot 2NH_3$, $SbF_3 \cdot 3NH_3$, $SbF_3 \cdot 4NH_3$, and $SbF_3 \cdot 6NH_3$. Hutton and Webb claimed to have obtained a seven covalent antimony compound similar to the compound they obtained with phosphorus pentachloride.(63 It was written



$$C_5H_5N\begin{matrix}\diagup Cl \\ \diagdown (SbCl_5) \cdot H \cdot C_5H_5N\end{matrix}$$

. Their evidence is rather inconclusive. They also obtained two other compounds from antimony pentachloride and pyridine, $SbCl_5 \cdot C_5H_5N$ and $2SbCl_5 \cdot 3C_5H_5N$.

Schwarz and Jeanmaire in 1932, working with antimony trichloride and liquid ammonia, isolated an imide and nitride of antimony, expressed by the following equations:(72

$$SbCl_3 + 3NH_3 \longrightarrow ClSb=NH + 2NH_4Cl$$

$$SbCl_3 + 4NH_3 \longrightarrow Sb\equiv N + 3NH_4Cl.$$

They did not isolate a monamide Cl_2SbNH_2.

6) <u>The reaction between bismuth halides and amines</u>

Compounds formed between bismuth halides and amines have also been investigated, but the structure of the resulting compounds does not seem to have been as well established as in the case of the corresponding arsenic and antimony compounds. Schiff, the first investigator to give a structure to the compounds formed between arsenic and antimony halides and aniline, likewise used bismuth trichloride. He obtained $(C_6H_5NH.HCl)_3Bi$, but this differed from the arsenic and antimony compounds in its reaction with water.(67

$$(C_6H_5NH.HCl)_3Bi \ + \ H_2O \longrightarrow 2C_6H_5NH_2HCl \ + \ C_6H_5NH.HCl.BiO$$

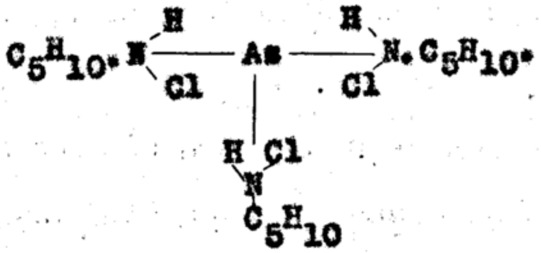
Montemartini in 1900, by adding varying amounts of pyridine to ether solutions of bismuth trichloride claimed to have obtained five different compounds.(73 These were $BiCl_3.C_5H_5N$, $BiCl_3.2C_5H_5N$, $BiCl_3.3C_5H_5N$, $BiCl_3.4C_5H_5N$, and $BiCl_3.5C_5H_5N$. However only chlorine analyses were made; the first compound $BiCl_3.C_5H_5N$ could not be obtained in a pure state, and the difference in chlorine analyses in the other four leads the author to state that they may all be the same compound. Vanino and Hauser, using anhydrous acetone as a solvent, obtained a number of compounds with bismuth halides and amines.(74 Thus they obtained $BiCl_3.C_9H_7N$ (quinoline), $BiI_3.C_9H_7N$, $(BiCl_3)_2.(C_5H_5N)_3$ (pyridine), $BiI_3.C_5H_5N$, $(BiCl_3)_3.(C_{10}H_7NH_2)_2$ (α-naphthylamine), and $BiI_3.(C_{10}H_7NH_2)_2$. Schiff in 1901 reports the compound $BiCl_3.3C_6H_5NH_2$ from aniline and bismuth trichloride by warming the two together. When hydrochloric acid is added $BiCl_3.C_6H_5NH_2HCl.3H_2O$ is formed and the water is lost at 100°.(64

Compounds of bismuth trichloride and thiourea have been made by several investigators. Hofmann and Gonder in 1904 obtained $BiCl_3.CS(NH_2)_2$ from the two compounds in either absolute alcohol or warm water.(75) Naumann obtained two compounds of bismuth trichloride and ammonia by regulating the amount of ammonia used.(65) These were $BiCl_3.2NH_3$ and $BiCl_3.3NH_3$. Franklin obtained the nitride, BiN, from bismuth bromide or iodide and potassium amide.(76) Naumann again in 1910 obtained $BiCl_3.2NH_3$ from bismuth trichloride and ammonia in anhydrous ethyl acetate solution.(66) Vanino and Mussgnug, working in aqueous solution acidified with hydrochloric acid, obtained two compounds of the formula $BiCl_3.3CS(NH_2)_2$ from bismuth trichloride and thiourea.(28) One was yellow in colour and melted at 180°, the other red-coloured and melted at 186°. They also obtained $BiBr_3.3CS(NH_2)_2$ and $BiI_3.3CS(NH_2)_2$. Vournazos in 1926 obtained complex double compounds from hydrasine salts and bismuth halides.(77) These were of the type

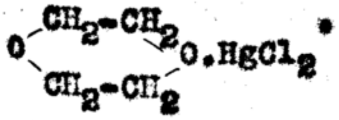
in which X and Y are different anions, and bismuth has a coordination number of four. The thioglycolamide compound of bismuth corresponding to the antimony compound was obtained by Harden and Dunning.(70) This had the structure $Bi(SCH_2.CONH_2)_3$. It was prepared by treating ethyl thioglycollate with bismuth oxide and saturating with ammonia. It was a crystalline material melting at 144.5°, and it is probable that the bismuth was linked to sulphur rather than to nitrogen.

7) The reaction between metallic halides and substances containing basic nitrogen, oxygen, sulphur, arsenic and phosphorus

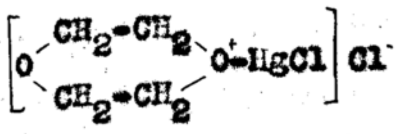
While there is still some uncertainty as to the structure of the compounds formed by the action of halides of phosphorus, arsenic, antimony, and bismuth on ammonia or amines, the majority of the evidence would seem to favour regarding these compounds as substituted ammonium halides. Thus Leonard believed his arsine-tri-1-piperidinium chloride to possess the structure



We might expect halides of phosphorus, arsenic, antimony, and bismuth to react, not only with basic nitrogen to form substituted oxonium, sulphonium, arsonium, and phosphonium halides respectively. There are numerous examples of the formation of so-called double salts between such halides as mercuric chloride and platinic chloride with such basic elements; but very few compounds of phosphorus, arsenic, antimony, or bismuth halides with these basic elements have been investigated.

Mercuric chloride reacts with alkyl sulphides such as ethyl sulphide to give crystalline compounds.[78] $(C_2H_5)_2S.HgCl_2$ is a white crystalline compound, m.p. 60-90°; $(C_2H_5)_2S.2HgCl_2$ is a crystalline compound, m.p. 120-122°. 1-4-dioxane reacts with mercuric chloride to give a white precipitate of the formula [79] Michaelis in 1902 showed that a large number of arsines reacted with mercuric chloride to form compounds of the type $R_3As.HgCl_2$.[80] Thus p-tolylarsine gave $(p-CH_3C_6H_4)_3.HgCl_2$, a crystalline compound, melting at 246 . If these are regarded as sulphonium, oxonium, and arsonium salts respectively, their structures may be represented as follows:

$[(C_2H_5)_2\overset{+}{S}{-}HgCl]Cl^-$

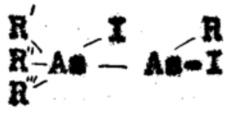


$[(CH_3C_6H_5)_3\overset{+}{As}{-}HgCl]Cl^-$.

Evidence for and against the "onium" structure of these compounds is presented in the theoretical portion of this thesis. It is not however surprising to find halides of the phosphorus-arsenic group reacting to give double compounds with oxygen, sulphur, and arsenic compounds.

8) <u>The reaction between arsines and halides of arsenic, phosphorus, antimony, and bismuth</u>

Burrows and Turner in 1920 in an article entitled "A new Type of Compound containing Arsenic" state that arsines of the type RRRAs, where the R's may be the same or different, combine with CH_3AsI_2, $C_2H_5AsI_2$ and $C_6H_5AsI_2$ to give compounds of the type $R_3As.RAsI_2$.(81) They are completely dissociated in benzene solution but on evaporation the complex is again obtained. The authors believe that these compounds possess the structure



and advance evidence in support of such a structure. They also found that phenyldichlorarsine, $C_6H_5AsCl_2$, gave an addition compound with phenyldimethylarsine, $C_6H_5(CH_3)_2As$. In 1921 they extended their work and found that tertiary arsines combine not only with arsenious iodide and alkyl diiodoarsines but also with iodides of phosphorus, antimony and bismuth.(82 The resulting compounds are highly coloured, high-melting solids, and easily hydrolysed in water. Arsine itself, AsH_3, does not react with arsenious iodide.

9) The reaction between oxygen compounds and halides of arsenic, phosphorus, antimony, and bismuth

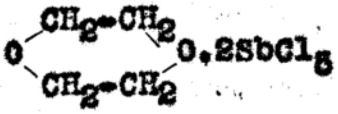
Compounds of phosphorus, arsenic, antimony, and bismuth halides with oxygen compounds are much commoner than those with arsines. Thus we find these halides reacting with ethers, esters, aldehydes, acid halides, etc. to form definite crystalline compounds. These have been investigated very thoroughly with antimony halides, hardly at all with arsenic halides. Puschin and Löwy showed that arsenious bromide did not combine with either resorcin or phenol.(34 In 1880 Liebermann and Landshoff showed that phosphorus pentachloride reacted with diethyl ether to give a crystalline product of the formula $2(C_2H_5)_2O.3PCl_5$.(83 They showed that this was not a simple molecular addition product. Guthmann in 1932 however obtained an oily product from the same reaction which he did not crystallize and stated that as it was probably a mixture, no analyses were made.(84 With water it yielded acetaldehyde and hydrochloric, phosphorous and phosphoric acids along with an unidentified phosphorus-containing residue.

In 1901 Rosenheim and Stellmann obtained crystalline compounds with antimony pentachloride and a large number of oxygen compounds.(85 These include the following: $SbCl_5.CH_3CHO$, $SbCl_5.(CH_3)_2CO$, $SbCl_5.C_6H_5COCl$, $SbCl_5.C_6H_5COOC_2H_5$,

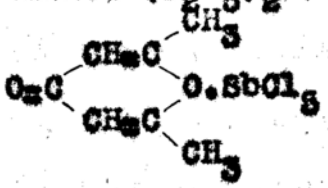
$2SbCl_5.(COOH)_2$, and $2SbCl_5.3CH_3CO.NH_2$. In 1912 Menshutkin studied phase rule diagrams of antimony trichloride and tribromide with phenol and aromatic ethers.(86 He obtained the following compounds:

$SbCl_3.C_6H_5OH$	m.p. 37°
$2SbBr_3.C_6H_5OH$	m.p. 66.5°
$SbCl_3.C_6H_5OCH_3$	m.p. 25.2°
$2SbCl_3.C_6H_5OCH_3$	m.p. 41.5°
$SbBr_3.C_6H_5OCH_3$	m.p. 30.5°
$SbCl_3.C_6H_5OC_2H_5$	m.p. 42.2°
$SbBr_3.C_6H_5OC_2H_5$	m.p. 48.8°.

