after the addition had been completed. It was then cooled and added to 400 ml. of water. The resulting solution was extracted with four 100-ml. portions of methylene chloride. The combined extracts were washed with three 100-ml. portions of 10% sodium bicarbonate solution and dried over magnesium sulfate. The solvent was evaporated under reduced pressure and the residual liquid was fractionated through a Holzman column.[11] After a small forerun had distilled, there was obtained 10.6 g. (77%) of colorless phenylnitromethane, b.p. 97–99° (4.0 mm.). The infrared spectrum of this sample was identical to that of an authentic specimen of phenylnitromethane.

Oxidation of Cyclopentanone Oxime to Nitrocyclopentane.—A solution of peroxytrifluoroacetic acid was prepared as described above. This solution was added over a one-hour period to a mixture of 2.0 g. of urea, 78 g. (0.55 mole) of disodium hydrogen phosphate, 9.9 g. (0.1 mole) of cyclopentanone oxime and 200 ml. of acetonitrile maintained at gentle reflux. After the addition was over, the mixture was heated under reflux one hour. The insoluble inorganic salts then were removed by centrifugation and the acetonitrile solvent was evaporated under reduced pressure. During this process a considerable quantity of inorganic salt precipitated. Accordingly, 150 ml. of water was added to dissolve these salts. The aqueous solution so obtained was extracted with one 300-ml. and two 50-ml. portions of methylene chloride. The combined organic extracts were washed with 100 ml. of 10% sodium bicarbonate solution and dried over magnesium sulfate. Evaporation of the solvent under reduced pressure yielded a residual oil which gave after fractionation through the Holzman column 6.9 g. (60%) of nitrocyclopentane,[4] b.p. 90–92° (40 mm.).

Oxidation of Dipropyl Ketone Oxime to 4-Nitroheptane.—A solution of peroxytrifluoroacetic acid in acetonitrile prepared as described above was added over an 80-minute period to a well-stirred suspension of 47 g. (0.55 mole) of sodium bicarbonate in a solution of 2 g. of urea, 12.9 g. (0.1 mole) of dipropyl ketoxime and 200 ml. of acetonitrile. Throughout the addition and for one hour after, the solution was heated under gentle reflux. The solution then was poured into 600 ml. of cold water and worked up in the usual manner. Fractionation of the product through the Holzman column yielded 9.3 g. (64%) of 4-nitroheptane,[4] b.p. 58–60° (3 mm.).

Oxidation of Diethyl Oximinomalonate to Diethyl Nitromalonate.—To a solution of 5.3 ml. (0.195 mole) of 90% hydrogen peroxide in 50 ml. of trifluoroacetic acid at 60° was added slowly 15.0 g. (0.0795 mole) of diethyl oximinomalonate. Addition was accompanied by a vigorous reaction which raised the temperature to 87°. The reaction mixture was then cooled with an ice-bath and at this point some evolution of nitrogen oxides was observed. The mixture was immediately quenched in 200 ml. of ice-water and the aqueous solution was extracted with three 100-ml. portions of methylene chloride. The combined extracts were washed with 100 ml. of 10% sodium bisulfite solution and then with 100 ml. of water. The methylene chloride solution was dried over magnesium sulfate and the solvent evaporated under reduced pressure to yield 12.0 g. (74%) of crude diethyl nitromalonate. Distillation of this product yielded 10.8 g. (66%) of diethyl nitromalonate, b.p. 80–83° (0.3 mm.), whose infrared spectrum was identical with that of an authentic sample.[12]

Oxidation of Phenylglyoxal Aldoxime to ω-Nitroacetophenone.—To a solution of 3.7 ml. (0.136 mole) of 90% hydrogen peroxide in 50 ml. of chloroform containing 0.3 g. of urea and 7.2 ml. (0.094 mole) of trifluoroacetic acid was added at 60° in small portions 7.45 g. (0.05 mole) of phenylglyoxal aldoxime. The resulting solution was heated under reflux for 90 minutes and 50 ml. of methylene chloride then was added. The methylene chloride–chloroform solution was washed with 15 ml. of water and the extract was dried over magnesium sulfate. Evaporation of the solvent yielded 7.0 g. (85%) of crude ω-nitroacetophenone, m.p. 90–100°. After recrystallization from an ether–petroleum ether mixture, there was obtained 6.3 g. (76%) of product, m.p. 106–107° (lit. m.p. 106–107°[13]). The infrared spectrum showed a nitro band at 1552 cm.$^{-1}$ and a carbonyl band at 1689 cm.$^{-1}$.

Oxidation of Ethyl α-Oximinoacetoacetate to Ethyl Nitroacetate.—To 50 ml. of chloroform was added 8 ml. (0.104 mole) of trifluoroacetic acid, 3 ml. (0.11 mole) of hydrogen peroxide and a pinch of urea. A solution of 9.0 g. (0.0565 mole) of ethyl oximinoacetoacetate in 20 ml. of chloroform was added at 55–60°. When addition of the oxime had been completed, an additional 1.5 ml. of 90% hydrogen peroxide was added. After the exothermic reaction had subsided, 200 ml. of methylene chloride was added, and the resulting solution was washed with 50 ml. of water and dried. Evaporation of the solvent yielded 5.5 g. of oil which on distillation yielded 3.0 g. (40%) of ethyl nitroacetate, b.p. 65–66° (0.6 mm.). The infrared spectrum of this product was identical with that of an authentic sample of ethyl nitroacetate.[14] Crystallization of the distillation pot residue yielded 0.3 g. of oxalic acid.

