mole) of 4-phenyl-4-piperidinol (IV) and 100 g. (1.0 mole) of concentrated hydrochloric acid was stirred on a steam-bath for 2.5 hr., cooled, poured into 300 ml. of water, and made basic with excess 50% sodium hydroxide solution. The amine was taken up in toluene, dried, and distilled to give 40 g. (89%) of 4-phenyl-1,2,3,6-tetrahydropyridine (II), b.p. 97–106° (1.2 mm.).

Anal. Calcd. for $C_{11}H_{13}N$: C, 82.97; H, 8.23; N, 8.80. Found: C, 82.86; H, 8.40; N, 8.74.

The hydrochloride melted at 200–201° after recrystallization from acetone containing about 5% isopropyl alcohol. A mixed melting point with the hydrochloride of a sample of 4-phenyl-1,2,3,6-tetrahydropyridine (II) prepared directly from α-methylstyrene, formaldehyde and ammonium chloride melted at 200–201°.

Anal. Calcd. for $C_{11}H_{14}NCl$: C, 67.51; H, 7.21; N, 7.16; Cl, 18.1. Found: C, 67.55; H, 7.23; N, 7.18; Cl, 18.0.

4-Phenylpiperidine.—A mixture of 90 g. (0.57 mole) of 4-phenyl-1,2,3,6-tetrahydropyridine (II), 200 ml. of ethanol and 5 g. of 5% palladium on alumina catalyst was shaken for 8 hr. in an autoclave at 65–70° under a pressure of hydrogen of 1500 p.s.i. After cooling, the contents were filtered and the filtrate was distilled to give 50 g. (55%) of 4-phenylpiperidine, b.p. 85–88° (1.2 mm.). This crystallized and after recrystallization from heptane melted at 60–63°.

Anal. Calcd. for $C_{11}H_{15}N$: C, 81.93; H, 9.38; N, 8.69. Found: C, 81.83; H, 9.10; N, 8.65.

PHILADELPHIA, PENNSYLVANIA

[CONTRIBUTION FROM ORGANIC CHEMISTRY SECTION, BALLISTIC RESEARCH LABORATORIES]

Direct and Reverse Addition Reactions of Nitriles with Lithium Aluminum Hydride in Ether and in Tetrahydrofuran

BY LOUIS M. SOFFER AND MANFRED KATZ

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The reductions of nitriles in ether and in tetrahydrofuran at various hydride–nitrile ratios have been investigated, using both direct and reverse addition procedures. The various reduction products include primary amines, aldehydes, hydrogen, 1,3-diamines (resulting from dimerization) and other higher products. Reaction sequences are proposed for the major processes in both types of reaction. No evidence was obtained for the presence of a carbon–lithium bond in the final reduction complexes. The presence of a small amount of carbon–aluminum bond, however, was indicated for the final reduction species from phenylacetonitrile. A one-step preparation of aromatic anils, $RCH{=}NCH_2R$, from aromatic nitriles, $RC{\equiv}N$, is described.

It has been reported[1] recently that the direct addition[2] (DA) reductions of *n*-butyronitrile and of *n*-valeronitrile by lithium aluminum hydride in ether occurred with only small amounts of hydrogen evolved, whereas much more gas was evolved when the identical reactions were performed in tetrahydrofuran. We have since observed that RA reductions of these nitriles in both ether and tetrahydrofuran evolve considerable hydrogen.[3] Experiments with various types of nitriles have been performed in order to determine the source of the gas as well as obtain a better understanding of the reduction of nitriles by hydride.[4]

Results and Discussion

DA Reductions of Nitriles in Ether.—Previous studies[4] were essentially concerned with the major product and the over-all stoichiometry. On the latter subject the earlier proposal[3,4a] that 0.5 mole of hydride was sufficient for the reduction of one mole of nitrile has been questioned by Amundsen and Nelson. These authors concluded, from experiments on caprylonitrile and benzonitrile, that at least one mole of hydride was necessary for optimum reduction.

In Table I, runs 1, 2 and 4, are shown typical DA reductions at molar ratios of hydride to nitrile (MRHN) of one or higher in which little or no hydrogen was evolved, and in which high yields of primary amines were obtained. At a MRHN of 0.5, however, the yield of *n*-butylamine was only 39.7%, or about one-half the optimum. For benzonitrile, runs 4–6, lowering the MRHN resulted in the increasing formation of benzaldehyde, which was isolated in the form of the anil, N-benzalbenzylamine.[5] It can be seen from these data that about half of the available hydride hydrogen is found in the identified products, thus supporting Amundsen's view that only half of the hydride hydrogen is available for reduction of nitrile groups at 35°.