With the ketone $CH_3COC_6H_5$, Menshutkin observed the formation of compounds $SbCl_3.CH_3COC_6H_5$, m.p. 60.5°, and $SbBr_3.CH_3COC_6H_5$, m.p. 37.5°.(87 With diphenylketone the compounds $SbCl_3.(C_6H_5)_2CO$, m.p. 76°, and $SbBr_3.(C_6H_5)_2CO$, m.p. 48.5°, were observed. Kurnakow in 1924 noted the formation of the compound $C_6H_5COCH_3.SbBr_3$ from phase rule diagrams.(68 Vanstone observed the formation of compounds of antimony halides and amides in which it is likely that the linkage is Sb-O rather than Sb-N due to the decreased basicity of the NH_2 group.(69 Thus he obtained $C_6H_5CO.NHC_6H_5.2SbCl_3$ and $C_6H_5CO.NHC_6H_5.SbCl_3$ from benzanilide and antimony trichloride, and two similar compounds using antimony tribromide. The antimony trichloride compounds were more stable than those obtained from antimony tribromide. Brus and Vebra in 1930 found that both borneol acetate and isoborneol acetate combined with compounds such as $SbCl_3$, $BiCl_3$, PCl_5, $SnCl_4$, and $ZnCl_2$ as well as ortho- and pyrophosphoric acids and arsenic acid to give crystalline compounds. They believe these to be oxonium salts. Thus they give the structure of the pyrophosphoric acid compound as $C_{17}H_{10}O-\underset{CH_3}{C}=O.H\,PO_4H$.(90) In 1932 Meerwein and Maier-Hüser, investigating the splitting of ethers with acid chlorides, believed that the catalysis of this reaction by means of metallic halides was due to intermediate compound formation between the ether and the metallic halide.(88) They isolated several crystalline compounds of antimony pentachloride and aliphatic ethers or acid chlorides. Thus they obtained $(C_2H_5)_2O.SbCl_5$,



(1,4-dioxane)

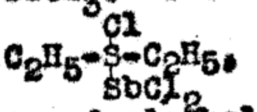


(dimethyl-pyrone) $CH_3CO.Cl.SbCl_5$, and $C_6H_5COCl.SbCl_5$.

Usanovich in 1932 found that $SbCl_3$, $SbBr_3$ and $AsBr_3$ showed no conductivity in anisole although he states that both $SbBr_3$ and $SbCl_3$ form complexes with the ether. Usanovich believes that the phenyl group prevents oxonium salt formation.(91) With diethyl ether and antimony trichloride he believes that an oxonium salt $(C_2H_5)_2O.2SbCl_3$ is formed. He bases his evidence on conductivity measurements.(92)

10) The reaction between sulphur compounds and antimony trichloride

Ray, Adhikari, and Roy in 1931 observed that antimony trichloride combines with aliphatic sulphides to form compounds which may possibly be sulphonium halides.(89) Thus they obtained the compounds $(CH_3)_2S.SbCl_3$, $(C_2H_5)_2S.SbCl_3$, and

$(n-C_3H_7)_2S.SbCl_3$. The authors believe these to have the structure  $C_2H_5-\overset{Cl}{\underset{SbCl_2}{S}}-C_2H_5$, that is, an antimony sulphonium chloride. Water and alcohol decomposed the compounds, molecular weights indicated the presence of two ions, and conductivity in acetone was high.

PART III

EXPERIMENTAL

1) Reagents

The arsenious chloride was Merck's arsenious chloride, purified by vacuum distillation. The majority of the amines were Eastman Kodak Company's and were not purified further. The ethylenediamine was Kahlbaum's reagent quality. The 1,4-dioxane was commercial dioxane obtained from the Carbon and Carbide Company, dried for one week over metallic sodium, and the fraction boiling 101-102° taken. The diethylsulphide was obtained from the Eastman Kodak Company. Both ethyldichlorarsine and ethyldiiodoarsine were prepared according to the method of McKenzie and Wood.(93 It was found that ethyldiiodoarsine could not be quantitatively converted into ethylarsineoxide by refluxing with anhydrous sodium carbonate and calcium chloride in benzene solution. Instead $Na_2CO_3 \cdot 10H_2O$ and a few ccs. of water were used and the calcium chloride omitted. In this way a quantitative yield of ethylarsineoxide was obtained which was then converted into ethyldichlorarsine by the action of HCl. The dimethylchlorarsine was prepared according to the method of Steinkopf and Mieg and distilled in an atmosphere of nitrogen gas.(94 The n-heptane was prepared from Diggers pine oil according to the method of Kremers.(95 The absolute ether was prepared by drying with calcium chloride, phosphorus pentoxide, and sodium-potassium alloy and finally distilled. The benzene was dried with metallic sodium and distilled.

2) Procedure

The general method for the study of the reaction between amines and arsenious halides was as follows: The amount of amine required by the equation

$$3RNH_2 + AsX_3 \longrightarrow As(RNH.HX)_3$$

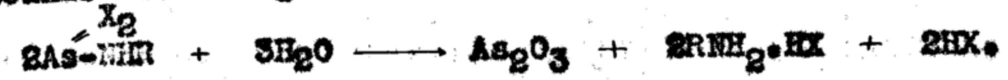
was weighed and added to the required amount of solvent, usually n-heptane. The arsenious halide was weighed and dissolved in the solvent. The amine solution was placed in a tall-form beaker and surrounded with an ice bath. The tall-form beaker was found most convenient for the reaction as the precipitate formed in the reaction could thus be easily removed quantitatively from the walls of the reaction vessel. The beaker was equipped with a cork through which passed a mechanical stirrer and dropping funnel. In some cases nitrogen gas was passed into the vessel during the course of the reaction but this was usually found to be unnecessary. The arsenic solution was then added dropwise to the amine solution, and the mixture was stirred during the addition and for one hour longer to ensure the completion of the reaction. The mixture was now filtered, using either a Büchner funnel or a sintered glass filter. In all cases nitrogen gas was used to protect the products from oxidation during the filtering process. The filter was further protected from moisture by placing P_2O_5 tubes in the suction and nitrogen lines. The precipitate was finally washed several times with the pure solvent used in the reaction, transferred to a vacuum desiccator, and the air removed by flushing several times with nitrogen gas. It was then dried for several days at

20 mms. pressure.

The dry precipitate consisted of the hydrohalide of the amine used and was always found to contain a considerable amount of arsenic. This arsenic undoubtedly is in the form of the arsentriamide trihydrohalide and arsendiamide dihydrohalide. The arsenic content of the precipitate was determined by arsenic analyses on the impure product, and the percentage conversion of the original arsenic halide to these arsenic compounds calculated. Thus for example, when 4.53 grams of arsenious halide and 6.97 grams of aniline were used, the dry precipitate weighed 6.12 grams. Arsenic analyses gave 10.27 p.c. arsenic, or 0.6285 grams of arsenic in the precipitate. Since we started with 4.53 grams of arsenious chloride or 1.873 grams of arsenic, 0.6285/1.873 x 100 = 33.56 p.c. of the arsenious halide is converted into the arsenamide hydrohalides.

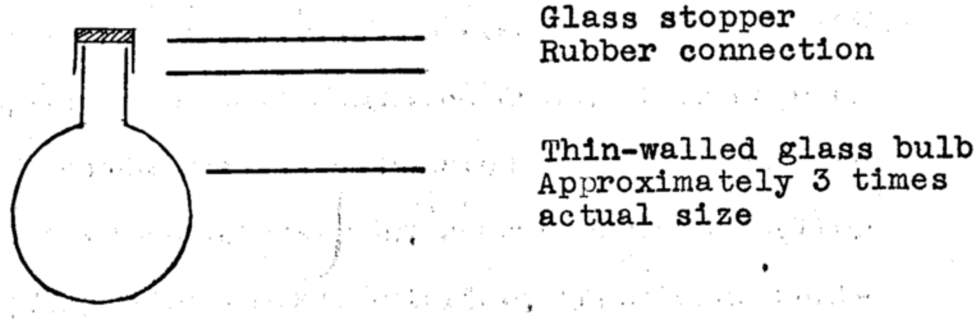
Attempts to separate the arsenic compounds from the amine hydrohalide were usually unsuccessful. The procedure was to attempt separation by vacuum sublimation. The apparatus used was similar to that described by Schmidt for the purification of aniline-arsentriamide trihydrochloride.(8 All sublimations were at 1-2 mms. pressure and the temperatures were carefully controlled by means of an oil bath. The sublimate was removed when a thin coating had formed and analyses made immediately. In a few cases separation was brought about by this method. When the arsentriamide trihydrohalide was not decomposed by absolute alcohol, it could be separated by fractional crystallisation. This method was successful with piperidine-arsentriamide trihydrohalide.

The filtrate from the original reaction contains the monosubstituted compounds of the type $X_2As-NHR$. As these are extremely susceptible to hydrolysis and oxidation, the filtrate must be handled with extreme care. Water decomposes these compounds according to the equation



$$2\overset{X_2}{As}-NHR + 3H_2O \longrightarrow As_2O_3 + 2RNH_2\cdot HX + 2HX.$$

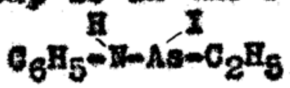
On coming in contact with a glass vessel a precipitate of arsenious oxide and the hydrohalide of the base is formed. It was found practically impossible to filter the original reaction mixture without some decomposition. The filtrate was placed in a distilling flask and the solvent removed by distillation in a stream of nitrogen at reduced pressure. The arsenic compound being high-boiling remained in the flask and was purified by distillation, usually at 1-2 mms. pressure. It was collected in special receivers which were filled with nitrogen gas. For the analysis of these extremely unstable liquids, special weighing bottles were used. These consisted of thin-walled glass bulbs, equipped with glass stoppers. Such a weighing bottle is illustrated in the diagram.



The liquids were quickly transferred to these bottles with a pipette, sealed, and weighed. These bottles could then be crushed under the liquid used for analysis. In this way decomposition of the highly unstable compounds was kept at a minimum. In spite of these precautions it was found to be extremely difficult to obtain accurate analyses of these unstable liquids, especially in the determination of the arsenic content.