HUNTSVILLE, ALABAMA

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[11] C. W. Gould, G. Holzman and C. Niemann, *Anal. Chem.*, **20**, 361 (1948).

[12] D. I. Weisblat and D. A. Lyttle, THIS JOURNAL, **71**, 3079 (1949).

[13] H. Wieland, *Ber.*, **36**, 2561 (1903).

[14] W. Steinkopf, *ibid.*, **37**, 4625 (1904).

[JOINT CONTRIBUTION FROM THE CHEMISTRY DEPARTMENTS OF MONTANA STATE UNIVERSITY AND THE UNIVERSITY OF WISCONSIN]

Secondary Products from the Catalytic Hydrogenation of Nitriles[1,2]

BY RICHARD JUDAY AND HOMER ADKINS[3]

RECEIVED SEPTEMBER 1, 1954

Secondary products formed during the Raney nickel hydrogenation of aliphatic and aromatic nitriles alone, or in the presence of various amines, have been studied. Aliphatic nitriles have been found to form secondary amines consistent with the mechanism first suggested by von Braun. Aromatic nitriles, however, formed Schiff bases, possibly through the intermediate formation of the dimer of an imine followed by hydrogenolysis.

The formation of secondary products, in addition to primary amines, during the hydrogenation of nitriles over nickel catalysts was noted by the first workers in the field.[4,5] Secondary and tertiary amines as well as Schiff bases have been reported as being formed. Two principal mechanisms have been proposed to explain the formation of the secondary products isolated. That of von Braun[6] presumes an interaction between an aldimine and a primary amine according to equations I, II or Ia and IIa, where R is either alkyl or aryl. Mignonac,[5] working only with aromatic nitriles, identified the

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[1] This paper is based on a Ph.D. thesis submitted at the University of Wisconsin in 1943. The data presented here are of recent origin.

[2] Research Corporation grant, 1952.

[3] Deceased August 10, 1949.

[4] P. Sabatier and J. B. Senderens, *Compt. rend.*, **140**, 482 (1905).

[5] G. Mignonac, *ibid.*, **171**, 114 (1920).

[6] J. von Braun, G. Blessing and F. Zobel, *Ber.*, **56**, 1988 (1923).

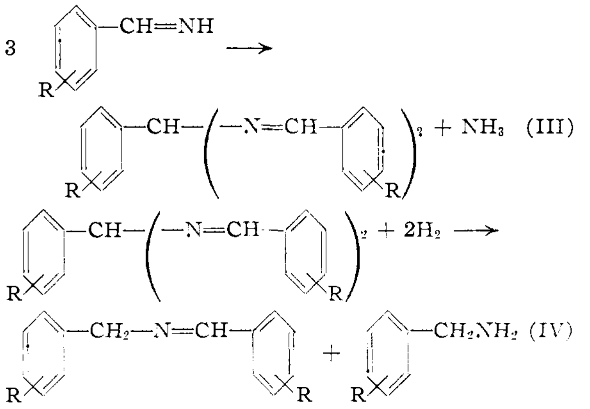
$$RCH{=}NH + RCH_2NH_2 \longrightarrow RCH(NH_2)NHCH_2R \quad (I)$$

$$RCH(NH_2)NHCH_2R + H_2 \longrightarrow RCH_2NHCH_2R + NH_3 \quad (II)$$

$$RCH{=}NH + RCH_2NH_2 \longrightarrow RCH{=}NCH_2R + NH_3 \quad (Ia)$$

$$RCH{=}NCH_2R + H_2 \longrightarrow RCH_2NHCH_2R \quad (IIa)$$

secondary products isolated as Schiff bases and, from the results obtained by Busch,[7] postulated the intermediate formation of hydrobenzamide followed by hydrogenolysis to the Schiff base according to equations III and IV. Winans and Adkins[8] supported the views of von Braun with their results on the hydrogenation of hydrobenzamide although they did not study the hydrogenation of aromatic nitriles themselves at that time. The present investigation was initiated in 1941 to test further these two mechanisms. Since previous workers had been concerned with the hydrogenation of the nitrile by itself, or in solution with solvents other than amines, it was hoped that a study of the effect of adding various amines on the course of the reaction would help to resolve some of the existing discrepancies in the mechanisms proposed for the reaction.



Aliphatic Nitriles.—Most runs were made using a Raney nickel catalyst prepared according to the method of Adkins and Pavlic (W-4)[9] and then deactivated slightly by treatment with ether (W-4a). Secondary amine formation was favored somewhat by the decrease in activity, but the differences were small.

Variation in pressure did not appear to have much influence on the course of reaction and, within 15° of the point at which rapid hydrogenation ensued, temperature also had little effect. A small amount of methanol was added to most runs since it increased the yield of secondary product and decreased the amount of high-boiling residue.

The effect of adding amyl-, benzyl- and substituted benzylamines on the reduction of valeronitrile is shown in Fig. 1. The addition of the benzylamines led to the formation of mixed secondary amines, but the formation of diamylamine was not entirely suppressed. The addition of more than one mole of amine had a relatively slight influence on secondary amine formation. No mixed secondary amine was formed when aniline was added and no tertiary amine was detected on adding diamylamine. Mixed secondary amines also were formed from *o*-methylbenzylamine and β-phenethylamine but in 10% lower yields.

Results obtained from the hydrogenation of α-tolunitrile in the presence of amyl- and β-phenethylamine were similar to those obtained from valeronitrile, but the yields were about 20% lower.