In accord with current ideas[4b,6] on the mechanism of hydride reactions the over-all process may be regarded as the formation of a primary aluminohydride ion capable of undergoing further reaction with another molecule of nitrile, producing a new species which is further reduced to the primary amine precursor. It will be noted that partial reduction, such as might result from an insufficient amount of hydride, yields aldehyde.

$$RCH_2C{\equiv}N + AlH_4^- \longrightarrow R{-}CH_2CH{=}NAlH_3^-$$

$$RCH_2C{\equiv}N + R{-}CH_2CH{=}NAlH_3^- \longrightarrow (RCH_2CH{=}N)_2AlH_2^-$$

$$(RCH_2CH{=}N)_2AlH_2^- + AlH_4^- \longrightarrow 2RCH_2CH_2NAlH_2^-$$

Of the nitriles studied at 1.1 MRHN, phenylacetonitrile (run 7) yielded considerably more gas and less primary amine. Concomitantly, there was a larger amount of higher products, among which was identified 2,4-diphenyl-1,3-butanediamine. Ex-

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[1] L. M. Soffer and E. W. Parrotta, THIS JOURNAL, **76**, 3580 (1954); R. F. Nystrom, *ibid.*, **77**, 2544 (1955).

[2] Direct addition means that the nitrile was added to the hydride solution; reverse addition (RA) is the opposite procedure.

[3] H. E. Zaugg and B. W. Horrom, *Anal. Chem.*, **20**, 1026 (1948), observed the evolution of hydrogen in RA reactions of diphenylacetonitrile.

[4] For previous studies see the preceding references, and the following: (a) R. F. Nystrom and W. G. Brown, THIS JOURNAL, **70**, 3738 (1949); (b) W. G. Brown, "Organic Reactions," R. Adams, ed., Vol. 6, John Wiley and Sons, Inc., New York, N. Y.; (c) L. H. Amundsen and L. S. Nelson, THIS JOURNAL, **73**, 243 (1951).

[5] The fair yield of N-benzalbenzylamine suggests the possibility of an easy, general preparation of aromatic anils, $RCH{=}NCH_2R$, from aromatic nitriles, $RC{\equiv}N$.

[6] H. R. Snyder and R. E. Putnam, THIS JOURNAL, **76**, 1893 (1954).

TABLE I

LITHIUM ALUMINUM HYDRIDE REDUCTIONS OF NITRILES IN ETHER (34°)

Run	Nitrile	Method	Moles hydride per mole nitrile (MRHN)	Mole % hydrogen	Primary amine % yield	Higher product[a]	Yield, %	Total recov. of identified prod., %
1	*n*-Butyro	DA	1.8	3	78.5[b]	Residue		78.5
2	*n*-Butyro	DA	1.1	8.8	77.0	Residue		77.0
3	*n*-Butyro	DA	0.5	8.2	39.7	Residue		39.7
4	Benzo	DA	1.1	Trace	85.9[c]			85.9
5	Benzo	DA	0.78	Trace	58.3	N-Benzalbenzylamine[d]	29.6	87.9
6	Benzo	DA	0.5	Trace	0	N-Benzalbenzylamine	58.5	68.3[e]
7	Phenylaceto	DA	1.1	61.4	41.0[f]	2,4-Diphenyl-1,3-butanediamine[g]		41.0
8	*n*-Butyro	RA	1.1	34.7	33.5	2-Ethyl-1,3-hexanediamine[h]	25.8	59.3
9	*n*-Butyro	RA	0.8	18.6	39.0	2-Ethyl-1,3-hexanediamine	26.0	65.0
10	*n*-Butyro	RA	.5	12.3	33.8			33.8
11	*n*-Butyro	RA	.28	14.3	0[i]	[j]		29.0
12	*n*-Capro	RA	1.1	32.5	33.6[k]	2-Butyl-1,3-octanediamine[l]	26.9	60.5
13	*n*-Capro	RA	0.5	15.0	24.4	Anil(s?) of 2-butyl-1,3-octanediamine and *n*-hexanal[m]		24.4
14	*o*-Tolu	RA	1.1	Trace	83.6[n]			83.6
15	*o*-Tolu	RA	0.5	Trace	20.6	N-(*o*-Methylbenzal)-*o*-methylbenzylamine[o]	35.5	59.5[p]
16	Benzo	RA	1.1	Trace	67.4	Residue		67.4