The Morgan and Walton method was found to give accurate results for arsenic analysis.(96 Where the amount of material to be analysed was small, the micro method of Willard and Thompson was used.(97 The micro method of Das-Gupta was also tried but was found to give extremely unsatisfactory results.(98 Halogens were usually determined by the method of Stepanow.(99 In a few cases the method of Willard and Thompson was used.

3) Nomenclature of the Arsenic Compounds

The naming of these arsenic compounds presents considerable difficulty. For the tri-substituted piperidine compound, $As(NC_5H_{10}.HCl)_3$, Leonard suggested the name arsine-tri-1-piperidinium chloride.(4 This system of nomenclature becomes complicated with other amines. Thus the compound $As(N(C_2H_5)_2HCl)_3$, would be named arsine-tri-diethylammonium chloride. This does not reveal the true structure of the compound. Similarily this method does not work satisfactorily with the mono-substituted compounds. Anschütz and Weyer named the two aniline arsines, $Cl_2As.NHC_6H_5$ and $ClAs(NHC_6H_5)_2$, arsenanilidodichloride and arsendianilidomonochloride respectively.(19 Mann and Pope investigated compounds containing the linkage $R_3As=N-$ which they termed "arsylimines".(46 Mann in a later paper describes these compounds as "arsinimines".(100 The name "arsenamide" is suggested for the linkage =As-NH_2. The arsenamides are therefore to be regarded as substitution products of arsine in which one or more hydrogen atoms have been replaced by monovalent amino groups. In naming these compounds the following rules are followed: The amine used is first named, then other substitutents on the arsenic, and finally the term arsenamide itself. Where the amino group is in the form of a hydrohalide, it is so indicated. Thus  $C_6H_5\text{-}\overset{H}{N}\text{-}\overset{I}{As}\text{-}C_2H_5$ is termed aniline-ethyliodoarsenamide, and $(C_2H_5)_2N\text{-}AsCl_2$ is diethylamine-dichlorarsenamide. The tertiary substituted hydrohalides will be named as arsentriamides. Thus $As(NC_5H_{10}.HCl)_3$ is piperidine-arsentriamide trihydrochloride. The compound $ClAs(NH.CH_2.CH_2.NH_2.HCl)_2$, formed by the action of arsenious chloride on ethylenediamine, is ethylenediamine-chlorarsendiamide dihydrochloride.

4) Reactions studied

A. Arsenious chloride and aniline

6.97 grams of aniline (3/40 mole) in 75 ccs. of heptane and 4.53 grams of arsenious chloride (1/40 mole) dissolved in 75 ccs. of heptane were used. The aniline was previously purified by distillation. The reaction was conducted according to the method outlined in the general procedure. The weight of the yellow precipitate obtained when dry was 6.12 grams. Arsenic analyses showed 10.27 p.c. arsenic in the precipitate, or 33.56 p.c. of the arsenious chloride is converted into arsenamide hydrohalides. These could not be separated by vacuum sublimation, and both water and absolute alcohol decomposed the arsenic compounds present. With water a precipitate of arsenic oxide was formed.

Aniline-dichlorarsenamide $Cl_2As-NHC_6H_5$

The heptane filtrate was distilled. When only a few ccs. of heptane remained the distillation was stopped and the residual liquid cooled. A light yellow crystalline material separated which was filtered under nitrogen gas and dried over P_2O_5 in a vacuum for 24 hours. The product fumed in the air and was decomposed instantly with water, m.p. 89° (corrected). The melting point of $Cl_2As.NHC_6H_5$ obtained by Anschütz and Weyer was 87-88°.(19

Calculated for $Cl_2As.NHC_6H_5$: arsenic, 31.50 p.c.; chlorine 29.83 p.c. Found; arsenic, 31.68 p.c.; chlorine, 29.92 p.c.

Aniline-arsentriamide trihydrochloride $As(NHC_6H_5.HCl)_3$

The reaction was repeated except that the aniline was added to a heptane solution of arsenious chloride. The same quantities of the reagents were used as in the previous experiment. The yellow precipitate obtained when dry weighed 10.2 grams as compared to 6.12 grams for the first experiment. Arsenic analyses showed 15.55 p.c. arsenic in the precipitate, or 84.74 p.c. of the arsenious chloride is converted into arsenamide hydrohalides.

The precipitate was sublimed at 100° and >1 mm. pressure and gave a yellow sublimate. This did not melt completely but softened at 148-150°. It rapidly became white in the air, and unless analysed immediately the arsenic analyses were somewhat low. Schmidt gave the melting point of this compound as 148-150° and observed the same phenomenon with regard to the analyses.(8

Calculated for $As(NHC_6H_5 \cdot HCl)_3$: arsenic, 16.28 p.c.

Found: 16.36 p.c.

That the heptane filtrate also contained a second unstable arsenic compound was evident from the fact that a precipitate was formed when the filtrate came in contact with a glass vessel. The heptane was removed by distillation except for a few ccs. On cooling this residual liquid a light yellow crystalline product was obtained. This melted at 108° whereas the product $ClAs(NHC_6H_5)_2$ obtained by Anschütz and Weyer melted at 127-128°. As only a very small amount of this crystalline substance was obtained, no analyses were attempted. Anschütz and Weyer also note the very low yields of this product.

B. Arsenious chloride and piperidine

10.20 grams of piperidine (3/25 mole) were dissolved in 100 ccs. of heptane, and 7.24 grams of arsenious chloride (1/25 mole) dissolved in 100 ccs. of heptane were used. The general procedure was used. The precipitate when dry weighed 9.2 grams. Arsenic analyses showed 8.56 p.c. arsenic in the precipitate, or 20.95 p.c. of the arsenious chloride used was converted into arsenamide hydrohalides.

Piperidine-arsentriamide trihydrochloride $As(NC_5H_{10} \cdot HCl)_3$

The compound was purified by fractional crystallization from absolute alcohol. It crystallized in long needles, m.p. 240-242° (corrected).

Calculated for $As(NC_5H_{10}.HCl)_3$: chlorine, 24.39 p.c. Found: 23.44 p.c. The compound is identical with that obtained by Leonard.(4 It is decomposed to a slight extent by water and by boiling with absolute alcohol.

The solubility of piperidine-arsentriamide trihydrochloride.

As Leonard states that this compound is somewhat soluble in heptane which is incompatible with the formula assigned to it by the author, solubility determinations were made. 0.5 grams of the substance and 25 ccs. of heptane were placed in a test tube equipped with a mechanical stirrer and placed in a constant temperature bath at 25° ± 1° for four hours. After allowing the solid to settle, two five cc. portions were withdrawn and placed in tared weighing bottles, the heptane removed in a vacuum at 35°, and the bottles reweighed. The solubility of the compound in n-heptane was found to be 4×10^{-6} grams per cc.

Piperidine-dichlorarsenamide $Cl_2As-NC_5H_{10}$

The heptane was removed from the filtrate by distillation and a light yellow liquid, b.p. 98°/1 mm., obtained. As the liquid was extremely unstable no analyses were made.

Piperidine-arsentriamide trinitrate $As(NC_5H_{10}.HNO_3)_3$

A sample of piperidine-arsentriamide trihydrochloride was carefully weighed and dissolved in 5 ccs. of distilled water. The theoretical amount of silver nitrate solution necessary to precipitate all the chlorine was added, and the mixture allowed to stand 12 hours to coagulate the silver chloride. This was filtered, dried, and weighed.

Weight of sample taken	0.1850 gms.
Weight of silver chloride	0.1818 gms.
Calculated weight of silver chloride for $As(NC_5H_{10}.HCl)_3$	0.1822 gms.

The aqueous filtrate was evaporated in a vacuum until crystals separated. These were filtered off, washed and dried at 40°/20 mms., m.p. 144° (corrected). They were very soluble in water.

Calculated for $As(NC_5H_{10}.HNO_3)_3$; arsenic, 14.52 p.c.
Found: 14.89 p.c.

Piperidine-arsentriamide triacetate $As(NC_5H_{10}.CH_3CO_2H)_3$

A sample of piperidine-arsentriamide trihydrochloride was weighed out and dissolved in distilled water. The theoretical amount of lead acetate solution just necessary to precipitate all the chlorine was added, the lead chloride filtered off, and the filtrate evaporated. White crystals of piperidine-arsentriamide triacetate were obtained, m.p. 304° (corrected).

C. Arsenious chloride and diethylamine

10.96 grams (3/20 mole) of diethylamine dissolved in 100 ccs. of heptane and 9.066 grams of arsenious chloride (1/20 mole) dissolved in 100 ccs. of heptane were used. The reaction was run as described in the general procedure. The precipitate formed in the reaction when dry weighed 10.4 grams. Arsenic analyses showed 8.78 p.c. arsenic in the precipitate, or 24.3 p.c. of the arsenious chloride was converted into arsenamide hydrohalides. The arsenic compounds present could not be crystallized from absolute alcohol. It was sublimed at 130-140°

at 1 mm. pressure, but chlorine analyses were several percent high showing that it was still contaminated with diethylamine hydrochloride.

Diethylamine-dichlorarsenamide $Cl_2As-N(C_2H_5)_2$

The heptane was removed from the filtrate by distillation, a yellow liquid remaining behind. This was distilled and yielded a liquid boiling at 107°/ 38 mms. It was extremely unstable in the air.

Calculated for $Cl_2As-N(C_2H_5)_2$: chlorine, 32.58 p.c.
Found: 32.35 p.c., 32.16 p.c.

D. Arsenious chloride and ethylenediamine

9.015 grams of ethylenediamine (3/20 mole) dissolved in 100 ccs. of heptane and 18.13 grams of arsenious chloride (1/10 mole) dissolved in 100 ccs. of heptane were used. The reaction was run as described in the general procedure. The precipitate when dry weighed 17.5 grams. It could not be purified by vacuum sublimation and was decomposed by water and alcohol. 4 grams of the crude precipitate were placed in a flask and 100 ccs. of anhydrous acetone added and the mixture refluxed for six hours. The residue was filtered, again refluxed with dry acetone, refiltered, and this process repeated a third time. The first filtrate was yellow in colour but the third time was colourless.

Ethylenediamine-chlorarsendiamide dihydrochloride

$Cl-As(NH.CH_2.CH_2.NH_2.HCl)_2$

The white residue which remained after extraction with dry acetone was washed several times with acetone and dried at 20 mms. and 45° for 12 hours. A yield of 2 grams was obtained. The compound was decomposed by water giving arsenious oxide and ethylenediamine hydrochloride. It did not melt but charred slowly above 225°.

Calculated for $ClAs(NH.CH_2.CH_2.NH_2.HCl)_2$: arsenic, 24.86 p.c., chlorine, 34.99 p.c. Found: arsenic, 24.20 p.c.; chlorine 34.09 p.c.