The secondary products formed from the aliphatic nitriles are compatible with the mechanism proposed by von Braun which would predict the formation of the mixed secondary amine from the added primary amine. The small effect that increasing primary amine concentration had on the proportion of secondary amine formed indicates that the alkylation reaction occurs on the catalyst in competition with the hydrogenation reaction, which is favored, and that the catalyst surface becomes saturated with respect to primary amine at approximately a 1:1 mole ratio of amine to nitrile.

Aromatic Nitriles.—The yields and products obtained on hydrogenating aromatic nitriles were more sensitive to reaction conditions than were the aliphatic nitriles. In general, conditions favoring hydrogenation (high catalyst activity, high catalyst ratio, high temperature, methanol) decreased the total yield of secondary products (Schiff base and secondary amine) but increased the proportion of secondary amine present in the product. For this reason W-4a catalyst was used in most runs and the addition of methanol avoided.

The secondary product obtained was a Schiff base containing varying amounts of the corresponding secondary amine. Hydrogenation of the product over palladium–carbon catalyst produced the secondary amine, and acid hydrolysis the corresponding aldehyde and primary amine. Since ammonia could not be detected among the hydrolysis products no hydro- or dihydrohydrobenzamide could be present. The failure of some workers[6] to isolate the Schiff base may be ascribed to the severity of their hydrogenating conditions.

Results obtained on hydrogenating aromatic nitriles in the presence of the corresponding primary amine are shown in Fig. 2. The yields of secondary product are higher than those obtained from aliphatic nitriles, but little increase in yield is obtained when the amine to nitrile ratio is raised beyond 1:1.

When amylamine was added instead of the corresponding primary amines, curves similar in shape to those in Fig. 2 were obtained. With the exception of anisonitrile, the maximum yields of secondary product were 10% smaller. When W-4a catalyst was used only a trace amount of the amylbenzylamine was formed. With W-4 catalyst enough mixed secondary amine was formed to be isolated (0.03–0.05 mole per mole of nitrile), although the amount was small when compared with that from valeronitrile. No benzalamylamine was isolated from the products of any of the reactions.

When *p*-tolunitrile and anisonitrile were hydrogenated in the presence of benzylamine, the secondary products did not contain an appreciable amount of the mixed Schiff base. When a mixture of benzonitrile and anisonitrile was hydrogenated, however,

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(7) M. Busch, *Ber.*, **29**, 2143 (1896).

(8) C. F. Winans and H. Adkins, THIS JOURNAL, **54**, 306 (1932).

(9) H. Adkins and A. A. Pavlic, *ibid.*, **69**, 3039 (1947).

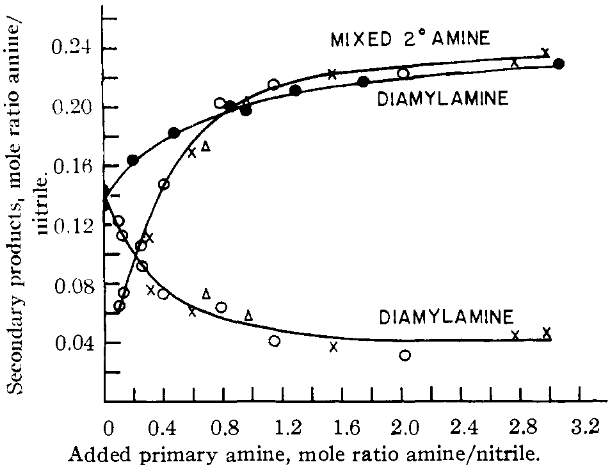


Fig. 1.—Valeronitrile hydrogenated in the presence of: ●, amylamine· ○, *p*-methoxybenzylamine; ×, benzylamine; △, *p*-methylbenzylamine.

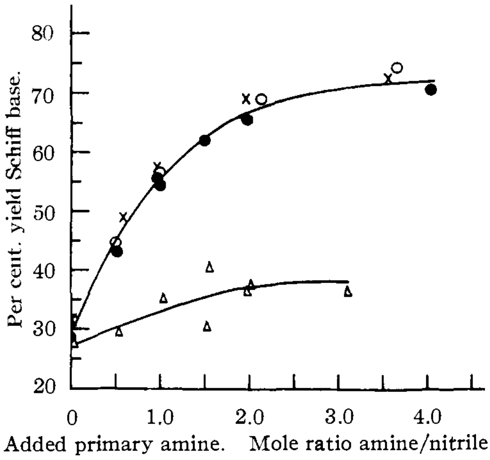


Fig. 2.—Aromatic nitriles hydrogenated in the presence of the corresponding primary amine; yield calculated assuming Schiff base to be the sole product: ●, benzonitrile; ○, anisonitrile; ×, *p*-tolunitrile; △, *o*-tolunitrile.

one of the two possible mixed Schiff bases, benzal-(*p*-methoxybenzyl)-amine, was formed together with anisal-(*p*-methoxybenzyl)-amine.

Hydro-amides.—Attempts to isolate hydrobenzamide by reducing benzonitrile with an insufficient amount of hydrogen to complete the reaction were unsuccessful, the secondary products being the same as those obtained from normal hydrogenation. However, some conclusions as to the probability of the hydro-amide being an intermediate in the Schiff base formation can be made from a study of the results obtained on hydrogenating the hydro-amide under conditions similar to those used with the nitrile, which are summarized in Table I.

