

THE REACTION OF SODIUM BOROHYDRIDE,  
WITH AMIDES IN THE PRESENCE  
OF A SUITABLE SOLVENT

By

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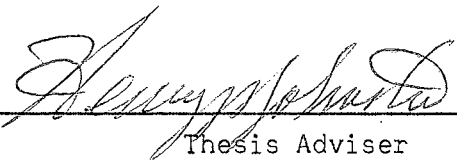
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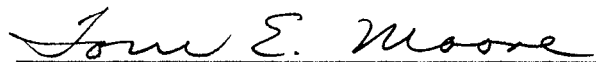
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## INTRODUCTION

In 1936 Stock and Laudenklos reported that a new compound could be prepared by shaking a sodium amalgam with excess diborane. This compound was called sodium diborane and it was given the formula  $\text{Na}_2\text{B}_2\text{H}_6$  (32). In 1949 Kasper (11) repeated the work that had been done by Stock and Laudenklos and reported that the product obtained gave an X-ray diffraction pattern identical with that of sodium borohydride as reported by Soldate in 1947 (30).

Schlesinger and co-workers reported the first planned synthesis of sodium borohydride in 1949 (23).

Since its discovery, sodium borohydride has been used extensively as a reducing agent in both organic and inorganic chemistry. Many aldehydes, ketones, and acid chlorides have been reduced by sodium borohydride.

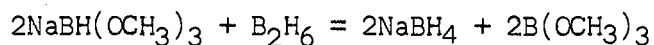
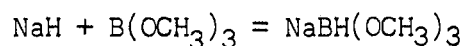
It was reported recently by Brown and co-workers (4) that nitriles and disubstituted amides were reduced by sodium borohydride in the presence of aluminum chloride.

The purpose of this research was to investigate the reaction of sodium borohydride with various unsubstituted amides in the presence of a suitable solvent.

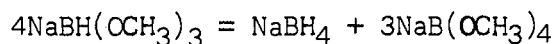
## HISTORICAL

### Preparation of Sodium Borohydride

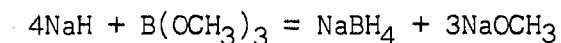
The first planned synthesis of sodium borohydride worked out by Schlesinger and Brown (23) involved two reactions. The first was the reaction of sodium hydride with methyl borate to form sodium trimethoxyborohydride; and the second was the reaction of diborane with sodium trimethoxyborohydride to form sodium borohydride.



Schlesinger, Brown, and Finholt (27) found that sodium trimethoxyborohydride disproportionates at high temperatures to form sodium borohydride as follows:

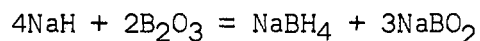


Schlesinger and Brown reported that sodium borohydride could be prepared by the reaction of sodium hydride and methyl borate as follows (24,27):



The reaction was carried out in an autoclave at 225-275° C, and the product obtained was 90-96% pure. The yield was reported as about 94%.

The reaction of boric oxide and sodium hydride was found to produce sodium borohydride in a 60% yield.



Schlesinger and Brown stated that the operations involved in this method of preparation were difficult and they suggested that other methods might be more convenient (27).

One of the newer methods of preparing sodium borohydride was reported in 1959 by Bronaugh (3). It involved the reaction of sodium hydride with boron phosphate in white mineral oil.

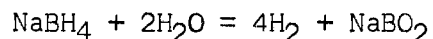
#### Physical Properties

Sodium borohydride is a white crystalline solid which can be heated above 400° C without decomposition (25). It is soluble in cold water, liquid ammonia, and various amines (26). The crystal structure of sodium borohydride has been studied (30). Many of its physical properties and thermodynamic properties have been investigated and can be found in the literature (10, 11, 17, 20, 21).

#### Chemical Properties

Sodium borohydride reacts with both organic and inorganic compounds and its reactions may be divided into these two classes.

Reactions with Inorganic Compounds: Sodium borohydride reacts very slowly with cold water and can be crystallized from it as the dihydrate; but if the water is warmed or certain metal salts are added, the reaction is greatly accelerated. Among those which are most effective in accelerating the hydrolysis of sodium borohydride are Mn(II), Fe(II), Co(II), Ni(II), and Cu(II) chlorides (26, 29). The equation for the hydrolysis of sodium borohydride is as follows:

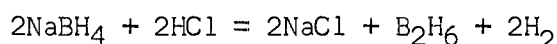


Aqueous sodium borohydride has been found to be very useful in the reduction of several metal salts to the free metal. Silver, bismuth, mercury, arsenic, and antimony salts are all reduced to the

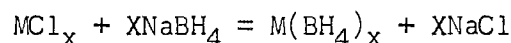


corresponding metals (23). It also effects the following reductions: Fe(III) to Fe(II); Th(III) to Th(I) in alkaline solution; V(V) as the sulfate to V(I) in acid, neutral, and alkaline solution respectively; Cr(VI) to Cr(III) in acid or neutral solution; Mo(VI) to Mo(V) in acid or neutral solution (22).