The filtrates from the acetone extraction were combined and the acetone removed in a vacuum. A few crystals mixed with a large amount of a red resinous material were obtained. No test for arsenic could be obtained with this mixture and it is possibly a polymer of ethylenediamine. The original heptane filtrate was not examined. Further work on the reaction between arsenious chloride and ethylenediamine is needed to determine the course of the reaction and the other products formed.

E. Arsenious chloride and methylaniline

16.06 grams of methylaniline (3/20 mole) dissolved in 75 ccs. of heptane and 9.06 grams of arsenious chloride (1/20 mole) dissolved in 75 ccs. of heptane were used. The methylaniline was previously purified by distillation. The weight of the precipitate obtained when dry was 9.84 grams. Arsenic analyses showed 5.92 p.c. arsenic in the precipitate, or 14.32 p.c. of the arsenious chloride was converted into arsenamide hydrohalides. The arsenic compounds could not be separated from the methylaniline hydrochloride by vacuum sublimation and were decomposed by water and absolute alcohol.

<u>Methylaniline-dichlorarsenamide</u> $Cl_2As-N(CH_3)C_6H_5$

The heptane filtrate was distilled in a current of nitrogen gas at 10 mms. pressure to remove the heptane and the methylaniline dichlorarsenamide which remained in the flask purified by distillation. It boiled at 116.5°/3 mms. pressure, was extremely unstable in the air, and was decomposed violently with water.

Calculated for $Cl_2As-N(CH_3)C_6H_5$: chlorine, 28.18 p.c. Found: 28.29 p.c.

F. Arsenious chloride and dimethylaniline

18.16 grams of dimethylaniline (3/20 mole) dissolved in 100 ccs. of heptane and 9.06 grams of arsenious chloride dissolved in 75 ccs. of heptane were used. The reaction was run as described in the general procedure. The dimethylaniline was previously purified by distillation. There was a change in colour on the addition of the arsenious chloride solution; the mixture became a yellowish-green but no precipitate formed. On filtering the mixture a very small quantity of gummy material was found in the bottom of the reaction vessel. The heptane was removed at 10 mms. pressure. The remaining liquid in the flask was fractionated at 3 mms. but gave only arsenious chloride and dimethylaniline.

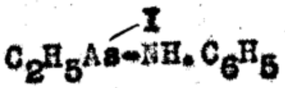
G. Arsenious iodide and aniline

As arsenious iodide is insoluble in heptane, dry benzene was used as a solvent. 5.58 grams of aniline (3/50 mole) dissolved in 50 ccs. of dry benzene and 9.172 grams of arsenious iodide (1/50 mole) dissolved in 600 ccs. of dry benzene were used. This amount of benzene was found necessary to dissolve the arsenious iodide. The reaction was run as described in the general procedure. The precipitate did not melt but decomposed above 175°, giving off brown fumes. Arsenic analyses gave 8.038 p.c. arsenic in the precipitate, or 32.18 p.c. of the arsenic is converted into arsenamide hydrohalides. Attempts to obtain these arsenic compounds by vacuum sublimation were not successful. Both water and absolute alcohol decomposed the arsenic compounds present. However the precipitate appeared to be slightly soluble in benzene and dioxan, and attempts were made to obtain the compounds by fractional crystallization from these solvents. Only amorphous resin-like solids were obtained. The benzene filtrate on evaporation yielded a brown residue which could not be crystallized. Some arsenious oxide and aniline hydroiodide were also obtained.

H. Ethyldiiodoarsine and aniline

9.30 grams of aniline (1/10 mole) in 75 ccs. of heptane and 17.79 grams of ethyldiiodoarsine (1/20 mole) dissolved in 200 ccs. of heptane were used. The reaction was run as described in the general procedure. The precipitate when dry weighed 9.87 grams. Arsenic analyses gave 5.018 p.c. arsenic, or 12.92 p.c. of the arsenic was converted into arsenamide hydrohalides. Crystallization from absolute alcohol gave only aniline hydroiodide.

Aniline-ethyliodoarsenamide



$C_2H_5As(I)-NH.C_6H_5$

On removal of the heptane from the filtrate a light yellow oil was obtained, boiling at 110°/10 mms. pressure. It tended to crystallize in the side arm of the distilling flask on distillation. It fumed in the air and reacted violently with water.

Calculated for $C_2H_5(I)As{=}NH.C_6H_5$: arsenic, 23.93 p.c.; iodine, 39.30 p.c. Found: arsenic, 23.84 p.c., 23.69 p.c.; iodine, 39.62 p.c.

I. Ethyldichlorarsine and piperidine.

4.0 grams of piperidine (1/20 mole) dissolved in 50 ccs. of dry ether and 4.37 grams of ethyldichlorarsine (1/40 mole) dissolved in 50 ccs. of dry ether were used. The reaction was run as described in the general procedure. The precipitate when dry weighed 4.8 grams. Arsenic analyses gave 7.44 p.c. arsenic, or 19.06 p.c. of the arsenic was converted into arsenamide hydrohalides.

Piperidine-ethylarsendiamide dihydrochloride

$C_2H_5As(NC_5H_{10}.HCl)_2$

The compound could not be satisfactorily separated from the large amount of piperidine hydrochloride by fractional crystallization from absolute alcohol. By vacuum sublimation at 95-105° and 1 mm. pressure a white solid, m.p. 196° (corrected), was obtained. This was soluble in water, ethyl alcohol and chloroform, insoluble in acetone, benzene and ether.

Calculated for $C_2H_5As(NC_5H_{10}.HCl)_2$: arsenic, 21.7 p.c.; chlorine, 21.0 p.c. Found: arsenic, 21.22 p.c.; chlorine, 20.5 p.c.

Piperidine-ethylchloroarsenamide $C_2H_5\overset{Cl}{As}{-}NC_5H_{10}$

The ether filtrate proved unsatisfactory for the separation of this compound. Evaporation of the filtrate yielded only high-melting solids which did not crystallize from the solvent but appeared as precipitates on the side of the vessel. Accordingly the reaction was repeated using heptane as a solvent. The heptane filtrate after removal of the heptane gave a light yellow liquid, b.p. 108°/8 mms. pressure. It decomposed rapidly in the air and could not be crystallized at 0°. It reacted violently with water to give piperidine hydrochloride and ethylarsineoxide.

Calculated for $C_2H_5(Cl)As{-}NC_5H_{10}$: arsenic, 33.52 p.c.; chlorine, 15.87 p.c. Found: arsenic, 33.30 p.c.; chlorine, 15.88 p.c.

<u>A comparison of the reaction in heptane and ethyl ether solutions.</u>

The white precipitate from the reaction in heptane solution when dry weighed 3.62 grams. Arsenic analyses gave 9.59 p.c. arsenic, or 18.52 p.c. of the arsenious chloride was converted into arsenamide hydrohalides. Since 19.06 p.c. arsenic was the value found when ethyl ether was used as a solvent, it appears that the solvent, as far as ethyl ether and heptane are concerned, does not materially influence the course of the reaction.

J. Dimethylchlorarsine and piperidine

8.50 grams of piperidine (1/10 mole) dissolved in 75 ccs. of heptane and 7.02 grams of dimethylchlorarsine (1/20 mole) dissolved in 75 ccs. of heptane were used. The reaction was run as described in the general procedure. Although there is only one replaceable chlorine atom in the arsenic compound, twice the molar equivalent of piperidine was used in anticipation that the following reaction would go to completion in the excess of the base:

$$(CH_3)_2AsCl \ + \ 2NH.C_5H_{10} \longrightarrow (CH_3)_2As-NC_5H_{10} \ + \ C_5H_{10}NH.HCl.$$

The white solid obtained from the reaction when dry weighed 5.0 grams. Only a slight trace of arsenic in this precipitate could be detected. It melted at 236-237° and appeared to consist of almost pure piperidine hydrochloride.

<u>Piperidine-dimethylarsenamide</u> $(CH_3)_2As-NC_5H_{10}$

When the heptane was distilled from the filtrate a colourless liquid remained which was purified by distillation, boiling point 75°/8 mms. It did not fume in the air and appeared to be more stable than the chlorarsenamides of the type

$Cl_2As-NHR$ and $R'\overset{Cl}{As}-NHR$.

Calculated for $(CH_3)_2AsN.C_5H_{10}$: arsenic, 39.64 p.c.

Found: 39.44 p.c., 39.50 p.c.

Kjeldahl nitrogens gave consistently low results which is characteristic of Kjeldahl determinations with piperidine compounds.

K. Arsenious chloride and 1,4-dioxane

26.4 grams of 1,4-dioxane (3/10 mole) were placed in a flask equipped with a mechanical stirrer and surrounded with ice. The mixture became warm and a precipitate formed when about one-third of the arsenious chloride was added. After the addition of all the arsenious chloride, the mixture was warmed, and the precipitate dissolved but crystallized out on cooling. These crystals were filtered off and a second crop obtained by evaporating the dioxane. They were dried over P_2O_5 in a vacuum for 24 hours. The total yield of crystalline material was 6 grams. The crystals were colourless, appeared to be deliquescent in the air, and possessed a strong odour of arsenious chloride. They were soluble in ethyl alcohol, ether, acetone, and benzene, insoluble in cold heptane, soluble in warm. With water a precipitate of arsenious oxide was formed, melting point, 62° (corrected).

Arsenic found: 23.84 p.c., 23.69 p.c.

Chlorine found: 33.66 p.c., 33.86 p.c.

This would correspond to an empirical formula of $2AsCl_3 3C_4H_8O_2$, the values for which are arsenic 23.93 p.c., chlorine 33.67 p.c. However as the substance appears to be deliquescent, it might possibly exist as a hydrate $AsCl_3 . C_4H_8O_2 . 2H_2O$, for which the arsenic and chlorine values would be 24.55 p.c. and 34.55 p.c. respectively. Accordingly the reaction was run a second time and the crystals thoroughly dried in a desiccator over P_2O_5. For analysis the sample was transferred directly from the desiccator to a tared weighing bottle containing absolute alcohol. In this way absorption of moisture was avoided during the weighing process.

Chlorine found: 33.57 p.c.

It is thus apparent that the compound is not a hydrate but corresponds to the formula $2AsCl_3 . 3C_4H_8O_2$. Dissolved in absolute alcohol the substance gave a precipitate of silver chloride with alcoholic silver nitrate. Pure arsenious chloride does not give such a precipitate with alcoholic silver nitrate.

An oxonium structure is thus suggested.