TABLE I

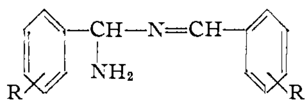
HYDROGENATION OF HYDRO-AMIDES IN AMINE SOLUTION OVER W-4a CATALYST

Run	Mole ratio of added ammonia to hydro-amide	Mole ratios of secondary products to hydro-amide: Schiff base	Sym. sec. amine	Mixed sec. amine
		Hydrobenzamide		
Benzylamine soln.				
1	. .	0.94	0.24	. .
2	0.9	.97	.12	. .
Amylamine soln.				
3	. .	.90	.09	0.26
4	. .	.92	.06	.29
5	1.0	.82	.06	.12
6	1.6	.73	.08	.07
		Hydroanisamide		
Amylamine soln.				
7	. .	1.32	0.05	0.08
8	1.2	0.65	.09	.06

There are two possible mechanisms which can explain the formation of a Schiff base from the hydro-amide: (1) reduction of a double bond followed by hydrogenolysis of the —C—NH— bond to form a molecule of Schiff base and one of primary amine, or (2) hydrogenolysis of a —C—N= bond to imine and Schiff base, with the imine undergoing self-condensation and reduction to form more Schiff base. Results from run 7 show that mechanism 2 must be predominant to account for the formation of 1.3 moles of Schiff base per mole of hydroanisamide. Since some of the secondary amine formed undoubtedly comes from the reduction of Schiff base, it is likely that reduction according to mechanism 2 also occurs in runs 1 and 2 with mechanism 1 being predominant. Addition of ammonia to the reaction mixture leads to a decrease in yield of Schiff base and a corresponding increase in yield of primary amine. This may be explained by the reaction of the hydro-amide with ammonia[10] to form imine, with reduction of the imine rather than condensation being favored by the ammonia.

In contrast to the behavior of aromatic nitriles, reduction of the hydro-amide in amylamine solution does lead to the formation of mixed secondary amines (runs 3–8, Table I). With no ammonia added, the yield is higher than for aliphatic nitriles (Fig. 1) and even with more than one mole of ammonia added per mole of hydro-amide, appreciable amounts are still obtained.

The failure of mixed Schiff bases to form from the added primary amine during the hydrogenation of aromatic nitriles suggests that the production of secondary products may be ascribed to intermediates formed solely from the imine, which would eliminate the von Braun reactions as a possible mechanism. The differences in behavior between the aromatic nitriles and hydro-amides on reduction indicate that the intermediate formation of the hydro-amide[5] is likewise not probable. The secondary products formed may be explained if one assumes the intermediate formation of a dimer of the imine I, followed by hydrogenolysis of the amino group to form the Schiff base.



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[10] H. H. Strain, THIS JOURNAL, 49, 1558 (1927).

The role of the primary amine appears to be one of catalyst deactivation. Its presence inhibits further hydrogenation of the imine so that condensation can occur, and also inhibits reduction of the Schiff base. The difference in behavior between aromatic and aliphatic nitriles may lie in the influence of the benzene ring which promotes condensation of the imine but decreases its tendency to add primary amine. With aliphatic nitriles, addition of the primary amine to the imine, followed by hydrogenolysis of the amino group produce secondary amines so that products of the Schiff base type are not formed.

Experimental[11]

Nitriles.—The nitriles were from Distillation Products Co. and were redistilled.

Hydrobenzamide.—The Distillation Products Co. product was recrystallized from cyclohexane-benzene solution and stored *in vacuo* over phosphorus pentoxide; m.p. 101–2°.

Hydroanisamide.—A mixture of 25 g. of anisaldehyde, 100 ml. of 28% ammonia, 1 g. of ammonium chloride and 45 ml. of 95% ethanol was shaken 6 hours in a pressure bottle. The product was filtered, dried, and recrystallized twice from methanol. The product was stored *in vacuo* over phosphorus pentoxide; m.p. 124–126° (125–127°).[12]

Primary Amines.—The primary amines used in these experiments were obtained from the reduction of the corresponding nitriles and were fractionally distilled through a modified Widmer column before use.

Catalysts.—Catalyst W-4 was prepared using the method of Adkins and Pavlic[9] starting with 200-g. portions of the alloy. The catalyst was washed in a 1-l. graduate with 40 l. of distilled water, washed by centrifugation at 3000 r.p.m. four times with reagent methanol and stored in the refrigerator under methanol.

To convert W-4 catalyst to the W-4a modification, after the final methanol wash the catalyst was allowed to stand under reagent at room temperature, in the dark, with occasional stirring, for one week or until it had the desired activity. It was then washed twice by centrifugation with methanol and stored in the refrigerator under methanol.

Hydrogenation Apparatus.—The hydrogenations were carried out in a Pyrex glass liner of 160-ml. capacity in a 300-ml. void Aminco high-pressure reaction vessel.

Hydrogenations.—The nitrile, together with the amine and solvent, if desired, was placed in the liner with the appropriate amount of catalyst and the stopper, greased lightly with Celloseal, placed in position. The liner was placed in the reaction vessel, hydrogen added, and the vessel heated, with rocking, to the desired temperature over a period of 15–20 minutes. The vessel was agitated until the pressure stopped dropping and then for an additional 10–15 minutes. After cooling and venting, the contents of the liner was filtered through a 3-mm. deep layer of Filter-cel supported on a sintered glass funnel. The liner and funnel were washed several times with ether and the combined filtrate and washings transferred to a 125-ml. flask and subjected to fractional distillation. Products distilling up to 236° (82° (0.5 mm.)) were distilled through a modified Widmer column with 6.5 in. spiral and equipped with a vacuum jacket. Supplementary heating of the column was supplied, when necessary, by means of a heating tape. High-boiling residues were transferred to a 25-ml. distilling flask having one inch of Vigreux indentations in the neck and distilled *in vacuo* using a silicone heating bath. The nitriles and amines were chosen so that the distilling apparatus would give effective separations except when diamylamine was present mixed with benzyl-, *o*-methylbenzyl-, *p*-methylbenzyl-, or β-phenethylamine, in which cases the amount of diamylamine present was estimated by analysis of the mixed hydrochlorides.