Sodium borohydride reacts with hydrogen chloride to produce sodium chloride, hydrogen and diborane (26).



It has been used to prepare other borohydrides. Aluminum borohydride and lithium borohydride (28) have been prepared from the corresponding chlorides according to the following equation:



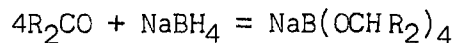
The borohydrides of potassium, rubidium, and cesium have been prepared from the hydroxide of potassium and the methoxides of rubidium and cesium (1).

Reactions with Organic Compounds: Sodium borohydride reacts with methyl alcohol to produce sodium tetramethoxyborohydride and hydrogen (26).

It is a very good reducing agent for several types of organic compounds. It can be used in water or alcohol, depending upon the solubility of the compound to be reduced. It reduces aldehydes, ketones, and acid chlorides to the corresponding alcohols. It will not reduce unsaturated bonds except in a very few cases (5).

Acetone reacts with sodium borohydride to form a product which yields isopropyl alcohol upon hydrolysis (26).

Aldehydes and ketones are reduced by sodium borohydride according to the following equation (5):



The intermediate is then hydrolyzed according to the equation:

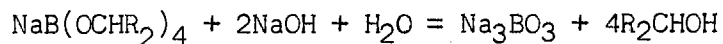


Table 1 lists some of the reductions that have been accomplished by the use of sodium borohydride.

It has been observed by Chaikin and Brown (5) that the double bonds in crotonyl chloride and cinnamoyl chloride undergo some slight reduction.

Sodium borohydride has been used to reduce lactones and carbohydrates, and it has also been used in the steroid field (14, 16, 19, 33, 35, 36). Kollonitsch and co-workers have reported the reduction of esters by sodium borohydride (13).

Sodium borohydride will not reduce nitriles or nitro groups. Acids and acid anhydrides are affected only slightly (5).

Brown and Subba Roa (4) have observed that sodium borohydride, in the presence of aluminum chloride, is a very powerful reducing agent. Nitriles and disubstituted amides are reduced to the corresponding amines.

Sodium borohydride has proved to be a very useful reducing agent for the selective reduction of certain functional groups in the presence of others.

#### Reduction of Amides

Amides have been reduced by lithium aluminum hydride. The substituted amides give secondary and tertiary amines, and the simple amides yield primary amines (6, 7, 18, 34). Lithium borohydride will reduce disubstituted amides to tertiary amines (9).

The classical method of reducing amides is by the use of sodium

TABLE I  
REDUCTIONS BY SODIUM BOROHYDRIDE

Compound	Product	Yield %
Acetylacetone	2,5-Hexanediol	86
<u>n</u> -Butyraldehyde	<u>n</u> -Butanol	85
Cyclopentanone	Cyclopentanol	90
Crotonaldehyde	Crotyl alcohol	85
Methyl ethyl ketone	2-Butanol	87
Cinnamaldehyde	Cinnamyl alcohol	97
Benzoyl chloride	Benzyl alcohol	76
<u>n</u> -Butyryl chloride	<u>n</u> -Butanol	81
Cinnamoyl chloride	Hydrocinnamyl alcohol	12
<u>m</u> -Nitrobenzaldehyde	<u>m</u> -Nitrobenzyl alcohol	82

and alcohol. The products are alcohols and amines, depending upon the conditions of the reaction. Nitrogen is lost as ammonia when alcohols are formed (31).

## EXPERIMENTAL

### Purification of Sodium Borohydride

The crude sodium borohydride that was obtained from Metal Hydrides Inc. required purification in order to have the purity desired. The method of purification was that used by Lindemann (15). The crude sodium borohydride was extracted with pyridine and the solution was filtered. The sodium borohydride was precipitated by adding diethyl ether. It was collected by filtration, washed several times with ether, and dried for several hours at 115° C.

A saturated solution of sodium borohydride in pyridine was prepared by dissolving crude sodium borohydride in pyridine and filtering the solution as in the above purification method. The concentration of this solution was determined by measuring the amount of hydrogen produced when the solution was acidified. The concentration was found to be .00148 moles/ml. of solution. This is equivalent to 5.6 gm./100 ml. of solution. Metal Hydrides Inc. reported that sodium borohydride was soluble in pyridine to the extent of 3.1 gm./100 ml. of solvent.