[a] Unless otherwise specified, physical constants are for non-redistilled fractions. [b] B.p. and refractive index agreed with accepted values; m.p. of hydrochloride, 205–209° (sealed tube); I. Heilbron, "Dictionary of Organic Compounds," Oxford University Press, N. Y., 1953, reports 195°; m.p. of 3,5-dinitrobenzamide derivative, 104.5°; lit., none. *Anal.* Calcd. for $C_{11}H_{13}O_5N_3$: N, 15.72. Found: N, 15.75. [c] B.p. 89–90° (29 mm.), 46° (2.5 mm.), n^{20}D 1.5424, n^{25}D 1.5403; picrate m.p., 194–196° dec.; hydrochloride, m.p. 247–249°. Heilbron gives for benzylamine, b.p. 90° (12 mm.), n^{20}D 1.5401; picrate, 194°; hydrochloride, 248°. [d] B.p. redistilled material, 124–126° (1.5 mm.), $n^{23.5}$D 1.5923; G. Mignonac, *Ann. chim.*, [11], **2**, 225 (1934), reports b.p. 142–143° (4 mm.), $n^{17.5}$D 1.6011. Hydrolysis gave benzylamine hydrochloride (m.p. 240–245°; Heilbron, 248°) and benzaldehyde (m.p. 2,4-dinitrophenylhydrazone, 235–236°; Heilbron, 237°). [e] 9.8% benzonitrile was recovered; residue contained a crystalline material, m.p. 228–230°; A. Lottermoser, *J. prakt. Chem.*, **54**, 113 (1896), gives 228° for m.p. of 2,4,6-triphenyl-1,3,5-triazine. [f] B.p. 98° (29 m.m), n^{25}D 1.5299; m.p. benzamide, 116°; m.p. picrate, 166°; Heilbron reports b.p. 197–198°; benzamide, 116°; picrate, 167°. The refractive index, 1.575, given in the "Handbook of Chemistry and Physics," 36th edn., 1955, is erroneous. [g] Enough product for physical constants and derivatives only; b.p. 130° (1 mm.), n^{25}D 1.5812. Dihydrochloride shrinks, but does not melt when m.p. capillary is inserted at 280°; H. Adkins and G. M. Whitman, THIS JOURNAL, **64**, 150 (1942), report b.p. 166–168° (1 mm.), n^{25}D 1.5803; m.p. hydrochloride, over 280°. M.p. of diacetyl derivative, 232–233°, mixed m.p. with an authentic sample of N,N′-diacetyl-2,4-diphenyl-1,3-butanediamine (m.p. 232–233°, see Experimental), no depression. [h] B.p. 78–84° (4 mm.), n^{25}D 1.4541; m.p. dihydrochloride, 158°; m.p. dibenzamide, 162–163°. Adkins and Whitman report b.p. 99° (17 mm.), n^{25}D 1.4554; dihydrochloride, 153–165°. *Anal.* Calcd. for $C_{22}H_{28}O_2N_2$: N, 7.96. Found: N, 7.97. [i] *n*-Butyronitrile recovered, 29%. [j] See Experimental, under reduction of nitriles. [k] B.p. 50° (33 mm.), n^{20}D 1.4224; m.p. chloroplatinate, 236–240° dec.; m.p. picrate, 124°; m.p. *p*-nitrobenzamide, 84–85°. *Anal.* Calcd. for $C_{11}H_{14}O_3N_2$: N, 11.19. Found: N, 10.97; Heilbron gives b.p. 129–130° (742 mm.); chloroplatinate, 236–238°; D. W. Adamson and J. Kenner, *J. Chem. Soc.*, 838 (1934), report m.p. picrate, 126.5°. [l] B.p. 104–114° (2 mm.), n^{17}D 1.4553; m.p. of N,N′-diacetyl-2-butyl-1,3-octanediamine, 132–133°; lit., none. Analysis in Experimental. [m] Hydrolysis yielded *n*-hexanal (m.p. of 2,4-dinitrophenylhydrazone, 107°; Heilbron, 107°) and 2-butyl-1,3-octanediamine, isolated as the diacetyl derivative (m.p. 132–133°, no depression upon admixture with authentic sample. There was also obtained an unidentified 2,4-dinitrophenylhydrazone, m.p. 119–120°. [n] B.p. 48° (1 mm.), n^{27}D 1.5399; m.p. hydrochloride, 220–221.5°; m.p. N-acetyl-*o*-methylbenzylamine, 77.5–78°; m.p. N-benzoyl-*o*-methylbenzylamine, 115–116°; Heilbron reports n^{19}D 1.5436; hydrochloride, 219–220°; benzamide, 88°. *Anal.* Calcd. for $C_{15}H_{15}ON$: C, 79.97; H, 6.66; N, 6.21. Found: C, 79.37; H, 6.51; N, 6.24. W. H. Carothers and G. A. Jones, THIS JOURNAL, **47**, 3051 (1925), report m.p. N-acetyl-*o*-methylbenzylamine 75–76°. [o] B.p. redistilled material 144° (1 mm.), n^{25}D 1.5878; lit., none. *Anal.* Calcd. for $C_{16}H_{17}N$: C, 86.05; H, 7.68; N, 6.27. Found: C, 86.33; H, 7.57; N, 6.25. Hydrolysis gave *o*-methylbenzylamine hydrochloride (m.p. 219–220°) and *o*-tolualdehyde (m.p. of 2,4-dinitrophenylhydrazone, 193–194°; Heilbron, same). Both showed undepressed m.p. when mixed with authentic samples. [p] 3.4% *o*-tolunitrile recovered.

planation of these results will be deferred until the following section.