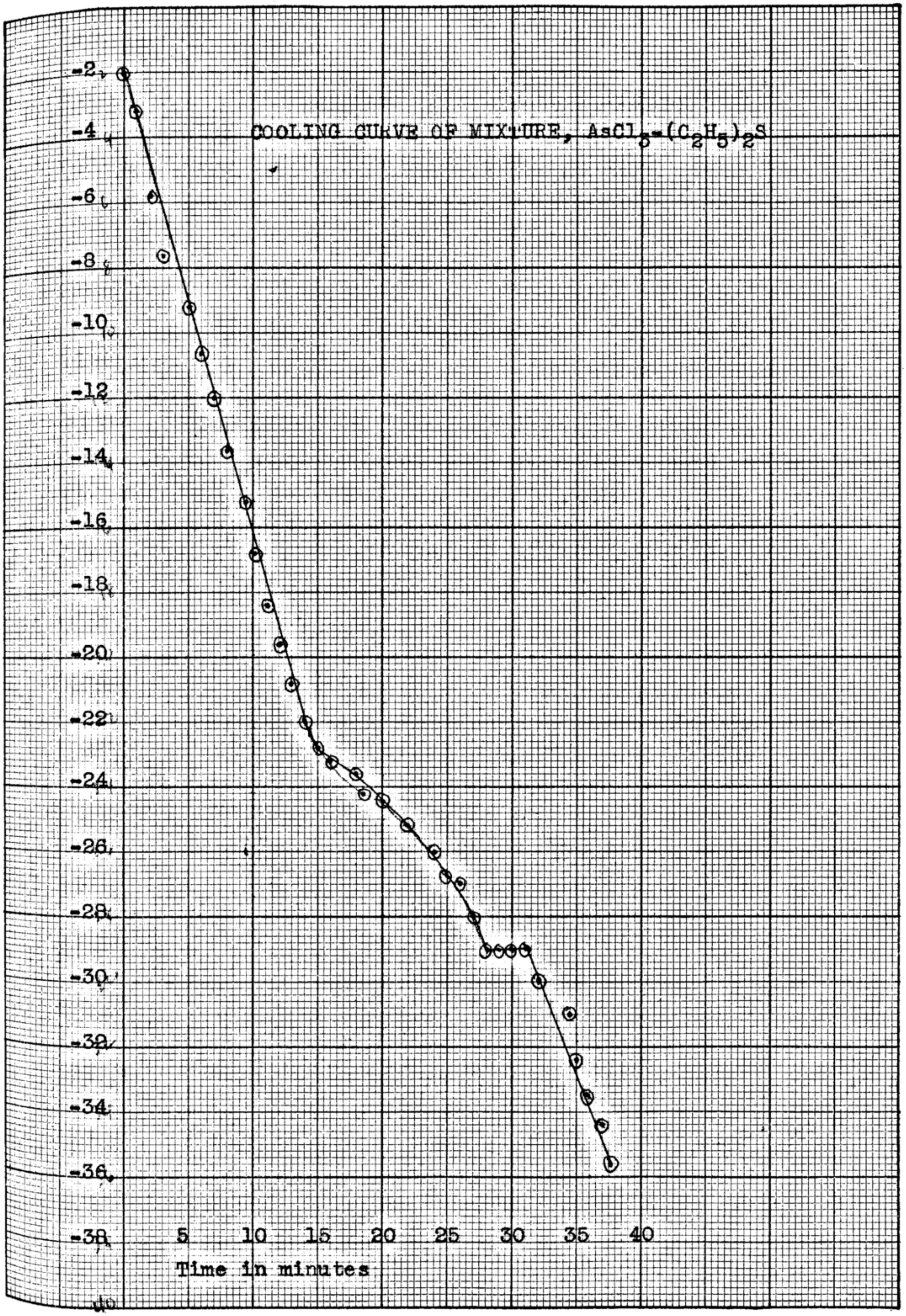
The molecular weight in benzene determined by the freezing point method was 157.0. The theoretical for $2AsCl_3.3C_4H_8O_2$ is 626.6. This suggests that it is highly dissociated in benzene solution. The molecular weight in acetone solution determined by elevation of the boiling point using the McCoy apparatus was 148.4.(102 As the dielectric constant of acetone is 21.4 and that of benzene 2.82, it is to be expected that the substance will be more highly dissociated in acetone than in benzene.(103

L. Arsenious chloride and diethylsulphide

9.0 grams of diethylsulphide (1/10 mole) were placed in a flask and 18.1 grams of arsenious chloride (1/10 mole) added dropwise. The mixture became warm but no precipitate formed. When all the arsenious chloride was added, the mixture was cooled to -15° but no solid phase separated. The addition of heptane to a portion of the mixture did not produce a precipitate. The mixture was distilled at atmospheric pressure. Arsenious chloride boils at 122°, diethylsulphide at 91.6°. The mixture commenced to distill at 109° and the temperature rose to 128° and remained constant at 128-130°. 15 grams were obtained at this temperature.

Chlorine analyses on this fraction gave 50.25 and 50.38 p.c. chlorine. This does not correspond to any simple compound between arsenious chloride and diethylsulphide. For $3AsCl_3.S(C_2H_5)_2$ the theoretical value for chlorine is 49.8 p.c., but such a combination seems unlikely. This fraction dissolved in absolute alcohol however gave a precipitate of silver chloride with alcoholic silver nitrate.

A cooling curve of the constant boiling fraction was obtained using solid carbon dioxide. The results are shown graphically in the accompanying diagram. It appears that a crystal phase separates at -22° and another at -29°. Arsenious chloride melts at -18°. It can only be concluded that arsenious chloride and diethylsulphide do not combine to give a crystalline compound at room temperature.



COOLING CURVE OF MIXTURE, $AsCl_3-(C_2H_5)_2S$

PART IV

THEORETICAL

Arsenious chloride, $AsCl_3$, can be regarded as the acid chloride of orthoarsenious acid in which all three hydroxyl groups have been replaced by chlorine atoms. In many of its reactions arsenious chloride acts in agreement with such a conception. Thus with sodium phenylate it gives, according to(115 Auger, the phenyl ester of orthoarsenious acid.

$$AsCl_3 + 3NaOC_6H_5 \longrightarrow As(OC_6H_5)_3 + 3NaCl$$

Just as the acid chlorides will react with ammonia or amines to form amides, so we might expect arsenious chloride to react with ammonia or amines to give the corresponding amides of orthoarsenious acid, the arsenamides. The comparison is seen in the reaction between acetyl chloride and arsenious chloride with aniline.

$$CH_3COCl + 2C_6H_5NH_2 \longrightarrow CH_3CO.NHC_6H_5 + C_6H_5NH_2.HCl$$

$$AsCl_3 + 2C_6H_5NH_2 \longrightarrow Cl_2As.NHC_6H_5 + C_6H_5NH_2.HCl.$$

The two reactions are not entirely parallel however. Since the amide group in the acid amides is very weakly basic, it will not form a hydrochloride. The reaction probably proceeds through the splitting off of HCl between the hydrogen of the amino group and the chlorine atom of the acid chloride, and this HCl reacts with the excess of amine to form the amine hydrochloride. Naturally the reaction will not take place with tertiary amines. In the case of arsenious chloride, since the arsenic atom is less acidic than the acetyl group, the resulting arsenamide can form a hydrochloride. Since the reaction also takes place with tertiary amines with the formation of compounds of the type $As(NH_3X)_3$ as well as with primary and secondary amines, the hydrochloride must be formed first, and this subsequently reacts with an excess of the amine to form the free arsenamide and the hydrochloride of the base. These reactions may be expressed thusly:

$$AsX_3 + RNH_2 \longrightarrow X_2As-NHR.HX$$

$$X_2As-NHR.HX + RNH_2 \longrightarrow X_2AsNHR + RNH_2.HX.$$

A better parallel than the reaction between an acid chloride and an amine might be the reaction between an alkyl halide and an amine.

$$R'NH_2 + RX \longrightarrow [RR'\overset{+}{N}H_2]X^-$$

$$R'NH_2 + AsX_3 \longrightarrow [X_2\overset{-}{As}-\overset{+}{N}H_2R]\, X^-$$

The analogy is even more striking when the properties of an arsenious halide, such as arsenious chloride, and an alkyl halide are compared. Arsenious chloride is a liquid in which the chlorine atoms are all attached by covalent or non-ionised bonds. Dissolved in absolute alcohol it does not give a precipitate of silver chloride with alcoholic silver nitrate. Walden however states that in sulphur dioxide solution it tends to ionise thus:

$$AsX_3 \longrightarrow [AsX_2]^+X^- \longrightarrow [AsX]^{++}X_2^{=} \longrightarrow [As]^{+++}X_3^{\equiv}$$

The dipole moment of arsenious chloride is 1.97 (105 as compared to 2.0 for alkyl halides. (106 Thus in its polar properties it is somewhat comparable to an alkyl halide, and there is no more necessity for assuming the ionisation of arsenious chloride in heptane solution in the reaction with an amine to form an arsenamide hydrohalide, than for assuming the ionization of an alkyl halide in its reaction with an amine to form an ammonium halide. The reaction takes place much faster in the case of an arsenious halide because the halogen atoms are less firmly bound to the arsenic, but the nature of the reaction is the same in both cases.

Since the reaction between aniline and arsenious chloride has been more extensively investigated by other workers, this amine was chosen for further investigation. The reaction was studied under two different conditions:

1. Where the arsenious chloride in heptane solution was added to aniline. In this case a heavy yellow precipitate formed which consisted of aniline hydrochloride admixed with a considerable proportion of arsenic. The heptane filtrate yielded the dichlorarsenamide $Cl_2As-NHC_6H_5$.
2. Where the aniline was added to a heptane solution of arsenious chloride. In this case the yellow precipitate was nearly pure arsentriamide trihydrochloride, $As(NHC_6H_5.HCl)_3$. The heptane filtrate yielded a minute amount of an unstable arsenic compound which was not characterized but possibly was $ClAs(NHC_6H_5)_2$.

For comparison the percentages of arsenic chloride found in the precipitates under both conditions are given in the following table:

Table I

	Wt. of ppt.	p.c. arsenic in ppt.	p.c. total arsenic used in ppt.
Arsenious chloride added to aniline	6.12 grams	10.27	33.56
Aniline added to arsenious chloride	10.2 grams	15.55	84.74

The percentage of arsenic in the precipitate from the addition of aniline to arsenious chloride is only about 1 p.c. lower than that of the pure arsentriamide trihydrochloride which shows the small amount of impurity that must be present.

When the arsenious chloride is added to the aniline, the base can react with the arsenamide hydrochloride formed, and hence the reaction mixture yields a considerable amount of aniline-dichlorarsenamide, $Cl_2As{-}NHC_6H_5$. When however the amine is added to the arsenious chloride, at no time is there any excess of amine so that this reaction is prevented. In this case the main product of the reaction is the arsentriamide trihydrochloride.