### Reaction of Urea with Sodium Borohydride

Run 1: .0074 moles of  $\text{NaBH}_4$  in 5 ml. of pyridine, 1.38 gm. (.0240 moles) of urea, and 50 ml. of pyridine were mixed in a three-necked round bottom flask that was fitted with a reflux condenser, thermometer, and a tube from a tank of nitrogen. The top of the reflux

condenser was connected to a gas collection apparatus and an ammonia trap which contained 100 ml. of .0950 N  $\text{H}_2\text{SO}_4$ . The apparatus was swept with nitrogen for several minutes before and for several minutes after the reactants were added. Heat was applied to the mixture and at  $50^\circ$  gas evolution started. The mixture was refluxed at  $115^\circ$  until all gas evolution ceased. .0146 moles of hydrogen were collected.

Pyridine carried over into the ammonia trap and an accurate determination of the amount of ammonia produced was impossible.

While the mixture was refluxing, a white solid precipitated from the solution. This solid was separated from the solution by filtration and was dried for several hours at  $115^\circ$ .

The remaining solution was distilled. The pyridine distilled at  $115^\circ$  and a small amount of solid residue was left in the flask after all the pyridine had been removed. There was no indication of any low boiling or high boiling components.

Run 2: .0148 moles of  $\text{NaBH}_4$  in 10 ml. of pyridine, 2.6692 gm. (.0445 moles) of urea, and 66 ml. of pyridine were mixed in a three-necked flask as before. 50 ml. of .0950 N  $\text{H}_2\text{SO}_4$  were placed in the ammonia trap and the apparatus was swept with nitrogen as in Run 1.

The mixture was heated at reflux for several hours until all gas evolution had ceased. As in Run 1, a white solid precipitated from the reaction while it was refluxing.

The amount of gas produced by the reaction was greater than the volume of the collection apparatus so that its volume could not be measured. The amount of ammonia produced was also greater than the capacity of the ammonia trap.

The solid which precipitated during the reaction was collected

by filtration and dried in an oven.

Run 3: .0222 moles of  $\text{NaBH}_4$  in 15 ml. of pyridine, 4.14 gm. (.0690 moles) of urea, and 200 ml. of pyridine were mixed in a three-necked flask. The apparatus was swept with nitrogen. 200 ml. of .0959 N  $\text{H}_2\text{SO}_4$  were placed in the ammonia trap.

The mixture was refluxed at  $117^\circ$  for 12 hours. At the end of this time all gas evolution had ceased and a white solid had precipitated from the reaction mixture. .0766 moles of hydrogen and .0151 moles of ammonia were collected during the reaction.

The solid that formed during the reaction was collected and dried.

Run 4: .0148 moles of  $\text{NaBH}_4$  in 10 ml. of pyridine, 2.67 gm. (.0445 moles) of urea, and 100 ml. of pyridine were mixed in the reaction vessel. 200 ml. of .0903 N  $\text{H}_2\text{SO}_4$  were placed in the ammonia trap. The apparatus was swept with nitrogen and the mixture was refluxed for eight hours. At the end of this time all gas evolution had ceased and .0424 moles of hydrogen had been collected. .00843 moles of ammonia were produced by the reaction.

The white precipitate that formed during the reaction was separated by filtration and the remaining solution was distilled. The first two ml. that distilled over were treated with a dilute solution of nitric acid and potassium dichromate. There was no color change from orange to green indicating that there was little or no oxidizable material, i.e. methanol, present.

Run 5: .0074 moles of  $\text{NaBH}_4$  in 5 ml. of pyridine, 1.33 gm. (.0222 moles) of urea, and 50 ml. of pyridine were mixed in the reaction flask. 100 ml. of .0903 N  $\text{H}_2\text{SO}_4$  were placed in the ammonia trap. The apparatus was swept with nitrogen and the reaction mixture

was refluxed for several hours until all gas evolution had ceased. .0211 moles of hydrogen were collected and .00285 moles of ammonia were produced by the reaction.

Run 6: .6180 gm. (.0163 moles) of  $\text{NaBH}_4$ , 3.054 gm. (.0509 moles) of urea, and 50 ml. of pyridine were mixed in the reaction flask. The apparatus was swept with nitrogen and the reaction mixture was refluxed for several hours until all gas evolution had ceased. .0466 moles of hydrogen were collected.

#### Examination of the Solid Produced by the Reaction of Urea with Sodium Borohydride

The white solid that precipitated from all the reaction mixtures was found to be non-hygroscopic and very stable to heat. It would not melt or decompose up to  $300^{\circ}\text{C}$ .

The odor of ammonia was detected upon ignition of some of the solid material. A black residue was formed, but this disappeared upon continued heating and left a white residue in its place.