RA Reductions of Nitriles in Ether.—As seen in runs 8–13, considerable amounts of hydrogen were evolved during the reductions of *n*-butyronitrile and *n*-capronitrile. The yields of primary amine were much lower than in analogous DA reductions, and the yields of other products higher. In these respects runs 8–13 resemble run 7. At the low MRHN of 0.28 (run 11) no *n*-butylamine was isolated and 29% of the original nitrile was recovered.[7]

With regard to the production of hydrogen it is to be noted that (1) significant amounts of gas were obtained only when the nitrile being reduced contained α-hydrogen and (2) the quantities of gas were dependent on the relative amounts of hydride present. Zaugg and Horrom[3] recognized the evolution of hydrogen during the RA reduction of diphenylacetonitrile as the reaction of the nitrile's active α-H with some hydride species. Hauser and Humphlett[8] have observed the formation of hydrocarbons and an intermediate Grignard complex from the reactions of nitriles and Grignard reagents. By analogy, hydride might be expected to

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(7) The other products were not completely identified. It was noted that *n*-butyraldehyde was obtained when these materials were warmed with dilute hydrochloric acid (Experimental). High yields of aldehydes are obtained in RA reduction at −70–0°; L. Friedman, Abstracts, 116th Meeting, A.C.S., New York, Sept., 1949, p. 5M.

(8) C. R. Hauser and W. J. Humphlett, *J. Org. Chem.*, **15**, 359 (1950).

react with nitriles to produce hydrogen and an intermediate species of the type R—$\underline{\text{C}}$H—C≡NAlH$_3$ (or a reduced version R—$\underline{\text{C}}$H—CH=NAlH$_2$). Further reaction of this intermediate with fresh nitrile could produce, after hydrolysis, substituted 1,3-diamines.[9]

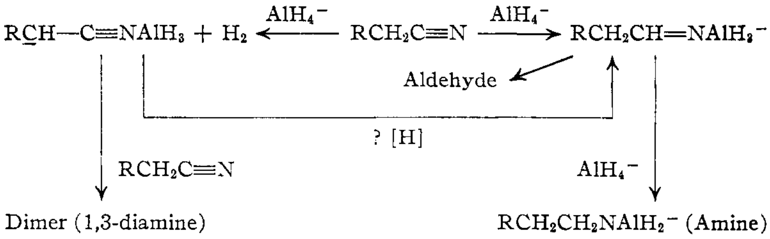
As shown in Table I, 1,3-diamines were found in runs 8, 9 and 12, and in the DA reduction of phenylacetonitrile (run 7).[10] The identities of these materials were established by comparison with the literature or by independent synthesis.

Lowering the MRHN to 0.8 decreased the gas evolved, but the yield of identified products remained unchanged. At 0.5 MRHN (runs 10 and 13) still less gas was obtained, but the major difference was in the higher products. Apparently these were in most part anil derivatives of the 1,3-diamine, because both the aldehyde and the diamine were readily isolated by acid hydrolysis (see Experimental). Anils resulted because of the greater concentration of aldehydes, which in turn were the result of RA reduction at low MRHN.[11]

In runs 14–16 essentially no gas was evolved, thus providing further support for the hydrogen-producing mechanism proposed above. Otherwise, the results are similar to those obtained in DA reduction, which suggests that similar processes are involved.[12]

Whereas a twofold increase in MRHN resulted in relatively minor differences in the yield of primary amine and higher products (runs 8–10), there was a threefold increase in the amount of gas produced. This can be explained by assuming that not all of the gas, particularly at higher MRHN, arises from abstraction on unreacted nitrile. A portion may be produced by the action of hydride on —CH$_2$—$\dot{\text{C}}$≡N groups in the dimeric and higher intermediate species. Such an abstraction (or enolization reaction) may well occur at a relatively low rate and therefore be pronounced only when sufficient hydride is present. Some evidence for this explanation may lie in the numerous observations of a slow but considerable evolution of gas after the hydride was added, lasting for several hours.

Thus, the major processes occurring in RA reduction of α-H nitriles may be summarized as[13]

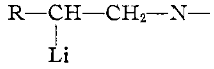


The differences in the courses taken by DA and RA reductions may be attributed to differences in (1) reaction environment and (2) solubility of reaction complexes, which was, of course, intimately related to environment. In DA runs the addition of nitrile to excess hydride in ether caused (except with phenylacetonitrile) the immediate precipitation of complex, whereas in RA runs the solutions remained relatively clear until a MRHN of 0.15–0.20 for n-butyronitrile and of 1.0 for n-capronitrile had been reached. Excess nitrile, besides favoring reactions of intermediates with nitrile, provided a considerably more polar environment; this, too, must have affected reactivities and solubilities of the intermediate species.