High boiling residues left after distillation amounted to 2–5% of the starting nitrile, except for α-tolunitrile where they were somewhat higher. Data from runs where the residue was more than 10% were not used. Since the primary amine added was frequently more than that obtained from the nitrile, it was not possible to determine the yield, but in general loss of amines boiling higher than amylamine did not amount to more than 3–5% based on the starting nitrile and amine.

Catalyst Ratios.—Reactions became sluggish and incomplete when the catalyst ratio was diminished beyond a certain point. Enough catalyst was used in each case to give a clear reaction. This amounted to 10–15% in the case of aromatic nitriles and 15–25% for aliphatic nitriles with about 1.5 g. of catalyst being the minimum amount used. Excess catalyst also was avoided because of the strong adsorption of amines on the catalyst with consequent loss of material.

The deactivating influence of the primary amine on the catalyst was shown by shaking Schiff base in amyl- or benzylamine solution over W-4a catalyst under normal hydrogenating conditions. Only about 4% of it was reduced in 0.5 hour, while in methanol solution, all of it was reduced to secondary amine.

Temperatures.—The temperature range selected for a reaction was the lowest compatible with rapid and complete hydrogenation. The yield of secondary products from aromatic nitriles tended to drop if too high temperatures were used. Less difference was noted with aliphatic nitriles. With W-4a catalyst, temperatures of 50–65° were used for aromatic nitriles and 65–85° for aliphatic nitriles. Temperatures ran about 10° lower for W-4 catalyst and were about 80–90° for commercially prepared catalyst. Valeronitrile was reduced at 120° by W-1 catalyst.

Analysis of Products.—The amines were converted to hydrochlorides by dissolving 1 ml. of the fraction in a mixture of 70 ml. of reagent ether with 20 ml. of U.S.P. ether added to help coagulate the precipitate formed. Dry hydrogen chloride was passed through the solution until it was saturated and the mixture was allowed to stand overnight. The mixture was then filtered and the precipitate washed with reagent ether and air-dried 24 hours before analysis.

The Schiff base-secondary amine mixture obtained from the aromatic nitriles was converted to amine hydrochlorides by acid hydrolysis. A 1–2-g. sample of product was placed in a 300-ml. boiling flask with 24/40 joint. A solution of 2 ml. of concentrated hydrochloric acid in 40 ml. of water was added and the mixture distilled until the volume of residue reached 10 ml. The aldehyde could be recovered, if desired, by ether extraction of the distillate. The flask was then placed in a water-bath and most of the remaining water removed by vacuum evaporation. The flask then was placed in a vacuum desiccator over phosphorus pentoxide overnight. The amine hydrochloride was removed from the flask and allowed to stand 24 hours before analysis.

The amine hydrochlorides were analyzed for chloride using the modification of Caldwell and Moyer[13] of the Volhard method. Since care was exercised to avoid the presence of more than two different amines in any fraction, the results could be used to estimate the composition of the mixture. A determination run on a Schiff base containing 2.3% of secondary amine gave an answer of 1.9% using the above method indicating that it is sufficiently accurate for the purpose.

1. **Amylbenzylamine. Secondary Products.**—This compound was formed when valeronitrile was hydrogenated in the presence of benzylamine. It formed a hydrochloride which, after recrystallization from 20% hydrochloric acid, melted at 239–241° (vac.).

Anal. Calcd. for $C_{12}H_{20}NCl$: Cl, 16.62. Found: Cl, 16.51, 16.54.

The amine, regenerated from the hydrochloride, distilled at 83–84° (0.9 mm.), $n^{20}D$ 1.4987.

Anal. Calcd. for $C_{12}H_{19}N$: C, 81.36; H, 10.73. Found: C, 81.21; H, 10.75.

2. **Amyl-(*p*-methylbenzyl)-amine.**—This compound was formed when valeronitrile was hydrogenated in the presence of *p*-methylbenzylamine. It formed a hydrochloride which, after recrystallization from 20% hydrochloric acid, melted at 237–238.5° (vac.).

Anal. Calcd. for $C_{13}H_{22}NCl$: Cl, 15.60. Found: Cl, 15.57, 15.57.

The amine, regenerated from the hydrochloride, distilled at 78–79° (0.4 mm.), $n^{20}D$ 1.4981.

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[11] All melting points in this paper are uncorrected.

[12] Cahours, *Ann.*, **56**, 309 (1845).

[13] J. P. Caldwell and H. V. Moyer, *Ind. Eng. Chem., Anal. Ed.*, **7**, 38 (1935).

Anal. Calcd. for $C_{13}H_{21}N$: C, 81.68; H, 10.99. Found: C, 81.75; H, 11.06.

3. **Amyl-(*o*-methylbenzyl)-amine.**—This compound was formed when valeronitrile was hydrogenated in the presence of *o*-methylbenzylamine. It formed a hydrochloride which, after recrystallizing from 20% hydrochloric acid, melted at 175–176.3° (vac.).

Anal. Calcd. for $C_{13}H_{22}NCl$: Cl, 15.60. Found: Cl, 15.61, 15.68.