Where the amine was in excess there was found to be a considerable proportion of arsenic in the precipitate. It is assumed that this arsenic occurs as the hydrochloride of the arsendiamide and arsentriamide and is not merely occluded arsenious chloride or free arsenamide. This was also the case in nearly every reaction between an arsenious halide and an amine in which the former was added to the latter. That this assumption is justified seems apparent from the following facts: The free arsenamides are very soluble in organic solvents, and the precipitate was always thoroughly washed with the solvent used in the reaction. Duplicate reactions gave within the limit of experimental error the same amount of arsenic in the precipitate. Finally in several cases it has been possible to separate the arsentriamide trihydrohalide from the amine hydrohalide. Thus $As(NC_5H_{10}.HCl)_3$ was separated from piperidine hydrochloride by means of fractional crystallization from ethyl alcohol in the interaction of arsenious chloride and piperidine. Similarily $C_2H_5As(NC_5H_{10}.HCl)_2$ was separated from piperidine hydrochloride by means of vacuum sublimation in the precipitate formed by the interaction of ethyldichlorarsine and piperidine. In the majority of cases however the arsentriamide trihydrohalide was decomposed by alcohol and water and was insoluble in organic solvents, and thus fractional crystallization could not be used. Nor did vacuum sublimation effect separation. In the case of piperidine-ethylarsendiamide dihydrochloride, the ethyl group apparently affected the ease of sublimation of the compound.

In addition to isolating the arsentriamide trihydrohalide, in several cases it has been possible to isolate the arsendiamide dihydrohalide. Thus in the reaction between ethylenediamine and arsenious chloride, $ClAs(NH.CH_2.CH_2.NH_2.HCl)_2$ was isolated. In a previous report the author has shown that both $ClAs(NH.CH_2C_6H_5.HCl)_2$ and $As(NH.CH_2C_6H_5.HCl)_3$ can be isolated in the reaction between arsenious chloride and benzylamine.(40 Anschütz and Weyer also report $ClAs(NHC_6H_5)_2$.

Thus the following types of compounds may be said to be the products of the reaction between an arsenious halide and an amine: X_2AsNHR, isolated in nearly every reaction where the halide was added to the amine; $XAs(NHR.HX)_2$, isolated only in a few cases although possibly occurring as a portion of the arsenic found in the precipitate when the halide was added to the amine; $XAs(NHR)_2$, not definitely proved to occur by the author but found by Anschütz and Weyer when arsenious chloride was added to a large excess of aniline; and $As(NHR.HX)_3$, isolated when the amine was added to the halide. These results together with the fact that the reaction takes place with a tertiary amine as readily as with a primary or secondary amine lead to the conclusion that the reaction between an arsenious trihalide and a primary or secondary amine proceeds according to the following equations:

1) $AsX_3 + RNH_2 \longrightarrow X_2As.NHR.HX$

2) $X_2As.NHR.HX + RNH_2 \longrightarrow X_2As.NHR + RNH_2.HX$

3) $AsX_3 + 2RNH_2 \longrightarrow XAs(NHR.HX)_2$

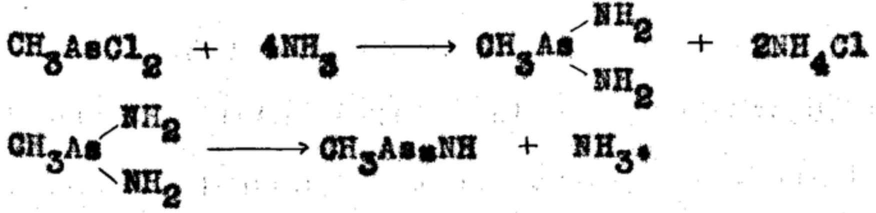
4) $XAs(NHR.HX)_2 + 2RNH_2 \longrightarrow XAs(NHR)_2 + 2RNH_2.HX$

5) $AsX_3 + 3RNH_2 \longrightarrow As(NHR.HX)_3$.

Clearly these results explain why previous investigators found different products. Thus Schiff(16, Leeds(17 and Schmidt all obtained the compound $As(NH.C_6H_5.HCl)_3$. As this is the main product of the reaction when aniline is added to arsenious chloride, the small amount of unstable material which is probably also a product of the reaction was overlooked. Had Schmidt distilled his heptane filtrate he would have discovered this second product. Anschütz and Weyer on the other hand worked with the filtrate rather than with the precipitate, and as the free arsenamides are soluble in anhydrous ether, the solvent used by these investigators, they were able to isolate the arsenamides $X_2As.NHC_6H_5$ and $XAs(NHC_6H_5)_2$. Their precipitate contained aniline hydrochloride when the aniline was added to the arsenious chloride, and they failed to isolate the compound found by Schiff, Leeds, and Schmidt, but believed the first two workers had been dealing with impure mixtures of aniline hydrochloride and occluded arsenic. These results also clearly indicate why the earlier workers in the field believed that more complex substances were formed. Thus such compounds as $2AsBr_3.7NH_3$, obtained by Landau,[7] and $2AsI_3.9NH_3$, obtained by Bamberger and Philipp,[18] would seem to be mixtures of ammonium halide and the arsenamide hydrohalides, which mixtures can only be separated in a few special cases.

Leonard, working with piperidine and adding the base to the arsenious chloride, obtained the arsentriamide trihydrohalide $As(NC_5H_{10}.HCl)_3$. As this substance is not decomposed by absolute alcohol and only slightly by water, it can be separated from the piperidine hydrochloride by fractional crystallization. Leonard however did not discover that piperidine hydrochloride was formed in the course of the reaction. The analyses for arsenic are several percent low, a fact which Leonard attributes to the method used for analysis (Ewins' method).[107] The piperidine was determined by hydrolysis with alkali and distillation of the free base into standard acid. But also the piperidine analyses were several percent high. It seems therefore probable that Leonard never obtained the product entirely free from piperidine hydrochloride. Nor did he isolate the free arsenamide also formed in the reaction. The calculated weight of the precipitate was only approximately sixty-six percent of the theoretical. Leonard accounted for this by the supposed solubility of piperidine-arsentriamide trihydrochloride in heptane, the solvent used for the reaction. The hydrochloride formula assigned to the compound by Leonard is incompatible with this solubility, and in the experimental part it has been shown that the actual solubility of the compound in heptane is 4×10^{-6} grams per cc. Leonard states that the excess of compound soluble in heptane can be precipitated with ether. It is apparent that unless anhydrous ether is used, the arsenamide, $Cl_2As{-}NC_5H_{10}$, present in the filtrate will be decomposed by the water present in ordinary ether into arsenious oxide and piperidine hydrochloride. This accounts for the precipitate obtained by Leonard on adding ether to his heptane filtrate.

It is also interesting to note that when ammonia is used an imide is formed instead of the arsenamide. Thus Michaelis obtained $C_6H_5As{=}NH$ from phenyldichlorarsine and ammonia;(41 and Ipatiew, Rasuwajew, and Stromski obtained $CH_3As{=}NH$ from methyldichlorarsine and ammonia.(42 It seems probable that the reaction proceeds in a similar manner, but the resulting amide can lose ammonia easily to give the imide thus:



$$CH_3AsCl_2 + 4NH_3 \longrightarrow CH_3As\begin{matrix}NH_2\\NH_2\end{matrix} + 2NH_4Cl$$

$$CH_3As\begin{matrix}NH_2\\NH_2\end{matrix} \longrightarrow CH_3As{=}NH + NH_3.$$

In both cases a precipitate of ammonium chloride was formed in the course of the reaction.

The amount of arsenic found in the precipitate varies with the amine and with the arsenious halide used. A comparison of the amounts of arsenic found in each case might possibly give information concerning the factors influencing the course of the reaction. As all reactions were run under identical conditions except in a few cases, it is immaterial whether the arsenic in the precipitate is in the form of the arsendiamide dihydrohalide, arsentriamide trihydrohalide, or what is most probable a mixture of both. The following table gives the percentage of the arsenic used that is found in the precipitate, which should be a measure of the amount of arsendiamide dihydrohalide and arsentriamide trihydrohalide formed in the course of the reaction. The strength of the bases used is also given.

Table II

Base used	Arsenious Halide used	p.c. total As started with found in ppt.	Strength of base pK_H
$C_6H_5NH_2$	$AsCl_3$	33.56	4.64
$C_6H_5NH_2$	AsI_3 (solvent benzene)	32.18	4.64
$C_6H_5NH_2$	$C_2H_5AsI_2$	12.92	4.64
$C_6H_5NH.CH_3$	$AsCl_3$	14.32	4.82
$C_6H_5N(CH_3)_2$	$AsCl_3$	no reaction	5.05
$C_5H_{10}NH$	$AsCl_3$	20.95	11.13
$C_5H_{10}NH$	$C_2H_5AsCl_2$	18.52	11.13
$C_5H_{10}NH$	$C_2H_5AsCl_2$ (solvent ether)	19.06	11.13

Table II (Continued)

Base used	Arsenious Halide used	p.c. total As started with found in ppt.	Strength of base pK_H
$(C_2H_5)_2NH$	$AsCl_3$	24.3	10.98

These values for the strength of the base are given in terms of the constant pK_H given by Hall and Sprinkle.(108 They are taken in aqueous solution. The assumption that the strength of the bases in aqueous and in non-aqueous solution will still bear the same relationship to each other is open to question. Heptane is a solvent of such low dielectric constant that it can have but little influence on the course of the reaction. The measure of the strength of a base according to Stewart and Aston(109 is its ability to attract hydrogen ions or protons. According to Brönsted acids and bases do not show acidic or basic properties in solutions such as benzene until the necessary proton acceptor or donor respectively is present.(110 Ammonia is a base because it can add a proton, just as picric acid is an acid because it can give up a proton. Brönsted has illustrated this by showing that picric acid in benzene solution does not show its acid character until a base such as aniline is added. Similarily then in heptane solution an amine would not show its basic properties until a proton donor is present. Kremers reported that the mixing of a heptane solution of ammonia and a heptane solution of hydrogen chloride resulted in the precipitation of ammonium chloride.(111 The hydrogen chloride has contributed the proton which allows ammonia to show its basic properties. Similarily when arsenious chloride is added, the $-AsCl_2$ adds to the amine instead of a proton. According to Lewis then, arsenious chloride would be an acid, although such a classification is not accepted by the majority of chemists.(112 The ability of the amine to add a proton or $-AsCl_2$ is dependent on the pull of the lone pair of electrons on the amine, and this pull is influenced by the substituent groups on the amine. Even in heptane solution it would seem that these substituent groups would influence the proton acceptor power of the amine, so that the course of the reaction between arsenious chloride and an amine would be influenced by the substituent groups on the amine. With a weak base such as aniline, the course of the reaction would favor the formation of the arsendiamide and arsentriamide hydrohalides, rather than the reaction between the amine and arsenamide hydrohalide to form the free arsenamide; i.e., equation 2) is favoured over equation 1).

