sodium acetate, 0.5 cc. of a 0.5% alcoholic solution of benzidine and an excess of an alcoholic solution of dimethylglyoxime. If nickel is present the solution is filtered. In the absence of cobalt the filtrate will be colorless to yellow. If cobalt is present the filtrate will have a red coloration. Should the concentration of cobalt be so small that the red color is not very pronounced, it may be intensified by adding solid sodium acetate and allowing to stand for several hours.

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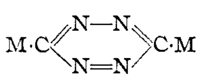
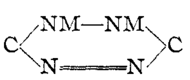
Tetrazine[1]

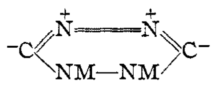
BY DENNISTOUN WOOD, JR., AND F. W. BERGSTROM

In connection with our attempts to prepare nitrogenous derivatives of divalent carbon,[2] we were interested by Müller's statement[3] that "1,2,4,5-tetrazine still contains two atoms of hydrogen which may be replaced by metals, and so have an acid character." In support of his statement, Müller has only his observation that tetrazine and silver nitrate form a precipitate of dark green needles,[4] but no analysis of this has been made.[5] On the other hand, Hantzsch and Lehmann[6] state that tetrazine forms no salts with either acids or bases, but that it reduces silver nitrate and mercuric chloride.

In view of these conflicting statements, it became desirable to see whether or not tetrazine[7] does form metallic salts corresponding to one or more of the formulas (M is a monovalent metal).







Preparation and Properties of Tetrazine.—Tetrazine was prepared from monochloroacetic acid through the following intermediates: glycine ethyl ester hydrochloride,[8] ethyl diazoacetate,[9] sodium bisdiazoacetate,[10] bisdiazoacetic acid,[8] tetrazine dicarboxylic acid.[11] Tetrazine[12] itself was prepared by heating an intimate mixture of its

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[1] Abstracted from the doctoral dissertation of Dennistoun Wood, Jr., Stanford University, 1930. Presented at the Denver Meeting of the American Chemical Society, August, 1932.

[2] Wood and Bergstrom, THIS JOURNAL, **55**, 3314 (1933).

[3] Müller, *Ber.*, **47**, 3001 (1914).

[4] Curtius, Darapsky and Müller, *ibid.*, **40**, 86 (1907).

[5] Müller, personal communication.

[6] Hantzsch and Lehmann, *Ber.*, **33**, 3678 (1900).

[7] Tetrazine is at the same time a derivative of formamidine (ammono formic acid), hydrazine and di-imide.

[8] Hantzsch and Silberrad, *Ber.*, **33**, 70–72 (1900).

[9] Curtius, *J. prakt. Chem.*, [2] **38**, 401–404 (1888); Silberrad, *J. Chem. Soc.*, **81**, 600 (1902).

[10] Curtius and Lang, *J. prakt. Chem.*, [2] **38**, 532 (1888).

[11] Curtius, Darapsky and Müller, *Ber.*, **40**, 1184 (1907).

[12] Curtius, Darapsky and Müller, *ibid.*, **40**, 84–85 (1907).

dicarboxylic acid with sand. A wad of glass wool is placed over the sand layer in the test-tube to prevent contamination of the tetrazine with undecomposed acid and sand. It is worthy of mention that we have found the yield of tetrazine to depend largely upon the length of time which the tetrazine dicarboxylic acid was dried in a vacuum, in conformity with the results of earlier investigators. The maximum amount obtained in this work was 16.8% of the theoretical. The total yield of tetrazine from 10 kg. of chloroacetic acid was only 7.9 g., or 0.18%, largely due to the fact that half of the dicarboxylic acid decomposed, apparently under the influence of radiant energy from a nearby muffle furnace.

Tetrazine itself is crimson colored, melting at 99° to a purple-red liquid. It is volatile even at room temperatures, and at higher temperatures is converted to a gas resembling iodine vapor in color. Its sharp irritating odor is also not unlike that of iodine. It has a bitter taste. Ethereal solutions of tetrazine cannot be concentrated even by vacuum distillation, because the solute volatilizes with the solvent. As will be shown later, liquid ammonia, maintained below --40°, is the only solvent from which tetrazine has ever been recovered. The solubility of tetrazine in water at 20° is roughly 6 g. in 100 cc. The solutions, even in great dilution, are pink.