The amine, regenerated from the hydrochloride, distilled at 80–82° (0.4 mm.), n^{20}D 1.5027.

4. **Amyl-(*p*-methoxybenzyl)-amine.**—This compound was formed when valeronitrile was hydrogenated in the presence of anisamine. It formed a hydrochloride which, after recrystallizing from 20% hydrochloric acid, melted at 221–223.5° (vac.).

Anal. Calcd. for $C_{13}H_{22}NOCl$: Cl, 14.58. Found: Cl, 14.65, 14.61.

The amine, regenerated from the hydrochloride, distilled at 119–122° (0.4 mm.), n^{20}D 1.5071.

Anal. Calcd. for $C_{13}H_{21}NO$: C, 75.36; H, 10.14. Found: C, 75.34; H, 10.19.

5. **Amyl-β-phenethylamine.**—This compound was formed when valeronitrile was hydrogenated in the presence of β-phenethylamine and when α-tolunitrile was hydrogenated in the presence of amylamine. It formed a hydrochloride which, after recrystallizing from 20% hydrochloric acid, melted at 269–272° (vac.).

Anal. Calcd. for $C_{13}H_{22}NCl$: Cl, 15.60. Found: Cl, 15.55, 15.57.

The amine, regenerated from the hydrochloride distilled at 94–95° (0.9 mm.), n^{20}D 1.4969.

Anal. Calcd. for $C_{13}H_{21}N$: C, 81.68; H, 10.99. Found: C, 81.62; H, 10.91.

6. **Di-β-phenethylamine.**—This compound was formed when α-tolunitrile was hydrogenated. It formed a hydrochloride which, after recrystallizing from 20% hydrochloric acid, melted at 264–267° (vac.) (265°[14]). The amine, regenerated from the hydrochloride, distilled at 118–120° (0.4 mm.), n^{20}D 1.5591.

7. **Benzalbenzylamine.**—A solution of 5.0 g. of benzaldehyde and 5.1 g. of benzylamine in 30 ml. of toluene was refluxed for two hours using a separator to remove the water formed. The solution was then evaporated and distilled *in vacuo*. A yield of 8.8 g. (96%) of material distilling at 116–117° (0.1 mm.), n^{20}D 1.6017, was obtained, $\lambda_{\max}^{\text{alc}}$ 248.5 mμ (*E* 20,000). This compound is reported as distilling at 205° (20 mm.).[15]

The secondary product obtained from the hydrogenation of benzonitrile distilled at about the same temperature. Analysis of the amine hydrochlorides obtained after hydrolysis indicated that runs with W-4a catalyst contained 4–10% dibenzylamine; with W-4 catalyst, 18–52%; $\lambda_{\max}^{\text{alc}}$ 248.5 mμ (*E* 16,700).

8. **Dibenzylamine.**—A solution of 5 g. of the crude benzalbenzylamine in 20 ml. of ethanol was hydrogenated at atmospheric pressure over 0.5 g. of 30% palladium–charcoal catalyst. One mole of hydrogen was absorbed in 55 minutes. The product, recovered in almost quantitative yield, distilled at 113–114° (0.1 mm.), n^{20}D 1.5737 (268–271° (250 mm.)).[16]

9. ***p*,*p*′-Dimethylbenzalbenzylamine.**—This compound was made by the same method used to prepare benzalbenzylamine. A 90% yield of material distilling at 147–149° (0.1 mm.) was obtained. On recrystallizing from methanol the product melted at 83–84°, $\lambda_{\max}^{\text{alc}}$ 256 mμ (*E* 21,640).

Anal. Calcd. for $C_{16}H_{17}N$: C, 86.10; H, 7.62. Found: C, 86.15; H, 7.82.

The secondary product obtained from the hydrogenation of *p*-tolunitrile distilled at about the same temperature and melted at 80–83°. Analysis of the amine hydrochloride obtained after hydrolysis indicated that the purest samples contained about 6% of di-*p*-methylbenzylamine, $\lambda_{\max}^{\text{alc}}$ 256 mμ (*E* 21,200).

The above hydrogenation product (12.0 g.) was hydrolyzed by heating with 15 ml. of concentrated hydrochloric acid and 25 ml. of water, in a 500-ml. 3-necked flask equipped with stirrer and still head, until 100 ml. of distillate was collected. The distillate was saturated with salt, extracted twice with ligroin and the combined extracts evaporated and distilled *in vacuo*. A yield of 5.5 g. (89%) of *p*-tolualdehyde distilling at 85–86° (13 mm.) was obtained, n^{20}D 1.5460 ($n^{16.6}$D 1.5469).[17] After removal of the aldehyde, the solution was distilled further to a volume of 50 ml. and then evaporated *in vacuo* almost to dryness. The residue was treated with excess 40% potassium hydroxide solution and extracted with ether. The ether extract was dried, evaporated and distilled *in vacuo* to give a yield of 5.1 g. (82%) of *p*-methylbenzylamine and 0.5 g. of di-*p*-methylbenzylamine identical with that made by reduction of the Schiff base; melting point and mixed melting point of the hydrochloride was 274–278° (vac.).

10. **Di-*p*-methylbenzylamine.**—This compound was prepared by reducing the crude Schiff base as described for dibenzylamine. The rate of hydrogen uptake slowed after the absorption of one mole of hydrogen in 45 minutes. The mixture was filtered and the filtrate evaporated and distilled *in vacuo*. A 95% yield of product distilling at 135–137° (0.1 mm.) was obtained. On recrystallizing from cyclohexane the product melted at 34.5–36.5°. It formed a hydrochloride melting at 276.5–278.8° (vac.) (272°).[18]

Anal. Calcd. for $C_{16}H_{20}NCl$: Cl, 13.57. Found: Cl, 13.47, 13.46.