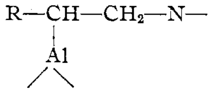
DA and RA Reductions of Nitriles in Tetrahydrofuran.—In general these reductions were quite similar in nature, differing only, as might be expected, in that DA runs afforded somewhat higher yields of primary amines and RA runs higher yields of the 1,3-diamines (Table II). The resemblance of both reductions to that of RA runs in ether suggests the same processes are involved. If the RA-ether reaction scheme is applied to DA reduction in tetrahydrofuran it must be concluded that the over-all influence of tetrahydrofuran as solvent[14,15] is greater than is the influence of an excess of hydride.

For highest yields of primary amines, DA reductions of aliphatic nitriles in tetrahydrofuran were distinctly inferior to their counterparts in ether. For benzonitrile, the yield of primary amine obtained in DA–tetrahydrofuran runs was comparable to that from DA–ether runs.

Structure of Reaction Complexes.—It was interesting to speculate on the presence, in the final reaction products, of species containing either a carbon–lithium bond or a carbon–aluminum bond.



$$\underset{\text{Li}}{\text{R—}\underset{|}{\text{CH}}\text{—CH}_2\text{—N—}}$$



$$\text{R—}\underset{\text{Al}}{\underset{|}{\text{CH}}}\text{—CH}_2\text{—N—}$$

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[9] Nitrile dimerizations induced by Grignard reagents and by alkali metals are well known. For leading references, see C. F. H. Allen in "Organic Chemistry, An Advanced Treatise," H. Gilman, ed., Vol. 1, 2nd ed., John Wiley and Sons, Inc., New York, N. Y., 1945, p. 661; Adkins and Whitman, Table I, ref. *g;* S. R. Best and J. F. Thorpe, *J. Chem. Soc.*, **95**, 685 (1909). H. R. Snyder and R. E. Putnam, THIS JOURNAL, **76**, 33 (1954), have found that analogous products were obtained when N,N'-disubstituted α,β-unsaturated amides were subjected to RA reduction with hydride.

[10] Some evidence was obtained for the formation, at low MRHN, of another type of dimer, an α-alkyl-β-aminonitrile; see discussion of run 11 in Experimental.

[11] Some of the unidentified portions of the higher products, particularly at 0.8 and lower MRNH, may be the result of aldehyde–amine reactions; see M. M. Sprung, *Chem. Revs.*, **26**, 297 (1940); W. S. Emerson, S. F. Hess and F. C. Uhle, THIS JOURNAL, **63**, 872 (1941).

[12] Besides by-products arising from aldehyde–amine reactions there were undoubtedly others similar to those known to result from the action of Grignard reagents and of alkali metals on all types of nitriles. For leading references see ref. 8, and the following: F. W. Swamer, G. A. Reynolds and C. R. Hauser, *J. Org. Chem.*, **16**, 43 (1951); R. M. Anker and A. H. Cook, *J. Chem. Soc.*, 323 (1951).

[13] From the results of DA reduction of phenylacetonitrile (run 7) it may be inferred that this RA scheme applies, given a sufficiently active α-H, no matter what the manner of addition.

[14] An approximate value of 7.18 (25°) for the dielectric constant of tetrahydrofuran was calculated from the data of C. P. Smyth and W. S. Walls, THIS JOURNAL, **54**, 3230 (1932). The dielectric constant of ether is 4.33 (20°) (A. E. Remick, "Electronic Interpretations of Organic Chemistry," John Wiley and Sons, Inc., New York, N. Y., 1943, p. 331).

[15] For DA reductions in tetrahydrofuran, precipitation began after the addition, to one mole of hydride, of 0.15–0.20 mole of n-butyronitrile or 0.25 mole of n-capronitrile. In RA reductions there was little complex visible until a MRHN of about 0.5 had been reached for both nitriles.

TABLE II

LITHIUM ALUMINUM HYDRIDE REDUCTIONS OF NITRILES IN TETRAHYDROFURAN (30–35°)