As a general rule, it is essential to use tetrazine immediately after its preparation, but a pure specimen may be kept without decomposition for many months if sealed in a tube under its own vapor pressure. Left in air-filled tubes, even pure tetrazine becomes dark and pasty in a few hours, while the impure compound prepared from slightly moist tetrazine dicarboxylic acid, decomposes more rapidly. Much of the tetrazine may be recovered from the unpromising looking pasty mass by mixing it with barium oxide and resubliming. Dilute hydrochloric or sulfuric acid slowly decomposes tetrazine with evolution of gas (undoubtedly nitrogen) and conversion to a colorless solution. Very dilute ammonium or sodium hydroxide causes no apparent immediate change. In greater concentration, these alkalies together with potassium hydroxide turn tetrazine solutions brown, but ether extracts practically no color from them. Very little if any of the tetrazine is regenerated on acidification.

Tetrazine in its aqueous solution may best be recognized in the following manner. Hydrogen sulfide is passed through the ice cold solution until the pink color has changed to pale yellow, because of the formation of dihydrotetrazine.[13] Excess hydrogen sulfide is removed by a stream of nitrogen. A little ether and a few drops of sodium nitrite solution are added, the mixture is acidified with dilute acetic acid and shaken. The ether layer assumes a beautiful violet color from the regenerated tetrazine.

Reactions of Tetrazine outside of Ammonia.—Aqueous solutions of tetrazine produce no precipitate with picric acid, ferric chloride, lead dichloride or mercuric cyanide. With silver nitrate, an unstable explosive gelatinous precipitate of variable composition is formed. Auric chloride and tetrazine react in water to form a buff-colored precipitate, with evolution of gas and the occasional formation of metallic gold. The analyses of the precipitate are inconsistent. Hot aqueous mercuric chloride is reduced to mercurous chloride. Chloroplatinic acid does not form a precipitate with tetrazine, but when the reagents are sufficiently concentrated there is a rapid evolution of gas, indicating decomposition. It is evident that tetrazine may act as a reducing agent, as might be anticipated since it is a derivative of hydrazine. With a diethyl ether solution of methylmagnesium iodide, tetrazine forms a precipitate, apparently of an addition compound, since no methane is evolved.

The Behavior of Tetrazine with Ammonia.—Tetrazine is colored a deep purple by a small amount of ammonia at room temperature, but in a rapid stream of this gas it soon becomes pasty, occasionally hardening again in the ammonia atmosphere. The product, whose nature we have not been able to ascertain, explodes when rubbed with a

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(13) Curtius, Darapsky and Müller, *Ber.*, **40**, 86, 815–837 (1907).

glass rod. It dissolves readily in liquid ammonia, usually with a purple color, which may alter on standing. After evaporation of the solvent there remains a brick-red to purple imperfectly crystalline residue, a number of analyses of which are included in Table I.

Pure tetrazine dissolves readily in liquid ammonia at −40°. The more concentrated solutions are dark brown, the very dilute solutions pale buff, and the intermediate ones deep blood-red.

When a liquid ammonia solution of tetrazine which has been kept constantly at −40° or below is evaporated dry in a vacuum, a purple or copper-red substance is left in which are imbedded numerous small red crystals. These latter have been positively identified as unchanged tetrazine. The purple or copper-red material seems to be tetrazine coated with a thin film of the substances formed by the reaction of tetrazine with gaseous ammonia.

In Table I are summarized the analyses of a number of specimens of tetrazine, treated with gaseous or liquid ammonia at various temperatures. The extent of the decomposition of the specimens may be judged by an inspection of the analyses, since, theoretically, none of the nitrogen of tetrazine can be determined by the Kjeldahl method[14] (actually, see preparation 5).

TABLE I

Specimen Number	I	II	III	IV	V
% "Kjeldahl" Nitrogen	20.2	19.0	18.9	3.7	6.0

SPECIMEN I.—Tetrazine added to liquid ammonia at −40°, and solution allowed to stand at room temperature overnight.