11. ***o*,*o*′-Dimethylbenzalbenzylamine.**—This compound was made by the same method used for benzalbenzylamine. A 91% yield of material distilling at 133–134° (0.1 mm.), n^{20}D 1.5948, was obtained, $\lambda_{\max}^{\text{alc}}$ 251 mμ (*E* 16,200).

Anal. Calcd. for $C_{16}H_{17}N$: C, 86.10; H, 7.62. Found C, 86.02; H, 7.85.

The secondary product obtained from the hydrogenation of *o*-tolunitrile distilled at about the same temperature. Analysis of the amine hydrochloride obtained after hydrolysis indicated that runs with W-4a catalyst contained 4–8% of di-*o*-methylbenzylamine, $\lambda_{\max}^{\text{alc}}$ 251 mμ (*E* 14,500).

A mixture of 16.2 g. of the above secondary product, 15 ml. of concentrated hydrochloric acid and 250 ml. of water was heated using the method outlined for the *para* isomer. A yield of 6.6 g. (86%) of *o*-tolualdehyde distilling at 83–85° (11 mm.) was obtained, n^{20}D 1.5483 (n^{19}D 1.5485).[17] A yield of 7.2 g. (92%) of *o*-methylbenzylamine and 1.8 g. of di-*o*-methylbenzylamine, n^{20}D 1.5692, was obtained.

12. **Di-*o*-methylbenzylamine.**—This compound was prepared by reducing the crude Schiff base as described for dibenzylamine, but using W-4 catalyst. One mole of hydrogen was absorbed in about 75 minutes. The reaction product was filtered and the filtrate evaporated and distilled *in vacuo*. A 93% yield of material distilling at 127–129° (0.1 mm.), n^{20}D 1.5689, was obtained. It formed a hydrochloride which, after recrystallizing from 20% hydrochloric acid, melted at 203–205° (vac.).

Anal. Calcd. for $C_{16}H_{19}N$: C 85.33; H, 8.44. Found: C, 85.28; H, 8.26. Calcd. for $C_{16}H_{20}NCl$: Cl, 13.57. Found: Cl, 13.70, 13.62.

13. **Anisal-(*p*-methoxybenzyl)-amine.**—This compound was made by the same method used to prepare benzalbenzylamine. An almost quantitative yield of material distilling at 173–175° (0.1 mm.) was obtained, m.p. 37–38°, $\lambda_{\max}^{\text{alc}}$ 271 mμ (*E* 22,600).

Anal. Calcd. for $C_{16}H_{17}NO_2$: C, 75.29; H, 6.67. Found: C, 75.10; H, 6.84.

The secondary product obtained from the hydrogenation of anisonitrile distilled at about the same temperature. Analysis of the amine hydrochloride obtained after hydrolysis indicated that runs with W-4a catalyst contained 3–10% dianisamine; with W-4 catalyst, 15–16%, $\lambda_{\max}^{\text{alc}}$ 271.5 mμ (*E* 22,600).

14. **Di-(*p*-methoxybenzyl)-amine.**—This compound was prepared by reducing the crude Schiff base as described for dibenzylamine. One mole of hydrogen was absorbed in about 45 minutes. The reaction mixture was filtered and the filtrate evaporated and distilled *in vacuo*. A 90% yield of material distilling at 161–163° (0.1 mm.) was obtained, m.p. 34–34° (34°).[19]

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[14] M. Fileti and A. Piccini, *Ber.*, **12**, 1308 (1879).

[15] Mason and Winder, *J. Chem. Soc.*, **65**, 191 (1894).

[16] W. H. Perkin, *ibid.*, **69**, 1208 (1896).

[17] K. v. Auwers, A. Boennecke, F. Krollpfeiffer and G. Peters, *Ann.*, **408**, 212 (1915).

[18] T. Curtius and Propfe, *J. prakt. Chem.*, [2] **62**, 100 (1900).

[19] O. Steinhart, *Ann.*, **241**, 333 (1887).

Hydrogenation of Hydro-amides.—The hydro-amides were hydrogenated under conditions similar to those used with aromatic nitriles. A solution of 7–12 g. of the hydroamide in 15–25 ml. of primary amine was shaken with 3–5 g. of W-4a catalyst at temperatures of 55–75° until hydrogen uptake ceased. When ammonia was added, the solution was first cooled in a Thermos containing Dry Ice and the liquid ammonia added. The liner was then placed in the reaction vessel which was closed as quickly as possible to avoid evaporational loss. The reaction mixture was worked up as previously outlined. The mixed secondary amine was isolated as a separate fraction. The high boiling product was identified as a mixture of Schiff base and corresponding secondary amine by methods previously outlined—acid hydrolysis and hydrogenation. The amount of secondary amine present in the fraction was estimated on the basis of refractive index. The Schiff base and secondary amine obtained from hydroanisamide are solids at room temperature but crystallize slowly enough for the refractive index to be determined.