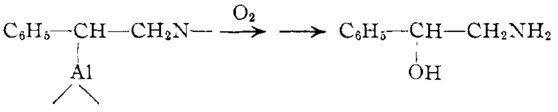
Run	Nitrile	Method	(MRHN)	Mole % hydrogen	Primary amine % yield	Higher product[a]	Yield, %	Total recov. of identified prod., %
1	*n*-Butyro	DA	1.1	45.8	48.7	2-Ethyl-1,3-hexanediamine[b]	28.9	77.6
2	*n*-Butyro	DA	0.8	28.0	39.8	[c]	*ca.* 14	*ca.* 54
3	*n*-Butyro	DA	0.5	14.0	29.9	[d]		29.9
4	*n*-Capro	DA	1.1	36.4	36.0	2-Butyl-1,3-octanediamine[e]	31.4	67.4
5	*n*-Capro	DA	0.5	16.7	18.4	Anil(s?) of 2-butyl-1,3-octanediamine and *n*-hexanal[f]		34.2[g]
6	Benzo	DA	1.1	Trace	84.7			84.7
7	*n*-Butyro	RA	1.1	31.9	23.4	2-Ethyl-1,3-hexanediamine	36.8	60.2
8	*n*-Butyro	RA	0.8	28.0	19.5	2-Ethyl-1,3-hexanediamine	35.4	54.9
9	*n*-Butyro	RA	0.5	14.9	29.4	Anil(s?) of 2-ethyl-1,3-hexanediamine and *n*-butyraldehyde[h]		29.4
10	*n*-Capro	RA	1.1	25.3	26.9	2-Butyl-1,3-octanediamine	36.0	62.9
11	Benzo	RA	1.1	Trace	58.2			58.2

[a] Ref. *a*, Table I. [b] Ref. *h*, Table I. [c] B.p. 118–122° (26 mm.), $n^{26}\text{D}$ 1.4505. A mixture containing mostly 2-ethyl-1,3-hexanediamine (identified as the dibenzoyl derivative). [d] No attempt at identification was made. Physical constants were similar to those of α-ethyl-β-aminocapronitrile (Table I, run 11). [e] Ref. *l*, Table I. [f] Hydrolysis yielded *n*-hexanal (ref. *m*, Table I) and 2-butyl-1,3-octanediamine. [g] 15.8% *n*-capronitrile was recovered. [h] Hydrolysis yielded *n*-butyraldehyde (m.p. of 2,4-dinitrophenylhydrazone, 122–123°; Heilbron, 123°, no depression with authentic sample) and 2-ethyl-1,3-hexanediamine.

The presence of the former species[16] was sought in several RA experiments (not reported here in detail) with *n*-capronitrile. After the reductions were performed as usual, dry carbon dioxide was passed into the reaction mixture for at least 8 hours.[16] Following hydrolysis, only 7–19% yields of *n*-hexylamine were obtained. In similar DA experiments the only identifiable product was *n*-hexylamine in low yield (20–40%). Although the carbon dioxide had reacted in some way with the reaction complexes, particularly in the RA runs, it was in no case possible to isolate material that could have been the desired α-(*n*-butyl)-β-aminopropionic acid.

Attempts were then made to carbonate the reaction products of DA reduction of phenylacetonitrile in the hope of obtaining α-phenyl-β-aminopropionic acid, a known material.[17] Again, the only identifiable product was the primary amine, phenethylamine, in low yield (12%). Therefore, although a carbon–lithium bond remains a possibility, no evidence for it was found.

The oxidation of a species containing a carbon–metal bond was then attempted with DA and RA reduction mixtures of phenylacetonitrile. Prior to hydrolysis, dry air (free of carbon dioxide) was passed through the reaction mixture for at least 5 hours.[16] The RA run produced phenethylamine in 13% yield. From the DA run, however, there was obtained, in addition to a 35% yield of phenethylamine, a 7% yield of α-phenyl-β-aminoethanol.[18] The latter product was taken as proof of the presence at the end of the reaction of some kind[19] of carbon–metal bond, possibly a carbon–aluminum species. Further study of this reaction is in progress.



$$C_6H_5\text{—}\underset{\substack{|\\ \text{Al}\\ /\ \backslash}}{CH}\text{—}CH_2N\text{—} \xrightarrow{O_2} \longrightarrow C_6H_5\text{—}\underset{\substack{|\\ OH}}{CH}\text{—}CH_2NH_2$$

Experimental[20–22]

Materials.—Lithium aluminum hydride was obtained from Metal Hydrides, Inc., Beverly, Mass. Anhydrous ether, Baker analyzed reagent grade, was used throughout the reactions. Tetrahydrofuran was purified by distillation from lithium aluminum hydride and used promptly. The various nitriles were either purified commercial materials or were prepared by standard methods. Infrared spectra assured the absence of hydroxylic materials.

Solutions of hydride, assayed by measurement of the hydrogen liberated upon reaction with water, were found to contain up to 3 g. of hydride per 100 ml. of tetrahydrofuran solution, and up to 4.5 g. of hydride per 100 ml. of ether solution. These solubilities were considerably smaller than were originally reported.[23]

Reduction of Nitriles.—Experiments were usually made with 0.15 mole of nitrile. Identical procedures were used in ether and in tetrahydrofuran, all runs in the latter being made at 30–35°. The RA reduction of *n*-capronitrile in tetrahydrofuran at 1.1 MRHN illustrates the procedure.