1) $Cl_2AsNHC_6H_5.HCl + C_6H_5NH_2 \longrightarrow Cl_2As.NHC_6H_5 + C_6H_5NH_2.HCl$

2) $AsCl_3 + 2C_6H_5NH_2 \longrightarrow As(NHC_6H_5.HCl)_2$

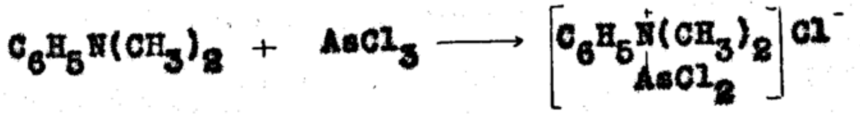
$+ 3C_6H_5NH_2 \longrightarrow As(NHC_6H_5.HCl)_3.$

In the case of a stronger base such as piperidine or diethylamine, equation 1) is favoured over equation 2). This is in accordance with the facts as given in table II. This does not hold true however in the case of methylaniline and dimethylaniline. Undoubtedly steric factors materially influence the course of the reaction. Thus dimethylaniline does not react with arsenious chloride under the condition of the reaction used for the other bases, and yet it is of the same order of strength as aniline and methylaniline. This would seem undoubtedly to be due to steric hindrance. Hofmann was the first to point out that there was considerable steric hindrance in the formation of quaternary ammonium salts from tertiary amines.(113 Wedekind also showed that with dimethylaniline and various alkyl iodides the percentage of quaternary ammonium iodide formed varied over wide limits.(114 Several of his values are given in the following table.

Table III

Dimethylaniline and R'I	Percentage of quaternary ammonium iodide formed.
Methyl iodide	89
Ethyl iodide	15
Allyl iodide	94
Propyl iodide	27.9
Isopropyl iodide	5.3
Isobutyl iodide	1.6

It would thus seem probable that the primary reaction

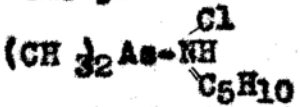


$$C_6H_5N(CH_3)_2 + AsCl_3 \longrightarrow \left[\begin{matrix} C_6H_5\overset{+}{N}(CH_3)_2 \\ AsCl_2 \end{matrix}\right]Cl^-$$

is prevented due to steric effects. When however the strength of the base is materially increased as in the case of tribenzylamine, this steric factor is overcome and the reaction proceeds. The compound $[As(C_6H_5CH_2)_3N_3]Cl_3$ was isolated by the author in the reaction between arsenious chloride and tribenzylamine.

While it does not seem possible to draw definite conclusions as to the quantitative influence of the strength of the base on the course of the reaction in the small number of cases tried, it seems probable that under identical conditions weaker bases yield more of the arsentriamide trihydrohalide than stronger bases. It also seems probable that alkyl groups substituted on the arsenic influence the course of the reaction. Thus with aniline and arsenious iodide, 32.18 p.c. of arsentriamide trihydrohalides are formed as compared to 12.92 p.c. with ethyldiiodoarsine. Similarily with piperidine and arsenious chloride, 20.95 p.c. of arsenamide hydrohalides are formed as compared to 19.06 with ethyldichlorarsine. It would seem that the halogens are more firmly bound in the case of alkyl halogen arsines than with the arsenious trihalides. This corresponds with the known chemical properties of these compounds. Arsenious chloride is hydrolysed completely and instantly with water; ethyldichlorarsine is miscible with but not hydrolysed by water. The influence of one alkyl group on the As-Cl bond is very striking. The reaction between dimethylchlorarsine and piperidine is of particular importance. In this case there is only one replaceable chlorine. The reaction proceeds according to the following equation:

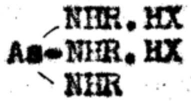
$$(CH_3)_2AsCl + 2C_5H_{10}NH \longrightarrow (CH_3)_2As{-}NC_5H_{10} + C_5H_{10}NH.HCl .$$

As in the previous cases it is probable that the ammonium halide,  $(CH_3)_2As{-}NH\begin{smallmatrix}Cl\\ C_5H_{10}\end{smallmatrix}$ is first formed, and then this reacts with the excess of piperidine present to give the arsenamide and piperidine hydrochloride. When sufficient of the base is present, then the arsenamide hydrohalide is completely converted into the free arsenamide.

Of the six types of compounds possible by the interaction of an arsenious trihalide and an amine, two types have not been isolated from the reaction mixture. The first of these, the dihalogen arsenamide hydrohalide, $X_2As(NHR.HX)$, would be found in the precipitate formed when the arsenious halide is added to the amine. The fact that the corresponding free arsenamide is nearly always present indicates that under the conditions of the reaction this type of compound reacts further with the excess of amine to give the free arsenamide and hydrohalide of the base. The second is the free arsentriamide, $As(NHR)_3$. The author has reported previously an attempt to prepare this type of compound by the action of dry ammonia gas on an ether suspension of benzylamine-arsentriamide trihydrochloride.(40 The reaction was not successful. Compounds such as

$\mathrm{As}\left\{\begin{array}{l}\mathrm{NHR.HX}\\ \mathrm{NHR}\\ \mathrm{NHR}\end{array}\right.$

and



$\mathrm{As}\left\{\begin{array}{l}\mathrm{NHR.HX}\\ \mathrm{NHR.HX}\\ \mathrm{NHR}\end{array}\right.$

are theoretically possible.

None of these have ever been isolated from the reaction mixture.

The structure of the various arsenamides follows from their mode of formation and physical properties. With the free arsenamides the only possible structure is that in which the nitrogen is joined directly to the arsenic. Michaelis and Rabinerson claim to have obtained the compound $(C_6H_4N(CH_3)_2)_3As$ from dimethylaniline and arsenious chloride.(21 Similarily Mroczkowski gave the reaction between methylaniline and arsenious chloride as

$$AsCl_3 + C_6H_5NH(CH_3) \longrightarrow Cl_2As{-}C_6H_4NH(CH_3).^{(25}$$

The product was converted into $O{=}As{-}C_6H_4NH(CH_3)$ with sodium hydroxide and the free imino group proved by acetylation. It has been shown in the present paper that under the conditions of the reaction dimethylaniline does not react with arsenious chloride. It is possible that under different conditions substitution on the benzene ring might occur. With monomethylaniline however this is not the case, and Mroczkowski's product undoubtedly was $Cl_2As{-}N(CH_3)C_6H_5$ and not $Cl_2As{-}C_6H_4NH(CH_3)$. This compound is similar in properties to the compounds formed between aliphatic amines and arsenious chloride, and it is inconceivable that HCl would be split off between an alkyl group and arsenious chloride in preference to the very reactive amino hydrogens:

$$AsCl_3 + (C_2H_5)_2NH \longrightarrow Cl_2As{-}C_2H_4NH.C_2H_5.$$

Since Mroczkowski's product was treated with sodium hydroxide which would immediately split the As-N linkage, acetylation of the imino group does not prove that arsenic was attached to the benzene nucleus in the original reaction product.

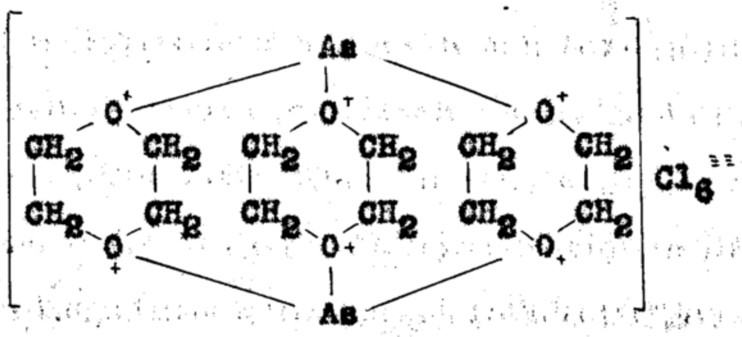
The arsenamide hydrohalides show properties very similar to those of the corresponding alkyl ammonium halides. They are high melting solids, insoluble in organic solvents, but are usually decomposed by water and alcohol. Leonard has shown that they will combine with metallic halides to give complex compounds in a similar manner to ammonium chloride.(4 Thus Piperidine-arsentriamide trihydrochloride triturated with lead iodide, mercuric iodide, or arsenic iodide gave complex addition compounds. With lead and mercuric iodides these complexes were light yellow in colour; with arsenic iodide a white crystalline compound was obtained. Ammonium chloride and lead iodide give a similar white crystalline complex,(116 piperidine hydrochloride and platinous chloride form the complex $C_5H_{10}NH.HCl.PtCl_2$,(117 while Dehn has shown that aniline hydrochloride will combine to give double salts with a number of metallic halides.(44 Leonard states that these compounds require extra or subsidiary valences of either nitrogen or halogen to explain their structure and regards them as Werner secondary compounds. Structures for similar compounds between ammonium salts and metal or metalloid halides have been suggested by Werner.(118 Thus $\left[Sn\begin{matrix}(Br.H.NH_2C_6H_5)_4\\ Br_2\end{matrix}\right]Br_2$ and $\left[Sb\begin{matrix}(INH_4)_4\\ I_2\end{matrix}\right]I$ formed between stannic bromide and aniline hydrobromide, and between antimony triiodide and ammonium iodide respectively. Whatever may be the structure of these complexes, the fact that the arsentriamide trihydrochlorides give similar compounds with metallic halides is evidence for the suggested structure.

The most convincing proof for the "onium" structure is given by the reaction between piperidine-arsentriamide trihydrochloride and silver nitrate or lead acetate. In these cases silver and lead chloride were precipitated quantitatively and the corresponding piperidine-arsentriamide trinitrate and piperidine-arsentriamide triacetate formed. Such a reaction can only be explained by giving to the compound the structure

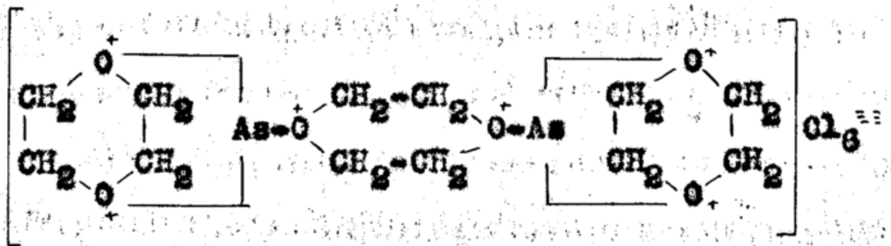
$\left[As\begin{matrix}\overset{+}{\leftarrow}NHC_5H_{10}\\ \overset{+}{\leftarrow}NHC_5H_{10}\\ \overset{+}{\leftarrow}NHC_5H_{10}\end{matrix}\right]Cl_3^{\equiv}$, in which all three chlorine atoms are in the ionised state. A study of the crystal structure of these compounds would be interesting. The melting points of these arsentriamide trihydrohalides are comparable to those of the corresponding amine hydrohalides. Wyckoff states that the alkyl substituted ammonium salts possess crystalline structures intermediate between ionic salts and molecular organic compounds. These structures can be thought of as similar to those of ammonium halides in which the presence of the alkyl groups has distorted the tetragonal symmetry.(118 It seems probable that the arsentriamide trihydrohalides exist in a similar lattice structure, intermediate between molecular compounds and true ionic salts.

