Anal. Calcd for $C_{16}H_{20}IN_3$: C, 50.4; H, 5.3. Found: C, 50.6; H, 5.3.

The free base **22** was obtained by the procedure described for **21**. Recrystallization from petroleum ether gave pale yellow crystals: mp 76–78°; nmr ($CDCl_3$) δ 2.64 (s, 3), 2.78 (s, 3), 2.87 (s, 3), and 6.9 (m, 10).

Anal. Calcd for $C_{16}H_{19}N_3$: C, 75.5; H, 7.6. Found: C, 75.6; H, 7.4.

***N*-Phenylbenzimidic Acid 2-Methyl-2-phenylhydrazide (23).**—*N*-Phenylbenzimidoyl chloride[13] (8.6 g) was slowly added to a solution of 5.0 g of 1-methyl-1-phenylhydrazine and 4.0 g of triethylamine in 25 ml of dry benzene. After the exothermic reaction had subsided, the reaction mixture was allowed to stand at room temperature overnight. An equal volume of benzene was added and the reaction mixture was extracted with water. Evaporation of the dried benzene solution gave 11 g of crude product, mp 91–97°. Recrystallization from petroleum ether gave yellow crystals: mp 100–101°; nmr (DMSO-d_6) δ 3.03 (s, 3), 6.5–8.1 (m, 16).

Anal. Calcd for $C_{20}H_{19}N_3$: C, 79.7; H, 6.4; N, 13.9. Found: C, 79.6; H, 6.3; N, 14.1.

***N*-Phenylbenzimidic Acid 1,1-Dimethyl-2-phenylhydrazide (27).**—The hydrazide imide **23** (2.5 g) was added to 10 ml of methyl iodide. After 5 days at room temperature the hydriodide **24** was precipitated with dry ether as an amorphous solid (2.5 g). This material could not be successfully crystallized. Treatment of the hydriodide with 50 ml of 6 *N* NaOH followed by extraction with chloroform afforded, after evaporation of the dried extracts, the free base (1.1 g) as a yellow oil.

The picrate on recrystallization from ethanol formed yellow needles: mp 168–169°; nmr (DMSO-d_6) δ 2.95 (s, *ca.* 2.5), 3.02 (s, *ca.* 0.5), 3.30 (s, *ca.* 2.5), 3.45 (s, *ca.* 0.5), 7.3 (m, 15), 8.5 (s, 2), 12.1 (broad, 1).

Anal. Calcd for $C_{27}H_{24}N_6O_7$: C, 59.6; H, 4.4; N, 15.4. Found: C, 59.6; H, 4.7; N, 15.2.

The picrate was also prepared by the following route. *N*-Phenylbenzimidoyl chloride[13] (4.3 g) was added to a solution containing 2.7 g of 1,2-dimethyl-1-phenylhydrazine[12] and 2.0 g of triethylamine in 25 ml of dry benzene. After 5 days at room temperature the oily product (5.0 g) was isolated as described for **23**. The picrate obtained from this product had a melting point and nmr spectrum identical with that described above.

Dimethyl[α-(Trimethylhydrazino)benzylidene]ammonium Iodide (30).—A solution containing 1 g of **21** in 2 ml of methyl iodide was gently warmed to induce an exothermic reaction. Anhydrous ether was added and the solid product was filtered off, giving 1.4 g of **30**, mp 177–183°. Recrystallization from ethanol gave white crystals: mp 186–188°; nmr ($CDCl_3$) δ 2.72 (s, 6), 2.90 (s, 6), 3.60 (s, 3), 7.6 (m, 5).

Anal. Calcd for $C_{12}H_{20}IN_3$: C, 43.3; H, 6.1. Found: C, 43.3; H, 6.2.

Registry No.—**4,** 38435-15-3; **5,** 38435-16-4; **9,** 38435-17-5; **9** picrate, 38435-18-6; **10** iodide, 38435-19-7; **10** tosylate, 38435-20-0; **11,** 38435-21-1; **11** picrate, 38435-22-2; **12** iodide, 38521-57-2; **13** (R = Ph; R′ = Me; X = TsO), 38435-23-3; **14,** 38435-24-4; **15,** 38435-25-5; **16,** 38435-26-6; **17,** 38435-27-7; **19,** 38435-28-8; **20,** 38435-87-9; **21,** 38435-88-0; **22,** 38435-89-1; **23,** 38554-60-8; **27** picrate, 38435-90-4; **30,** 38435-91-5; *N*-methylbenzimidoyl chloride, 21737-87-1; 1,1-dimethylhydrazine, 57-14-7; 1-methyl-1-phenylhydrazine, 618-40-6; *N*,*N*-dimethylbenzamide, 611-74-5; *N*,*N*-dimethylpropionamide, 758-96-3; 1,2-dimethyl-1-phenyl-2-propionylhydrazine, 38435-93-7; 1,2-dimethyl-1-phenylhydrazine, 29195-01-5; propionic anhydride, 123-62-6; *N*-phenylbenzimidoyl chloride, 4903-36-0.