Qualitative tests for boron and nitrogen indicated that both elements were present in the solid material.

The solid was extracted with acetone and the acetone was evaporated. There was no residue, indicating that there was little or no urea mixed with the material. It was then dissolved in water; the water was evaporated; and the residue was extracted with acetone. When the acetone was evaporated, there was a solid left. This solid was found to be urea.

Some of the solid was hydrolyzed and treated with a dilute solution of nitric acid and potassium dichromate. An absence of a green color indicated that there was little or no oxidizable material, i.e. methanol, present.



The solid obtained from the reaction of urea with sodium borohydride was very similar in all its properties to that obtained and reported by Beaver (2).

#### Reaction of Benzamide with Sodium Borohydride

Run 1: 1 gm. (.009 moles) of benzamide, .0148 moles of  $\text{NaBH}_4$  in 10 ml. of pyridine, and 100 ml. of pyridine were mixed in a three-necked flask. The mixture was refluxed for several hours until all gas evolution had ceased. The reaction mixture had turned a red-brown color at the end of this time.

Run 2: 1.112 gm. (.00918 moles) of benzamide, .00740 moles of  $\text{NaBH}_4$  in 5 ml. of pyridine, and 50 ml. of pyridine were mixed in a three-necked flask. 100 ml. of .0959 N  $\text{H}_2\text{SO}_4$  were put in the ammonia trap. The reaction mixture was refluxed until all gas evolution ceased. The mixture was a dark orange color with some solid material in the bottom. .00113 moles of hydrogen were collected from the reaction.

The reaction mixture was filtered and 6 N  $\text{H}_2\text{SO}_4$  was added until the solution was acidic. This acidic solution was then extracted with ether. The ether was evaporated from its extract and a liquid having a sweet odor was left. The infrared spectrum of the liquid showed a sharp peak in the nitrile region (4.47 microns) and also a peak in the carbonyl region (5.95 microns). Pyridine was also shown to be present.

Titration of the  $\text{H}_2\text{SO}_4$  in the ammonia trap indicated that no ammonia had been produced by the reaction.

Run 3: 15.70 gm. (.1296 moles) of benzamide, .0370 moles of  $\text{NaBH}_4$  in 25 ml. of pyridine, and 100 ml. of pyridine were mixed in a three-necked flask. Water was put in the ammonia trap.

The mixture was refluxed for 24 hours. At the end of this time, all gas evolution had ceased and .0840 moles of hydrogen had been collected.

An attempt to filter the mixture failed due to some very fine suspended particles, so the pyridine was distilled off. It came off nearly pure as shown by the refractive index. The refractive index at 25° was 1.5076 and the corrected literature value was also 1.5076.

The residue in the flask was extracted with ether and when the ether was evaporated a liquid was left. This was found to be a mixture of benzonitrile, benzamide, and pyridine.

Water was added to the material that would not dissolve in ether and this mixture was filtered. The solid left in the funnel was washed with water, then with ethanol, and then with ether. It appeared to be insoluble in all three solvents. The melting point was found to be 230-31°. This solid was dried, put in a vial, and kept for future examination.

Run 4: 17.44 gm. (.144 moles) of benzamide, .0370 moles of  $\text{NaBH}_4$  in 25 ml. of pyridine, and 125 ml. of pyridine were mixed in a three-necked flask. The mixture was refluxed for 36 hours. At the end of this time, all gas evolution had ceased and .0883 moles of hydrogen had been collected. There was also a solid precipitate in the flask.

The reaction mixture was transferred to a 500 ml. flask and ether was added to the mixture. Dilute  $\text{H}_2\text{SO}_4$  was then added and a solid material formed between the aqueous layer and the ether layer. The mixture was filtered and the solid was washed with water and ether, and then dried and kept for future examination. The melting point was found to be 230-31°.

The aqueous and ether solutions were separated by means of a separatory funnel. The ether was evaporated from its solution and benzonitrile was found to be present.

Run 5: 2.5048 gm. (.0207 moles) of benzamide, .8929 gm. (.0236 moles) of  $\text{NaBH}_4$ , and 43 ml. of the dimethylether of triethyleneglycol (triglyme) were mixed in a three-necked flask. The mixture was heated at  $120-150^\circ$  until all gas evolution had ceased. A leak in the gas collection apparatus prevented an accurate measure of the amount of gas produced.

The reaction mixture was acidified with 6 N HCl and .0493 moles of hydrogen were collected. The mixture was then extracted with ether and when the ether was evaporated, a liquid identified as benzonitrile was obtained.

The aqueous acid solution was made basic by adding NaOH and distilled under vacuum. Water, triglyme, and a very small amount of benzonitrile were the only products identified.