The reaction between amines and arsenious halides to form arsenamide hydrohalides is paralleled by the reaction between arsenious chloride and 1,4-dioxane to form a compound, the properties of which suggest an oxonium structure. The compound crystallises from dioxane and can be easily purified in this manner. The substance is soluble in the usual organic solvents, alcohol, acetone, ether, and benzene, and also soluble in warm heptane. Water decomposes it with the precipitation of arsenious oxide. It melts at 62°. Arsenic and chlorine analyses suggest the empirical structure $2AsCl_3 \cdot 3C_4H_8O_2$. Molecular weight determinations in benzene and acetone solution gave values of 157 and 148.4 respectively, whereas the theoretical for the above formula is 626.6. Dissolved in absolute alcohol, a precipitate of silver chloride is formed on the addition of alcoholic silver nitrate; arsenious chloride under similar conditions does not give a precipitate. If the compound is an oxonium halide two structures are possible.

(I)



(II)



Of these two, II appears to be the more probable since it contains five membered rings as compared to ten membered rings in I. It is not surprising to find that the compound is highly dissociated in benzene and acetone. Ray, Adhikari and Roy found that the sulphonium halide formed by the interaction of $SbCl_3$ and diethylsulphide $\left[(C_2H_5)_2\overset{+}{S}\text{-}SbCl_2\right]Cl^-$ was dissociated into two ions in benzene solution.(89 Since acetone has a higher dielectric constant than benzene, 21.4 as compared to 2.82, we would expect the molecular weight to be lower in acetone solution than in benzene solution by the Nernst-Thompson rule. Nor is the solubility of the compound in organic solvents incompatible with the oxonium halide structure if one considers this dissociation. The compound undoubtedly is dissociated in benzene, ether, and the other solvents tried. It is insoluble in cold heptane, but on warming the compound dissociates and the component molecules are soluble in heptane.

This is the first recorded instance of an arsenious halide reacting with a compound containing basic oxygen to form an oxonium halide. Bayer and Villiger have studied the ability of oxygen compounds to form oxonium salts and have shown that oxygen in heterocyclic rings, such as cineol and dimethylpyrone, showed enhanced basis properties.(120 Collie and Tickle have also shown that dimethylpyrone and diacetylacetone formed oxonium salts with a number of acids.(121 Finkelshtein and Kurnosova investigated dimethylpyrone in benzene solution in which it showed normal molecular weight.(130 Halides of antimony and arsenic were also undissociated in benzene solution, but the addition of dimethylpyrone caused autosolvation and subsequent dissociation. The authors interpret this as meaning that the dimethylpyrone possesses sufficient of a dipole moment to penetrate within the halide molecules and cause an ionic complex to be formed. They express this as follows:

$$AsCl_3 + nC_7H_8O_2 \rightleftharpoons \left[AsnC_7H_8O_2\right]Cl_3 \rightleftharpoons \left[AsnC_7H_8O_2\right]Cl_2^{+} + Cl^{-}$$
$$\rightleftharpoons \left[AsnC_7H_8O_2\right]Cl^{++} + 2Cl^{=} \rightleftharpoons \left[AsnC_7H_8O_2\right]^{+++} + 3Cl^{\equiv}$$

Clearly this reaction of dimethylpyrone and arsenious halides is similar to that of 1,4-dioxane and arsenious chloride as described above. Since dioxane has become readily available in a fairly pure state, it was chosen for the above study.

As Rây, Adhikari and Roy have shown that antimony trichloride reacts with alkyl sulphides to give crystalline compounds of the type $\left[R_2S\text{-}SbCl_2\right]Cl$, it might be expected that arsenious chloride would react similarily. Such was not the case however. When the two were mixed some heat was evolved which is probably heat of solution. No crystalline product separated on standing, nor was there a precipitate formed on adding heptane as would be expected if a sulphonium halide was present. Distillation showed that about one-half of the mixture boiled between 109 and 128°, and the remainder boiled constantly at 128-130°. Chlorine analyses on this fraction did not correspond to any simple combination of the two components. A time-temperature curve indicated the separation of two crystal phases at -22° and -29° respectively. Temperature-concentration diagrams would undoubtedly reveal whether a compound is formed, but unfortunately diethylsulphide melts at -102.1°, and the experimental difficulties inherent in working at such low temperatures prevented such a determination with the available laboratory facilities. The constant boiling fraction when dissolved in absolute alcohol gave a precipitate of silver chloride with alcoholic silver nitrate indicating the presence of chloride ions. However on such meagre evidence it is impossible to say that arsenious chloride and diethylsulphide react together in any way.

The reaction between a metalloid halide, such as arsenious chloride, and an amine differs materially from the reaction of a metal halide and an amine. In the case of the metalloid halide we are dealing with a substance in which the halogen atoms are attached by covalent or non-ionic bonds; in the case of a metallic halide the reaction takes place between the amine and the metal and halogen ions. A metalloid halide, such as arsenious chloride, must be considered as an intermediate between a strictly covalent halide, such as alkyl halides, and a completely ionized salt, such as lithium chloride or platinic chloride. When an ionized metallic halide reacts with an amine or ammonia, the base is absorbed to give an addition compound known as a complex ammine. The addition of ammonia to lithium chloride has already been referred to in the historical section. Four complex ammines are formed depending on the conditions of the reaction:

$[Li.NH_3]Cl$, $[Li(NH_3)_2]Cl$, $[Li(NH_3)_3]Cl$ and $[Li(NH_3)_4]Cl$

Practically all the ionized metallic halides will give similar complex ammines. Miss Sutherland in her book "The Metal-Ammines" has outlined the preparation and properties of these compounds.(122

In the case of arsenious chloride the resulting arsenamide hydrochlorides are best regarded as arsenic substitution products of ammonium chloride. This is the view considered in this thesis. The complex ammines, in which there are more amine molecules present than the number of halogen atoms present in the original halide, cannot possibly be classified in this manner. Nor do their chemical properties justify such a classification. The arsenamide hydrochlorides will react further with the amine to give the free arsenamide and the amine hydrochloride. The complex ammines either absorb more ammonia or do not react further. A consideration of Fajans' classical theory offers a possible explaination for the difference between the two classes of compounds.(123 Fajans arrived at the conclusion that an electro or ionic valency would tend to pass over into a covalency under three sets of conditions: (1) when the charge on either ion is large, (2) when the cation is small, (3) when the anion is large. In the case of arsenious chloride, if any arsenious or chloride ion exists at all, it must be present to a very slight extent because no precipitate of silver chloride is obtained with alcoholic silver nitrate. The arsenic then does not tend to increase its coordination number on the addition of ammonia or an amine but ionizes one chlorine atom for each molecule of base absorbed. The arsenic is then attached to the nitrogen by the same type of bond that exists between the nitrogen and hydrogen atoms in an amine or ammonia; i.e., a covalent bond formed by the sharing of two electrons, one from each atom concerned.

Compare this reaction with that of platinous chloride and ammonia. Depending on conditions three types of compounds are obtained: $\left[Pt(NH_3)_2Cl_2\right]$, $\left[Pt(NH_3)_3Cl\right]Cl$ and $\left[Pt(NH_3)_4\right]Cl_2$. The charge on the platinous ion being large, it increases its coordination number to four with a change of ionized chlorine to covalent chlorine. Further addition of ammonia results in one and finally two chlorine atoms being ionized. Platinic chloride forms a similar series of complex ammines in which the coordination number of platinum is six.

$\left[Pt(NH_3)_2Cl_4\right]$ $\left[Pt(NH_3)_3Cl_3\right]Cl$ $\left[Pt(NH_3)_4Cl_2\right]Cl_2$
$\left[Pt(NH_3)_5Cl\right]Cl_3$ $\left[Pt(NH_3)_6\right]Cl_4$

Sidgwick considers that the ammonia molecules in these and similar complex ammines are attached to the metal atom by what he terms a coordinate covalency; that is, where the two electrons necessary to form a chemical bond are both contributed by the nitrogen.$^{(124}$ There is no such supposition needed in the case of the arsenamides.

Such covalent halides as BCl_3, PCl_3 and $GeCl_4$ react similarily to arsenious chloride; the final product when an excess of base is used is the amide or in the case of ammonia the imide. Thus Joannis obtained $B(NH_2)_3$ and $B_2(NH)_3$ as well as ammonium chloride from boron trichloride and ammonia.$^{(125}$ Germanium tetrachloride with ammonia or amines gives the germanium imides  $\mathrm{Ge}\begin{smallmatrix}=\mathrm{NH}\\=\mathrm{NH}\end{smallmatrix}$ and  $\mathrm{Ge}\begin{smallmatrix}=\mathrm{NR}\\=\mathrm{NR}\end{smallmatrix}$ and ammonium chloride or the corresponding amine hydrochloride. With secondary amines, $Ge(NR_2)_4$ and the amine hydrochloride is formed.$^{(126}$ These compounds are similar in structure to the arsenamides, or the arsenamide $As_2(NH)_3$ obtained by Hugot.$^{(22}$ Metalloid halides in which the charge on the cation has become greater may possibly act both as an acid chloride and a metallic salt. Thus antimony trichloride forms compounds $Sb(NHR.HCl)_3$ and $ClSb=NH$ which are comparable to the compounds formed with arsenious chloride. There is also considerable evidence to show that antimony trichloride will form complex ammines, such as $Sb(NH_2C_6H_5)_6\ Cl_3$ and $Sb(NH_2C_6H_5)_4\ Cl_3$. The evidence for arsenic forming such complex ammines is not very convincing. Titanium would seem to be another example which forms such complex ammines as $\left[Ti(NH_3)_6\right]Cl_4$ and $\left[Ti(NH_3)_8\right]Cl_4$, but with liquid ammonia these products react to form the amide, $Ti(NH_2)_4$.$^{(127}$

Thus we may consider that arsenious chloride reacts as an acid chloride because the ionic charge is still too weak to form a complex ammine. With antimony trichloride it has increased sufficiently to allow the substance to act as a metallic chloride although it still will also react as the acid chloride of antimonious acid. Beck from a consideration of the strength of the valence field of the halides of many elements has arrived at a quantitative expression for the difference in behaviour between the various halides in their reaction with amines or ammonia.(128

PART V

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