Acknowledgment.—We thank the donors of the Petroleum Research Fund, administered by the American Chemical Society, and the Research Foundation of State University of New York for support of this project.

(13) J. von Braun and W. Pinkernelle, *Chem. Ber.*, **67B**, 1218 (1934).

Monomethylation of Aromatic Amines *via* Sodium Borohydride Mediated Carbon–Nitrogen Bond Cleavage

SAUL B. KADIN

Medical Research Laboratories, Pfizer Inc., Groton, Connecticut 06340

Received November 6, 1972

Arylaminomethylsuccinimides (I) displaying a variety of substituents are rapidly and conveniently converted into the corresponding *N*-methyl aromatic amines (II) upon treatment with sodium borohydride in dimethyl sulfoxide. The presence of ester, amide, or nitrile functions does not affect the facility with which this reaction occurs. The reaction mechanism appears to involve base-catalyzed elimination of succinimide from I followed by reduction of the resulting aldimine intermediate.

Of numerous methods available for the monomethylation of primary aromatic amines, none is without serious deficiencies. Direct or Eschweiler–Clarke[1] alkylation is complicated by the formation of tertiary amines as well as other products; hydrolytic cleavage of *N*-methyl-*p*-toluenesulfonanilides or *N*-methylformanilides[2] requires sufficiently drastic conditions as to preclude the use of starting materials exhibiting labile ester, amide, or nitrile groups; lithium aluminum hydride reduction of formanilides or aryl isocyanates is applicable only to those substrates which do not bear substituents which will also be altered under the reaction conditions. We wish to report that sodium borohydride, the use of which in the hydrogenolysis of alkyl and aralkyl halides and tosylates[3a–d] has received increasing attention, can also be employed to effect the cleavage of carbon–nitrogen bonds with the consequential formation of *N*-methyl aromatic amines. Furthermore, the procedure reported herein may be utilized in the presence of ester, amide, or nitrile functions.

The reaction of aromatic amines with aqueous formaldehyde and succinimide in refluxing ethanol was reported by Winstead, *et al.*,[4] to provide good yields of *N*-arylaminomethylsuccinimides (I). Treatment of these aminal-type substances with sodium borohydride

(1) M. L. Moore, *Org. React.*, **5**, 301 (1949).

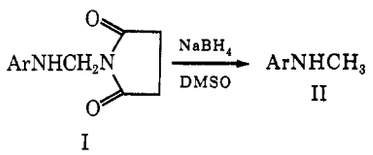
(2) R. M. Roberts and P. J. Vogt, *J. Amer. Chem. Soc.*, **78**, 4778 (1956).

(3) (a) H. M. Bell and H. C. Brown, *ibid.*, **88**, 1473 (1966); (b) H. M. Bell, C. W. Vanderslice, and A. Spehar, *J. Org. Chem.*, **34**, 3923 (1969); (c) R. O. Hutchins, D. Hoke, J. Keogh, and D. Koharski, *Tetrahedron Lett.*, 3495 (1969); (d) J. Jacobus, *Chem. Commun.*, 338 (1970).

(4) M. B. Winstead, K. V. Anthony, L. L. Thomas, R. G. Strachan, and H. J. Richwine, *J. Chem. Eng. Data*, **7**, 414 (1962).

in dimethyl sulfoxide (DMSO) resulted in an exothermic reaction which, upon aqueous work-up, furnished the desired *N*-methyl aromatic amines (II) (Scheme I). Yields were generally satisfactory and, as Table

SCHEME I



I II

I illustrates, this procedure is applicable not only to the preparation of aniline derivatives displaying a