Run 6: 5.569 gm. (.0460 moles) of benzamide, 1.740 gm. (.0460 moles) of  $\text{NaBH}_4$ , and 60 ml. of triglyme were mixed in a three-necked flask. The mixture was heated at  $125-30^\circ$  for 4 hours and then it was refluxed at  $220^\circ$  for about  $6\frac{1}{2}$  hours. At the end of this time, all gas evolution had ceased and .0933 moles of hydrogen had been collected.

The reaction mixture was distilled at 30-35 mm. of pressure and two fractions were collected. The first contained benzonitrile and triglyme, and the second was only triglyme. There was considerable charred material left in the flask which was not identified. The fraction which contained the benzonitrile was refluxed with 6 N NaOH for several hours in order to hydrolyze the benzonitrile to benzoic

acid. 2.12 gm. of benzoic acid were obtained. This is equivalent to 37.7% of the benzamide used at the start of this reaction.

Run 7: 1.791 gm. (.0148 moles) of benzamide, .0148 moles of  $\text{NaBH}_4$  in 10 ml. of pyridine, and 75 ml. of pyridine were mixed in a three-necked flask. The mixture was refluxed for 9 hours, and at the end of this time .0245 moles of hydrogen had been collected.

Water was added to the mixture and then it was extracted with ether. Benzonitrile was the only product that was identified.

Run 8: 2.233 gm. (.0184 moles) of benzamide, 1.398 gm. (.0368 moles) of  $\text{NaBH}_4$ , and 105 ml. of pyridine were mixed in a three-necked flask. The mixture was refluxed until all gas evolution had ceased. .0351 moles of hydrogen were produced by the reaction. The only other product of this reaction that was identified was benzonitrile.

Run 9: 8.100 gm. (.0670 moles) of benzamide, .632 gm. (.0167 moles) of  $\text{NaBH}_4$ , and 70 ml. of pyridine were mixed in a three-necked flask and heated at reflux until all gas evolution had ceased. .0349 moles of hydrogen were collected.

The pyridine was distilled from the mixture and water and ether were added to the residue. There was a considerable amount of solid that would not dissolve. This was filtered off and recrystallized from benzene. The solid melted at  $130^\circ$  and was found to be benzamide. The benzene that was used for recrystallization was evaporated and the residue was washed well with ethanol and filtered. .346 gm. of a solid (M.P.  $230-31^\circ$ ) was obtained.

Benzonitrile was also identified as one of the products.

Run 10: 6.000 gm. (.0496 moles) of benzamide, .620 gm. (.0164 moles) of  $\text{NaBH}_4$ , and 50 ml. of triglyme were mixed in a three-necked flask.

The mixture was heated gradually over a five hour period until it reached a maximum temperature of  $215^{\circ}$ . All gas evolution had ceased at the end of this time.

The mixture was distilled in order to remove most of the solvent and benzonitrile formed by the reaction. The distillate was collected and then refluxed with 6 N NaOH for 21 hours. 1.183 gm. of benzoic acid were collected.

The solid residue left after distillation of the mixture was extracted with ethanol and filtered. The precipitate was washed well with water and then with ethanol in order to remove any excess benzamide. A small amount of solid residue which melted at  $230-31^{\circ}$  was obtained. This was bottled and put with the corresponding material isolated from previous runs.

Run 11: 8.096 gm. (.06675 moles) of benzamide, 5.050 gm. (.1333 moles) of  $\text{NaBH}_4$ , and 150 ml. of triglyme were mixed in a three-necked flask. The mixture was heated at  $120-30^{\circ}$  for 48 hours at which time nearly all gas evolution had ceased. No attempt was made to collect the hydrogen produced by this reaction.

The reaction mixture was distilled at 30 mm. until pure solvent (as shown by the refractive index) was obtained. The distillate was then refluxed with 25% NaOH for 7 hours and then the mixture was acidified. Benzoic acid precipitated from the mixture after allowing it to stand for 4 hours. The benzoic acid was removed by filtration and the remaining solution was distilled at 30 mm. to remove the water present. When most of the water had been removed, the mixture was treated with  $\text{Na}_2\text{CO}_3$  and the rest of the water present was then removed. The solid residue left in the flask was extracted twice with diethyl

ether. The ether was evaporated and there was a liquid left. The liquid was distilled at 30 mm. and two fractions were collected.

<u>Fraction</u>	<u>Refractive Index @ 28°</u>	<u>B.P. @ 30 mm.</u>
1	1.4295	100-123°
2	1.4200	124-125°
Triglyme	1.4201	-----

Fraction two was shown to be triglyme. Fraction one was apparently triglyme with a small amount of an impurity which raised the refractive index. Reaction of fraction one with acetyl chloride indicated the possible presence of benzylamine (refractive index @ 28° 1.5369).