In a flask equipped with condenser (−70°) and stirrer were placed 100 ml. of tetrahydrofuran and 14.6 g. (0.15 mole) of *n*-capronitrile. The outlet from the top of the condenser led successively through a drying tube, a vapor trap (−70°), and terminated at an inverted water-filled graduate. To the stirred solution was added over a 50-minute interval 151 ml. of tetrahydrofuran solution containing 6.3 g. (0.165 mole) of hydride. The reaction mixture was kept at 30–35° by external cooling. A total of 850 ml. (0.0379 mole)

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(16) It was assumed that a carbonation reaction would be more likely an indication of a carbon–lithium bond than of a carbon–aluminum bond. F. A. Hochstein and W. G. Brown, THIS JOURNAL, **70**, 3484 (1948), have given one example of a hydride complex containing a carbon–aluminum bond which did not react with carbon dioxide.

(17) A. McKenzie and R. C. Strathern, *J. Chem. Soc.*, **127**, 82 (1925).

(18) Identified by means of infrared and mixed melting point comparisons of the benzamide derivative with an authentic sample prepared by the sodium borohydride reduction of ω-aminoacetophenone hydrochloride. See also A. J. Castro, D. K. Brain, H. D. Fisher and R. K. Fuller, *J. Org. Chem.*, **19**, 1444 (1954).

(19) The possible presence of a carbon–lithium bond prohibits the conclusion that a carbon–aluminum bond has been assured by the oxidation reaction. Assuming a carbon–aluminum bond were present, the actual structure and size of the complex remains unknown. For relevant speculations on such complexes in nitrile–hydride reductions, see M. Mousseron, *et al.*, *Bull. soc. chim. France*, **19**, 1042 (1952).

(20) M.p.'s and b.p.'s are uncorrected.

(21) Initial experiments were performed by Mrs. Elizabeth W. Parrotta and certain analyses by Miss Eloise Carpenter.

(22) Microanalyses by Dr. Carl Tiedcke, Laboratory of Microchemistry, Teaneck, N. J.

(23) Reference 4b, p. 484.

of gas was evolved. Stirring was continued for an additional 1.5 hours and the reaction mixture permitted to stand overnight. The mixture was carefully decomposed by the dropwise addition of 10 ml. of water followed by 6 ml. of 20% sodium hydroxide. The total hydrogen evolved during decomposition of excess hydride and complexes was 6150 ml. (0.274 mole). The mixture was filtered and the salts washed twice with small portions of solvent. The solutions were combined, dried over anhydrous sodium sulfate, and most of the ether removed. Fractional distillation of the remainder gave 4.1 g. of *n*-hexylamine (27% yield) and 5.4 g. of 2-butyl-1,3-octanediamine (36% yield); mixed m.p. of the latter's diacetyl derivative (132–133°) with an authentic sample, no depression. *Anal.* Calcd. for $C_{16}H_{32}O_2N_2$: C, 67.56; H, 11.34; N, 9.84. Found: C, 67.50; H, 11.20; N, 9.37. The total recovery of identified products was 63%.

In run 11 (Table I) the reaction mixture was stirred for two hours and decomposed by the careful addition of water. Besides 3.0 g. of *n*-butyronitrile (29% yield) there was obtained 3.6 g. of material A (b.p. 78–90° (1.5 mm.), n^{24}D 1.4516). On warming with dilute hydrochloric acid, A yielded *n*-butyraldehyde (m.p. of 2,4-dinitrophenylhydrazone, 121–122°; mixed m.p. with authentic sample, no depression) and material B (b.p. 64–68° (0.5 mm.), n^{26}D 1.4459). The infrared spectrum of B indicated the presence of both nitrile and amine functions. Reduction of B with hydride, followed by benzoylation, gave crystals of m.p. 164–165°, identical with N,N′-dibenzoyl-2-ethyl-1,3-hexanediamine (Table I, ref. *h*). Although not positively identified, it would appear that B was the unknown α-ethyl-β-aminocapronitrile and that A was the anil of *n*-butyraldehyde and α-ethyl-β-aminocapronitrile.

Carbonation of the Products from DA Reduction of Phenylacetonitrile.—The reduction of 0.15 mole of phenylacetonitrile in ether (1.1 MRHN) was accompanied by the evolution of 0.0817 mole of gas. Dry carbon dioxide gas was bubbled into the stirred reaction mixture for eight hours. After the usual hydrolysis and isolation procedure there was obtained 2.1 g. of phenethylamine (12% yield, b.p. 104° (34 mm.), n^{25}D 1.5299) and 8.9 g. of residue. Exhaustive studies of both the residue and of the ether-insoluble inorganic solid from hydrolysis failed to uncover any α-phenyl-β-aminopropionic acid.[17]