Benzal-(*p*-methoxybenzyl)-amine.—A solution of 12.0 g. of anisonitrile, 9.2 g. of benzonitrile in 20.5 g. of benzylamine was shaken for 3 hours at 55–60° with 5 g. of W-4a catalyst under a pressure of 80 atmospheres of hydrogen. The pressure drop was 33 atmospheres. The reaction product was worked up using the method previously outlined. A yield of 25.5 g. of benzylamine and 1.2 g. of anisamine were obtained. From the high boiling fraction 2.6 g. of product distilling at 160–165° (0.1 mm.), $n^{20}\text{D}$ 1.5986, was obtained. On acid hydrolysis, benzaldehyde was the only product in the steam distillate. The amine hydrochloride residue had a chloride equivalent to 178.0 (173.5 for *p*-methoxybenzylamine) indicating that the product was mostly benzal-(methoxybenzyl)-amine with about 3% of the corresponding secondary amine present. When the amine hydrochloride residue was made alkaline and distilled no appreciable amount of benzylamine could be found. In addition to the above fraction, a 4.2-g. fraction was obtained distilling at 165–175° (0.1 mm.) which was a mixture of the above Schiff base with anisal-(*p*-methoxybenzyl)-amine and 4.6 g. of anisal-(*p*-methoxybenzyl)-amine.

When 8 g. of anisonitrile was hydrogenated in solution with 19.6 g. of benzylamine, only anisal-(*p*-methoxybenzyl)-amine was obtained as a secondary product.

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[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, PURDUE UNIVERSITY]

Conversion of the Lactone of *trans*-2-Hydroxycyclohexaneacetic Acid to its *cis* Isomer[1]

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trans-2-Hydroxycyclohexaneacetamide, prepared from the corresponding lactone, reacts with *p*-toluenesulfonyl chloride in pyridine to form a sulfonimido ether which can be hydrolyzed to the lactone of *cis*-2-hydroxycyclohexaneacetic acid. The course of these reactions is discussed.

In connection with other work it was desired to find a method for converting the lactone of *trans*-2-hydroxycyclohexaneacetic acid (II)[2,3] to its *cis* isomer with retention of configuration at one of the asymmetric carbon atoms.[4] It seemed likely that the tosylate of the *trans*-hydroxy acid I could yield the desired *cis*-lactone VII by displacement of tosylate by the carboxylate ion.[5] Attempts to carry out this process were, however, unfruitful, starting materials and the *trans* lactone being the only products which could be isolated.[6]

trans-2-Hydroxycyclohexaneacetamide (III) was prepared by reaction of the *trans* lactone with ammonia. Tosylation of this material in pyridine solution gave a compound, $C_{15}H_{19}O_3NS$, the structure of which is discussed below. This product furnished the *cis* lactone (VII) on saponification and treatment with acid. The two lactones have been characterized by infrared spectra, melting points and by preparation of the hydroxy amides and hydroxy-N-benzylamides. The *cis* lactone, in agreement with the findings of Newman and VanderWerf,[4] is much more resistant to ring-opening reactions than is the *trans* lactone[7]; it could not be converted to an isolable hydroxy acid. The infrared spectra of the two lactones are distinctly different. The carbonyl stretching absorption of the *cis* compound occurs at a higher wave length (5.70 μ) than does that of the *trans* compound (5.62 μ). Both values are consistent with the formulation of these substances as γ-lactones; the shift of this band is consistent with the greater reactivity of the *trans* compound.

Structure VI has been assigned to the intermediate tosylate on the basis of its composition, which shows that dehydration has accompanied the tosylation, and on the basis of its hydrolysis to the *cis*-lactone VII. The infrared spectrum shows that OH, NH, C≡N and C=O structural units are not present in this substance. Strong absorption bands at 7.40, 8.48 and 8.56 μ are consistent with the presence of either a sulfonamido or sulfonate linkage.

The reaction sequence III–VI is proposed to account for these results. The occurrence of inversion at the carbinol carbon atom in the formation of VI suggests that a tosylate IV is formed first; in-

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[1] Presented at the 126th Meeting of the American Chemical Society, New York, N. Y., Sept., 1954.

[2] Available by way of reaction of cyclohexene oxide with sodiomalonic ester; S. Coffey, *Rec. trav. chim.*, **42**, 387 (1923).

[3] The corresponding cyclopentane derivative, prepared by this method, has been shown unequivocally to have the *trans* structure; W. E. Grigsby, J. Hind, J. Chanley and F. H. Westheimer, THIS JOURNAL, **64**, 2606 (1942).

[4] The *cis*-lactone has been prepared by catalytic hydrogenation of the β,γ-unsaturated lactone derived from 2-ketocyclohexaneacetic acid; M. S. Newman and C. A. VanderWerf, *ibid.*, **67**, 233 (1945).

[5] Stereochemically identical displacements of tosylate have been noted previously; S. Winstein, *et al.*, *ibid.*, **70**, 828 (1948), and earlier papers; G. E. McCasland, R. K. Clark, Jr., and H. E. Carter, *ibid.*, **71**, 637 (1949); H. J. Lucas, F. W. Mitchell, Jr., and H. K. Garner, *ibid.*, **72**, 2138 (1950).

[6] Studies with other systems in this Laboratory indicate that the lactonization observed here may well have occurred under the influence of the toluenesulfonyl chloride rather than during the isolation of products; J. H. Brewster and C. J. Ciotti, unpublished work.

[7] This difference would not, at first sight, be expected if the cyclohexane ring has a chair structure. S. J. Angyal and J. A. Mills, *Rev. Pure Appl. Chem.* (*Australia*), **2**, 185 (1952), have pointed out that a cyclohexane ring with a *trans*-fused five-membered ring is twisted so that 1,3-interactions of axial hydrogen atoms are increased; these interactions are decreased when the five-membered ring is fused *cis*.