Identification of the Solid Produced by the Reaction of Benzamide with Sodium Borohydride

The solid material was examined in order to find certain physical and chemical properties. The following results were obtained:

Melting Point: M.P. was found to be 230-31°.

Solubility: It was insoluble in water, alcohol, ether, dilute acids, and bases. It was soluble in benzene, toluene, and concentrated H<sub>2</sub>SO<sub>4</sub>. Upon addition of a small amount of water to the concentrated H<sub>2</sub>SO<sub>4</sub> solution, the material reprecipitated unchanged. The solid was found to be insoluble in, and inert to, boiling 6 N NaOH.

Qualitative Elemental Analysis: Upon ignition, the material burned with a sooty flame. Nitrogen was shown to be present by a sodium fusion test.

Quantitative Elemental Analysis: A sample of the material was sent to Midwest Microlab Inc. for a duplicate carbon, hydrogen, and nitrogen analysis. The results were reported as follows:

<u>Element</u>	<u>Per Cent Present</u>		<u>Average</u>
Carbon	80.72	80.99	80.86
Hydrogen	4.91	5.03	4.97
Nitrogen	<u>13.94</u>	<u>14.11</u>	<u>14.03</u>
Total	99.57	100.13	99.86

The empirical formula was calculated to be  $C_7H_5N$ .

A search of the literature revealed that 2,4,6-triphenyl-s-triazine had a molecular formula of  $(C_7H_5N)_3$ , very similar solubilities, and a melting point of  $232^\circ$ .

2,4,6-triphenyl-s-triazine was prepared by letting a mixture of benzonitrile and chlorosulfonic acid stand at  $0^\circ$  for several hours (8). The mixture was then poured over ice, filtered, and the precipitate was recrystallized from benzene. The melting point was observed to be  $230-31^\circ$ .

A mixture of 2,4,6-triphenyl-s-triazine and the solid formed by the reaction of benzamide with  $NaBH_4$  was prepared, and a melting point was obtained ( $230-31^\circ$ ).

The infrared spectrum of the solid material in "Nujol" was found to be identical with that of 2,4,6-triphenyl-s-triazine in "Nujol".

#### Reaction of Benzonitrile with Sodium Borohydride

Run 1: A small amount of  $NaBH_4$  and benzonitrile were dissolved in pyridine. This mixture was poured into a flask that was fitted with a reflux condenser and refluxed for 3 hours. The mixture was then poured into dilute HCl in order to decompose any excess  $NaBH_4$ . There was no precipitate (i.e. 2,4,6-triphenyl-s-triazine) noted in the mixture. Benzonitrile was present as a layer on top of the aqueous mixture.

Run 2: .373 gm. (.00985 moles) of  $\text{NaBH}_4$ , 3.06 gm. (.0296 moles) of benzonitrile, and 15 ml. of pyridine were mixed in a flask that was fitted with a reflux condenser. The mixture was refluxed for  $4\frac{1}{2}$  hours. It was then poured over a mixture of ice and dilute HCl. There was no 2,4,6-triphenyl-s-triazine formed by the reaction.

Run 3: .587 gm. (.0150 moles) of  $\text{NaBH}_4$ , .80 gm. (.00775 moles) of benzonitrile, .20 gm. (.0111 moles) of water and 15 ml. of pyridine were mixed and refluxed for 17 hours. Most of the pyridine was then distilled from the mixture. Benzene was added to extract any 2,4,6-triphenyl-s-triazine which might be formed. There was no solid material isolated from the mixture.



## DISCUSSION

### Reaction of Urea with Sodium Borohydride

The reaction of urea with sodium borohydride in the absence of a solvent has been studied by Beaver (2). It appears that the presence or absence of a solvent has no appreciable effect upon the reaction. The major difference noted was that a 3:1 mole ratio (urea:NaBH<sub>4</sub>) of reactants gave a 3:1 mole ratio of hydrogen to NaBH<sub>4</sub>. Beaver reported that a 4:1 mole ratio of hydrogen was obtained from the same reaction mixture in the absence of a solvent.

Ammonia was reported by Beaver to be a minor product. This was also the case when urea reacted with sodium borohydride in the presence of pyridine. Trace amounts of methanol were reported to be formed in the absence of a solvent, but in this investigation methanol was not found to be one of the products. If it was formed, it was present only in very small amounts.

The solid which precipitated from the reaction mixture in pyridine solution was found to be very similar to that reported by Beaver. It was non-hygroscopic, very stable to heat, contained both boron and nitrogen, and upon hydrolysis gave urea as one of the major products. Tests for methanol indicated that very little, if any, methanol was formed upon hydrolysis of the solid.