SPECIMEN II.—Same as above, but solution allowed to stand at room temperatures for five to six hours.

SPECIMEN III.—Liquid ammonia distilled onto the purple product formed by the action of ammonia gas on tetrazine; solution allowed to stand for one day.

SPECIMEN IV.—Tetrazine added to liquid ammonia at −40°, and solution kept at this temperature until evaporated dry in a vacuum.

SPECIMEN V.—Pure tetrazine, not treated with ammonia.

The Reaction with Potassium Amide.—The reaction of tetrazine with potassium amide in liquid ammonia solution is carried out in Faraday tubes of the type described by Franklin[15a] and by Schurman and Fernelius,[16] in accordance with the technique first developed by Franklin and his co-workers.[15]

The addition of potassium amide to an excess (1.5 moles) of tetrazine causes the formation of a dark brown solution, from which nothing definite was isolated. The reverse addition of tetrazine to potassium amide in excess of 2 equivalents results in the precipitation of a substance approximating a dipotassium salt, $C_2N_4K_2$, in composition. If prepared in the customary manner from tetrazine that has reacted with liquid or gaseous ammonia at room temperatures, there are obtained gray-green to dark brown curdy or stringy precipitates, which usually can be hydrolyzed by water vapor without accident, giving solutions from which only relatively small amounts of tetrazine can be recovered. Since dilute sulfuric acid slowly decomposes these solutions with the formation of some hydrocyanic acid, it is concluded that the potassium salt, prepared in the described manner, is for the most part not a true derivative of tetrazine.

The decomposition of the dipotassium tetrazine is largely prevented if it is prepared and washed at a low temperature. To this end, tetrazine is dropped into liquid ammonia

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[14] Curtius, Darapsky and Müller, *Ber.*, **40**, 1176–1193 (1907).

[15] (a) Franklin, THIS JOURNAL, **27**, 831–833 (1905); (b) **35**, 1460–1462 (1913); (c) *J. Phys. Chem.*, **15**, 511–517 (1911).

[16] Schurman and Fernelius, THIS JOURNAL, **52**, 2428 (1930).

maintained around −40° by an external bath. The ammonia is contained in one leg of a reaction tube described by Schurman and Fernelius,[16] the other leg containing a solution of an excess of potassium amide, likewise cooled to −40°. With the addition tube sealed shut, the tetrazine is slowly poured into the potassium amide solution, producing a blood-red finely divided crystalline precipitate. This is thoroughly washed with liquid ammonia, still taking care that the temperature of the solvent does not rise above its normal boiling point. The legs of the reaction tube are separated, the precipitate leg evacuated at room temperature, the substance moistened with dry benzene, then hydrolyzed with moist benzene, and finally with water. A trace of air or of the vapor of air-free water invariably explodes the compound, and even a slight shock may detonate it. The explosions are remarkably violent, and may prove disastrous out of all proportion to the small amount of material involved.

That the blood red crystalline precipitate obtained in this manner is a true derivative of tetrazine is shown by the addition to this salt of an excess of cooled ammonium bromide solution, all reactants necessarily being held at a temperature of −40°. The precipitate dissolves to form a dull red solution, from which the solvent is removed by evaporation under diminished pressure. From the reddish purple solid, crystals of tetrazine are sublimed and condensed on a portion of the tube cooled by a swab dipped in liquid ammonia; m. p. 96–97°. The reduction–oxidation test, previously described in this article, likewise shows the presence of tetrazine.

TABLE II

ANALYSES OF THE PRECIPITATES FORMED BY THE ACTION OF TETRAZINE ON AN EXCESS OF POTASSIUM AMIDE

Specimen No.	I	II	III	IV	V	VI	VII	VIII	IX	X
Moles KNH_2 per mole tetrazine[a]	2.79	3.30	3.34	3.50	7.4	3.30	2.40	2.5	3.75	3.75
% K	45.2	52.7	45.5	50.0	49.0	54.0 50.6	49.8	45.6	48.5	51.4
% "Kjeldahl N_2"[b]	14.9	15.3					23.6			

Average: K, 49.4. Calcd. for $K_2C_2N_4$: K, 49.4, "Kjeldahl Nitrogen" 0.0. Calcd. for $C_2H_2N_4 \cdot 2KNH_2$: K, 40.7.