TABLE I

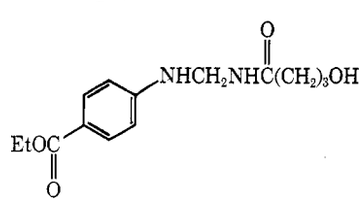
REPRESENTATIVE SODIUM BOROHYDRIDE REDUCTIONS

No.	Aromatic amine	Reactant (I)[a] mp, °C	Product (II)[b] bp, °C (mm)	Yield of II, %
1	Aniline	171.5–173[c]	193	64
2	4-Chloroaniline	152.5–153.5[c]	112–113 (12)	70
3	4-Ethoxyaniline	120.5–121.5[c]	120–122 (8.5)	73
4	2-Bromoaniline	69.5–73[d]	107–109 (12)	72
5	2,4-Xylidine	115–116[c]	107–109 (18)	77
6	Ethyl 4-aminobenzoate	135–136.5[c]	62–63[e]	77
7	4-Aminobenzonitrile	188–190	88–89[e]	59
8	4-Methylthioaniline	127–128	142–146 (10)	84
9	4-Aminobenzamide	207–210[d]	143.5–145.5[e]	40
10	2-Aminopyridine	124.5–125	172–173[e,f]	41
11	3-Aminopyridine	140–141	102 dec[e,g]	34
12	2-Fluorenamine	201–202	76–77[e]	62
13	2-Naphthylamine	189–190	150–155 (7.5)	79

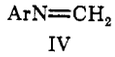
[a] Elemental analyses within ±0.3% of calculated values were obtained for newly reported imides except for those for which recrystallization solvents could not be found. Previously reported imides exhibited melting points in accord with literature values (see ref 4). [b] Elemental analyses within ±0.3% of calculated values were obtained for all *N*-methyl aromatic amines. Boiling points and melting points are in accord with literature values where known. [c] See ref 4. [d] Not purified. [e] Melting point. [f] Isolated and analyzed as hydrochloride salt. [g] Isolated and analyzed as oxalate salt.

variety of substituents, some of which exhibit significant lability under hydrolytic and $LiAlH_4$ conditions, but also to other aromatic carbocyclic and heterocyclic amines.

The reaction of I (Ar = *p*-carbethoxyphenyl) with sodium borohydride in ethanol led to cleavage of the imide ring and isolation of III. Reductive ring



III

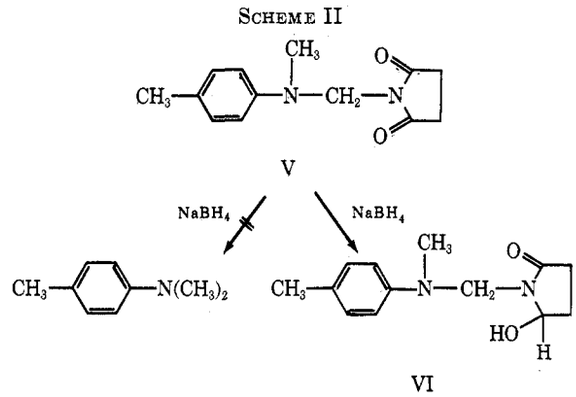


IV

opening of cyclic imides upon treatment with sodium borohydride has been described previously,[5] but this complication was readily avoided when DMSO was employed as the reaction medium. Although the conversion of I into II using Raney nickel has been reported,[6] the high pressure (80 kg/cm²) and temperature conditions (65–130°) required as well as the difficulties posed by the use of Raney nickel with sulfur, nitrile, and certain halogen-containing compounds clearly make the present procedure a more attractive one.

Mechanistically, two pathways for the conversion of I into II appear plausible. The reaction may proceed through (a) base-catalyzed elimination of succinimide followed by reduction of the resulting aldimine intermediate (IV) or (b) direct displacement of the succinimide moiety by borohydride anion. The contribution of pathway b seems minimal since reduction of *N*-methyl-*p*-toluidinomethylsuccinimide[4] (V), which cannot proceed by way of the aldimine mechanism, did not afford *N*,*N*-dimethyl-*p*-toluidine (Scheme II).

SCHEME II



Instead, the product (VI) derived from reduction of the imide ring was isolated. The structure of hydroxypyrrolidinone VI was elucidated by elemental analysis as well as by means of infrared, mass, and nmr spectroscopy. The nmr spectrum was most illuminating and displayed, in addition to the expected aromatic and methyl signals, a pair of doublets centered at δ 4.68 and 5.12 (J_{gem} = 13 Hz) and a doublet at δ 6.05 (J = 6 Hz). The former pair of doublets, produced by the aminal methylene protons, arises as a result of the introduction of an asymmetric center into the N-containing ring while the latter doublet, disappearing on addition of D_2O, is due to the hydroxy proton which is split by the lone methine hydrogen. These results indicate that direct displacement of the imide function by borohydride anion is unlikely and that arylaminomethylsuccinimides derived from primary aromatic amines are apparently reduced *via* the aldimine intermediate. The possibility that steric effects play a dominant role in the reduction of V compared to that of I appears improbable since hydride anion displacement in both substrates would be directed at primary carbon atoms which, in the reduction of alkyl halides and tosylates with sodium borohydride, have been shown to be readily attacked.[3b,c]