Table II gives a summary of the results obtained from the investiga-

TABLE II

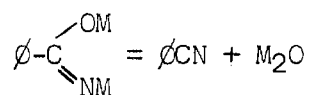
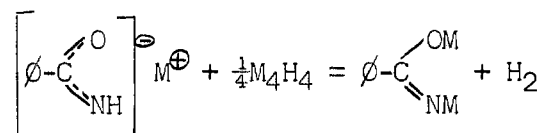
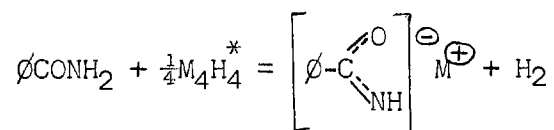
## REACTION OF UREA WITH SODIUM BOROHYDRIDE

Reaction Number	Mole Ratio Urea/ $\text{NaBH}_4$	Moles of Hydrogen	Mole Ratio $\text{H}_2/\text{NaBH}_4$	Moles of Ammonia
1	3.24	.0146	1.98	+
2	3.02	-----	-----	+
3	3.11	.0766	3.40	.0152
4	3.01	.0424	2.86	.0084
5	3.00	.0211	2.85	.0029
6	3.12	.0466	2.87	+

tion of the reaction of urea with sodium borohydride in pyridine.

#### Reaction of Benzamide with Sodium Borohydride

It was recently reported that benzamide was reduced by lithium aluminum hydride to benzylamine through a nitrile intermediate (18). The proposed mechanism involved the dehydration of the amide to the nitrile and then reduction of the nitrile. The mechanism for the dehydration was proposed as follows:



$$*\text{M} = \text{LiAl}/4$$

The reaction of benzamide with sodium borohydride follows a similar course except for the reduction of the nitrile to the amine, which occurs very little, if any.

This reaction was studied by using three different types of reaction mixtures. The following equations represent these and the results obtained.

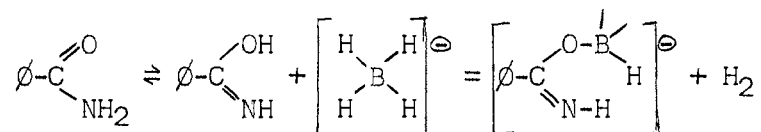
1.  $1 \phi\text{CONH}_2 + \text{Xs NaBH}_4 = 2 \text{H}_2 + \phi\text{CN}$
2.  $1 \phi\text{CONH}_2 + 1 \text{NaBH}_4 = 2 \text{H}_2 + \phi\text{CN}$
3.  $\text{Xs } \phi\text{CONH}_2 + 1 \text{NaBH}_4 = 2 \text{H}_2 + \phi\text{CN}$

Quantitative determinations of the amount of benzonitrile were not made except in two cases. These were very rough and probably very

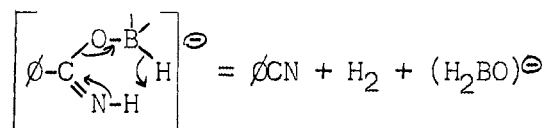
inaccurate. In one case, a 1:1 reaction mixture gave benzonitrile equivalent to 40% of the benzamide used. In another case, a 3:1 mixture (excess benzamide) gave benzonitrile equivalent to 20% of the benzamide used and 60% of the  $\text{NaBH}_4$  used. These results, along with others, are shown in Table III.

In equations 1 and 2, the maximum amount of hydrogen that can be liberated is two moles. In equation 3, four moles are possible but only two were obtained. Thus the reaction of benzamide must fundamentally involve the formation of only two moles of hydrogen.

The following mechanisms are postulated in order to explain the results obtained from this investigation. The first point of attack of the  $(\text{BH}_4)^{\ominus}$  is at an active hydrogen on the amide. This liberates one mole of hydrogen.



Due to the close proximity of the active hydrogen on the nitrogen and the hydride, the complex could rearrange to liberate another mole of hydrogen and form benzonitrile.



The net result to the  $(\text{BH}_4)^{\ominus}$  is the exchange of two hydride ions for one oxide ion. The presence of the oxygen in the  $(\text{H}_2\text{BO})^{\ominus}$  would tend to decrease the hydride character of the two hydrogens left by withdrawing electrons from them. This would cause them to become more difficult to remove by reaction with an acid, i.e., it would require a stronger acid than benzamide to react with them.