Oxidation of the Products from DA Reduction of Phenylacetonitrile.—Reduction of phenylacetonitrile (0.15 mole) was carried out in the usual way at 0.8 MRHN, with evolution of 0.092 mole of hydrogen. After standing overnight, dry (carbon dioxide-free) air was bubbled through the stirred mixture for 5.5 hours at an approximate rate of 70 cc./minute. The color progressed from yellow-green to dark green to red. Hydrolysis afforded 0.038 mole of gas and a deep red reaction mixture. The products of the reaction were 6.4 g. of phenethylamine (34.9% yield) and 1.2 g. of α-phenyl-β-aminoethanol (6.6% yield).[18]

Reduction of β-Iminonitriles to 1,3-Diamines.—α-(*n*-Butyl)-β-iminocaprylonitrile was prepared from *n*-capronitrile by the Thorpe reaction (b.p. 144–150° (1.5 mm.), n^{23}D 1.4954, d^{23}_4 0.8948, yield 45.2%).[24] Attempted reduction of the β-iminonitrile with hydride in ether (DA, 3 MRHN), and in refluxing tetrahydrofuran (DA, 4 MRHN), failed to give the desired 1,3-diamine. In each case some reaction had occurred, but 60–70% of unchanged β-iminonitrile was recovered.[25] Catalytic reduction[26] over platinum oxide in acetic anhydride (40 lb. hydrogen), however, yielded N,N′-diacetyl-2-butyl-1,3-octanediamine, m.p. 132–133°, identical with the product obtained in the hydride reduction of *n*-capronitrile (Table I, run 12).

α,γ-Diphenyl-β-iminobutyronitrile was prepared from phenylacetonitrile in 44.5% yield (b.p. 204–208° (1 mm.), lit. 203–205° (1 mm.).[24] Catalytic reduction, as described above, gave N,N′-diacetyl-2,4-diphenyl-1,3-butanediamine in low yield (m.p. 232–233°), identical with the material obtained in hydride reduction of phenylacetonitrile (Table I, run 7). *Anal.* Calcd. for $C_{20}H_{24}N_2O_2$: C, 74.04; H, 7.46; N, 8.63. Found: C, 73.76; H, 7.49; N, 8.41.

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(24) Adkins and Whitman, Table I, ref. *g*.

(25) No instances of the successful reduction of ketimines to secondary amines by hydride appear to have been reported.

(26) C. Weygand, "Organic Preparations," Interscience Publishers, Inc., New York, N. Y., 1945, p. 228.

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[CONTRIBUTION FROM THE LABORATORY OF THE ALDRICH CHEMICAL COMPANY]

Unsaturated Phenols. III.[1a,b] Alkali Isomerization

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The alkali isomerizations of the six β,γ-unsaturated phenols I–VI have been compared with that of *o*-allylphenol. All six are isomerized with greater difficulty than is *o*-allylphenol and, surprisingly, the *ortho* isomers are isomerized faster than the corresponding *para* isomers. The possible mechanisms of isomerization are considered.

The ease[2] of isomerization of allyl- to propenylphenol and of related systems, such as eugenol to isoeugenol, raises the question of whether that ease of isomerization is due largely to the products' conjugation with the benzene ring or to their hyperconjugation with the terminal methyl group. To answer this, the isomerizations of six β,γ-unsaturated phenols, I–VI, accessible through the acid-catalyzed reactions of dienes with phenol[3–5] have been studied.

o-Allylphenol is isomerized to *o*-propenylphenol by the action of methanolic potassium hydroxide at 110° in six to ten hours.[6] Under those conditions *none* of the phenols I–VI is isomerized to any measurable extent. After 100 hours, both cyclopentenylphenols, II and V, and *p*-3-methylcrotylphenol (VI) were recovered, essentially unchanged, while there was found to be *ca.* 80 and 60% isomerization in the *o*-substituted phenols I and III, respectively, and 30% isomerization in the *p*-crotylphenol (IV). Only when I–VI were heated with potassium hydroxide without solvents at 200° could the six conjugated phenols be isolated in good yields.

When the difficulty of isomerizing all γ-substituted β,γ-unsaturated phenols was realized, but before the surprisingly faster isomerization of *ortho* alkenylphenols in a given *ortho-para* pair was noted, an attempt was made to highlight the difference in reactivity of allylphenol and γ-substi-

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(1) (a) For Paper II, see THIS JOURNAL, **77**, 4155 (1955); (b) presented in part before the XIV International Congress of Pure and Applied Chemistry, Zürich, July, 1955.

(2) D. S. Tarbell in R. Adams, "Organic Reactions," Vol. II, John Wiley and Sons, New York, N. Y., 1944, p. 19.

(3) W. Proell, *J. Org. Chem.*, **16**, 178 (1951).

(4) A. R. Bader, THIS JOURNAL, **75**, 5967 (1953).

(5) H. Pines and J. A. Vesely, U. S. Patents 2,553,470 and 2,578,206 (May and December, 1951).

(6) See p. 27 of ref. 2.