The disparate results obtained with DMSO and ethanol also support these conclusions since base-promoted eliminations are known to be facilitated in dipolar aprotic solvents.[7,8] Preferential nucleophilic attack at the imide carbonyl function in ethanol may

(5) Y. Kondo and B. Witkop, *J. Org. Chem.*, **33**, 206 (1968).

(6) M. Sekiya and K. Ito, *Chem. Pharm. Bull.*, **15**, 1339 (1967).

(7) V. J. Traynelis, W. L. Hergenrother, H. T. Hanson, and J. A. Valicenti, *J. Org. Chem.*, **29**, 123 (1964).

(8) A. J. Parker, *Advan. Org. Chem.*, **5**, 1 (1965).

be due either to a comparatively slower rate of elimination in this protic solvent or to a different mode of hydride addition, perhaps analogous to that occurring in the reduction of unsaturated ketones by sodium borohydride in ethanol and pyridine wherein 1,4 addition is favored in the latter solvent.[9,10]

Experimental Section

Melting points are uncorrected. Aromatic amines used as starting materials were commercially available. Infrared spectra were obtained using a Perkin-Elmer Model 21 infrared spectrophotometer. Mass spectra were recorded on an Hitachi Perkin-Elmer RMU-5E mass spectrometer. An Hitachi A-60D spectrometer was used to obtain nmr spectra.

Arylaminomethylsuccinimides (I).—These compounds were prepared by the method of Winstead, *et al.*[4] A solution of 0.1 mol of aromatic amine, 11.9 g of succinimide, and 9.1 ml of 37% aqueous formaldehyde in 100–150 ml of ethanol was refluxed for 2–5 hr (except in those instances where the product precipitated during reflux for which shorter periods of time were used). Cooling usually resulted in precipitation of the desired imide. If this did not occur, evaporation of the ethanol and trituration of the residue with water produced crystalline material.

***N*-Methyl Aromatic Amines (II).**—A warm solution of I in DMSO (2–3 ml of DMSO/g of I) was treated, during 5–10 min, with an equimolar amount of sodium borohydride. An exothermic reaction resulted but was easily controlled, the temperature not rising above *ca.* 100°. After heating on the steam bath for 10–15 min after completion of the borohydride addition, the reaction mixture was poured into cold water. The resulting mixture was extracted three times with ether. The combined ether extracts were dried; the ether was evaporated and the residual oil distilled. (Solid material was recrystallized.) In the case of water-soluble amines, the reaction mixture was poured into 10 *N* KOH instead of water.

***N*-(4-Carbethoxyanilinomethyl)-4-hydroxybutyramide (III).**—A solution of 2.7 g. (0.01 mol) of I (Ar = *p*-carbethoxyphenyl) and 0.42 g (0.011 mol) of sodium borohydride in 40 ml of ethanol was refluxed for 2.5 hr. The ethanol was evaporated under reduced pressure, and the residue was slurried in 50 ml of 3 *N* NH_4OH. The resulting solid was filtered free, dried, and recrystallized from toluene: mp 112–114°; mass spectrum *m/e* 280 (M^+); ir (KBr) 5.9 (ester carbonyl) and 6.05 μ (amide carbonyl).

Anal. Calcd for $C_{14}H_{20}N_2O_4$: C, 59.98; H, 7.19; N, 9.99. Found: C, 60.01; H, 7.12; N, 9.92.

***N*-(*N*-Methyl-*p*-toluidinomethyl)-5-hydroxypyrrolidin-2-one (VI).**—A warm solution of 11.6 g (0.05 mol) of V[4] in 20 ml of DMSO was treated, during 10 min, with 1.9 g (0.05 mol) of sodium borohydride. Internal temperature rose to 85°; stirring was continued for 0.5 hr after addition of the borohydride was complete. The reaction mixture was poured into cold water which was then extracted three times with methylene chloride. The combined methylene chloride extracts were dried. The methylene chloride was evaporated and the residue (8.0 g) recrystallized from benzene to yield VI: mp 121–122°; mass spectrum *m/e* 234 (M^+); ir (KBr), 6.0 μ (carbonyl); nmr (DMSO-d_6) δ 2.28 (s, 3, aromatic CH_3), 1.65–2.4 [m, 4, $-C(=O)CH_2CH_2-$], 3.0 (s, 3, NCH_3), 4.68 (d, 1), and 5.12 (d, 1) (J_{gem} = 13 Hz, NCH_2N), 5.15 (m, 1, methine H), 6.05 (d, 1, J = 6 Hz, OH), 6.8–7.2 (m, 4, phenyl). Addition of D_2O caused the disappearance of the doublet at δ 6.05.