Small amounts of 2,4,6-triphenyl-s-triazine were formed in the

TABLE III

## REACTION OF BENZAMIDE WITH SODIUM BOROHYDRIDE

Reaction Number	Mole Ratio $\phi\text{CONH}_2/\text{NaBH}_4$	Mole Ratio $\text{H}_2/\text{NaBH}_4$	Mole Ratio $\text{H}_2/\phi\text{CONH}_2$	$\phi\text{CN}$ Formed
1	0.61	----	----	Present
2	1.24	1.53	----	Present
3	3.50	2.27	----	Present
4	3.49	2.38	----	Present
5	0.88	----	2.18'	Present
6	1.00	2.03	2.03	40%
7	1.00	1.67	1.67	Present
8	0.50	----	1.91	Present
9	4.01	2.09	----	Present
10	3.02	----	----	20%, 60%"
11	0.50	----	----	Present*

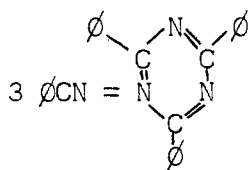
' Calculated from the amount of hydrogen produced upon acidification of the mixture.

" 20% of the  $\phi\text{CONH}_2$  was converted to  $\phi\text{CN}$ . The 60% yield is based upon the assumption that 1  $\text{NaBH}_4$  gives 1  $\phi\text{CN}$ .

\* A trace of benzylamine was indicated by a reaction with acetyl chloride.

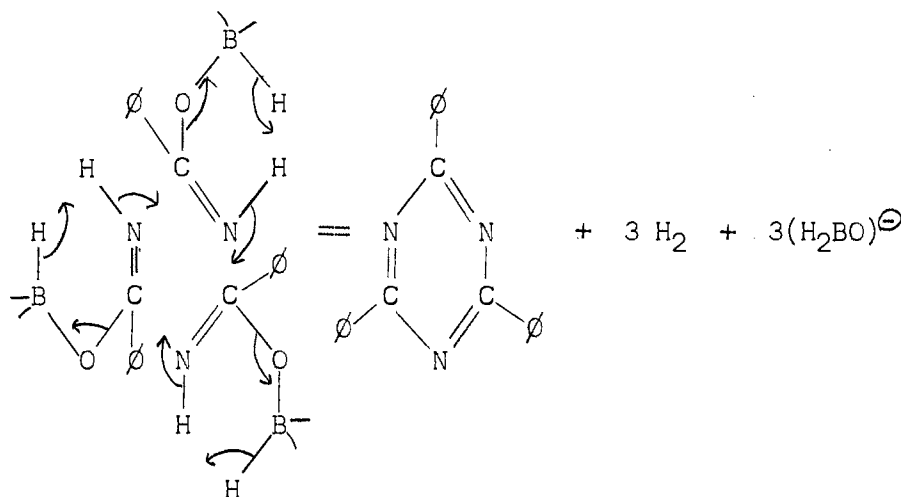
reaction. This compound could be formed in two different ways:

1. Trimerization of the benzonitrile present.



2. Formation from an intermediate present in the reaction.

Three attempts to prepare 2,4,6-triphenyl-s-triazine by the reaction of benzonitrile with sodium borohydride failed, so, it must have come from an intermediate. The 2,4,6-triphenyl-s-triazine could have been formed by intermolecular rearrangement between three moles of the intermediate postulated in the formation of benzonitrile.



The amount of hydrogen produced per mole of complex is the same for both the formation of benzonitrile and 2,4,6-triphenyl-s-triazine.

Any benzylamine formed by the reaction could come from the reduction of benzonitrile. But since the reduction of benzonitrile by sodium borohydride has never been observed, it is doubtful that benzylamine was formed to any appreciable extent.

The reaction of benzamide with sodium borohydride, as studied in

this investigation, was carried out in two different solvents - pyridine (B.P. 115°) and the dimethylether of triethyleneglycol (B.P. 216°). The choice of solvent seemed to have no effect upon the reaction.

The only effect noted, due to temperature variations, was the time required for complete evolution of hydrogen.

The mechanisms postulated in this discussion explain the results obtained during the investigation. Their proof is left as a proposal for future study.

Since hydrogen gas and a nitrile are the principle products of the reaction of benzamide with sodium borohydride, it might prove profitable to investigate the reaction in the presence of a platinum or palladium catalyst.

## SUMMARY

The reaction of urea with sodium borohydride in the presence of a solvent was studied and the results were compared with those obtained by Beaver (2), who carried out the reaction in the absence of a solvent. The solvent has little effect on the reaction. The main products are hydrogen; a urea -  $\text{NaBH}_4$  complex which yields urea upon hydrolysis; and lesser amounts of ammonia.

The reaction of benzamide with sodium borohydride is entirely different from that of urea. The main products here are hydrogen, benzonitrile, and a small amount of 2,4,6-triphenyl-s-triazine.

The postulates presented in this discussion are open to criticism, but they do explain the results obtained in this investigation.



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