[a] Reagents used in the reaction. [b] The Kjeldahl nitrogen is a quantity that cannot be calculated, since hydrolysis of the salt gives locally a high concentration of potassium hydroxide, which decomposes tetrazine in an unknown manner. Kjeldahl N is higher in the salts in which some previous decomposition is known to have occurred (No. VII).

Specimens I to VI were prepared from the cold solution of tetrazine in liquid ammonia. They were therefore all blood-red precipitates, except the second specimen VI. Specimen I was prepared with as great speed as possible at −40°. Specimens II to V stood overnight covered by liquid ammonia at room temperatures. Specimens VI were the products of continued washing of the precipitated salt with liquid ammonia. The upper analysis was of the red residue less soluble in ammonia, the lower analysis of the yellow substance left by evaporation of the wash liquid. Specimens VII to X were prepared from solutions of tetrazine which had reacted with ammonia, and so were brown or green precipitates. Specimen VII was made from tetrazine which had stood in liquid ammonia for seventy hours. Specimens VIII to X were made from tetrazine which had reacted with gaseous ammonia before being dissolved in the liquid.

The Reaction of Alkyl and Aralkyl Halides with Dipotassium Tetrazine.—The freshly prepared, and therefore reactive, salt of tetrazine explodes violently when exposed to methyl iodide vapor. Potassium cyanide is found among the reaction products.

Benzyl bromide reacts readily with the undecomposed salt in liquid ammonia solution, but no definite products were isolated.

Decomposition of Dipotassium Tetrazine under Liquid Ammonia.—When the blood-red dipotassium salt of tetrazine is allowed to stand for some hours under liquid ammonia at room temperature, the supernatant liquid becomes yellow, and the precipitate, while still explosive, has lost some of its sensitiveness. It may be safely hydrolyzed with water vapor. In the evaporation of a sulfuric acid solution of the substance some hydrazine sulfate appears to be formed.

In order to accelerate its decomposition, the dipotassium salt from 2.56 millimoles of tetrazine was heated for seven hours at 95–100° in liquid ammonia,[17] 2.50 millimoles of N_2 and 0.38 millimole of H_2 were obtained. The hydrolysate of the buff-colored precipitate could not be shown definitely to contain tetrazine, but a small amount of hydrazine was formed and identified by conversion to benzalazine. No N-aminotriazole was found.

Attempts to Synthesize Tetrazine by Other Methods.—Formimidoethyl ester hydrochloride, $H{\cdot}C(=NH)OC_2H_5{\cdot}HCl$, reacts with an aqueous solution of hydrazine hydrate and potassium hydroxide, or with a solution of hydrazine in liquid ammonia, to form small amounts of dihydrotetrazine, which are oxidized to tetrazine by atmospheric oxygen. The tetrazine was recognized by qualitative test, since it could not be isolated.

Dibenzyl- and Diphenyltetrazine.[18]—Both of these substances are sparingly soluble in liquid ammonia but dissolve readily in solutions of sodium or potassium amide at $-40°$ or room temperatures to form, respectively, a deep red, and a lighter colored orange solution. Some nitrogen is evolved at the same time. The results will be reported at a later date.

Summary

1. Tetrazine reacts with aqueous solutions of silver nitrate, mercuric chloride, auric chloride and chloroplatinic acid, but without the formation of metallic salts or of definite addition compounds. The salt is often reduced to free metal.

2. Tetrazine dissolves in liquid ammonia and may be recovered from it unchanged, if the solution be kept at or below $-40°$. Otherwise, decomposition occurs. A number of new properties of tetrazine have been described.

3. Potassium amide reacts with tetrazine in liquid ammonia at $-40°$ to form a red, highly explosive ammonia insoluble salt, approximately $K_2C_2N_4$, from which tetrazine may be recovered. At higher temperatures, the salt is slowly decomposed.

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[17] Using the method of Blair, THIS JOURNAL, **48**, 90–92 (1926).

[18] The authors are indebted to Mr. A. E. Gilmore for their preparation.