Anal. Calcd for $C_{13}H_{18}N_2O_2$: C, 66.44; H, 7.74; N, 11.96. Found: C, 66.33; H, 7.58; N, 11.64.

Registry No.—I-1, 13314-99-3; I-2, 38359-09-0; I-3, 38359-10-3; I-4, 38359-11-4; I-5, 38359-12-5; I-6, 17647-08-4; I-7, 38359-14-7; I-8, 38359-15-8; I-9, 38359-16-9; I-10, 18932-40-6; I-11, 38359-18-1; I-12, 38359-19-2; I-13, 38359-20-5; II-1, 100-61-8; II-2, 932-96-7; II-3, 3154-18-5; II-4, 6832-87-7; II-5, 13021-13-1; II-6, 10541-82-9; II-7, 4714-62-9; II-8, 104-96-1; II-9, 38359-26-1; II-10 (mono HCl), 27433-30-3; II-11 (*x*-oxalate), 38359-27-2; II-12, 38359-28-3; II-13, 2018-90-8; III, 38359-29-4; V, 38359-30-7; VI, 38359-31-8.

Acknowledgment.—The author thanks Mr. Charles Lamphere for expert technical assistance and Professor D. S. Kemp for helpful discussions.

(9) W. R. Jackson and A. Zurqiyah, *J. Chem. Soc.*, 5280 (1965).
(10) S. B. Kadin, *J. Org. Chem.*, **31**, 620 (1966).

An ESCA Study of the Sulfur–Nitrogen Bond in Sulfimides

CRAIG E. MIXAN[1a] AND JOSEPH B. LAMBERT*[1b]

Department of Chemistry, Northwestern University, Evanston, Illinois 60201

Received October 24, 1972

The O(1s), N(1s), and S(2p) binding energies have been measured from the X-ray photoelectron spectra of the sulfoxide, sulfone, *N*-tosylsulfimide, and *N*-tosylsulfoximide derivatives of benzyl methyl sulfide. The sulfur(IV) binding energy in the *N*-tosylsulfimide is found to be 0.4 eV larger than that in the sulfoxide. The sulfur atom in the sulfimide therefore carries a larger positive charge, and the S(IV)–NTs bond has a larger contribution from the semipolar form than in the sulfoxide. The data also indicate that the parent sulfimide bond, S(IV)–NH, is electronically very similar to the S–O bond in the sulfoxide.

The nature of the sulfur–nitrogen bond in sulfimides, like that of the sulfur–oxygen bond in sulfoxides, has perplexed chemists for several decades.[2,3] Two models have been proposed to explain the properties of these functionalities, a covalent form (1) and a semipolar

X = O, NH, NTs

form (2). The semipolar structure 2 conforms to the octet rule, whereas the covalent formulation does not. The double bond in 1 arises from donation of a 2p electron pair on oxygen or nitrogen to an empty 3d orbital on sulfur. The actual nature of the sulfoxide and sulfimide bonds lies between the canonical extremes, but no general agreement has been reached as to which form should be considered dominant. Recently

(1) (a) National Science Foundation Trainee, 1968–1969. (b) This work was supported by the National Science Foundation (Grant No. GP-22942 and GP-34259X) and by the Advanced Research Projects Agency of the Department of Defense through the Northwestern University Materials Research Center. The authors wish to thank Dr. J. E. Lester for useful discussions during the course of this work.

(2) For leading references to the sulfimide question, see (a) Á. Kucsman, F. Ruff, and I. Kapovits, *Tetrahedron*, **22**, 1575 (1966); (b) K. Tsujihara, N. Furukawa, and S. Oae, *Bull. Chem. Soc. Jap.*, **43**, 2153 (1970); (c) N. Furukawa, K. Harada, and S. Oae, *Tetrahedron Lett.*, 1377 (1972).

(3) For a review of the sulfoxide problem, see C. C. Price, *Chem. Eng. News*, 58 (Nov 30, 1964).