

Rearrangements of Diphenylamine Derivatives. Part III.¹ The Reilly-Hickinbottom Rearrangement

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N-Methyl-, *N*-ethyl-, and *N*-isopropyl-diphenylamine rearrange in the presence of cobalt(II) chloride at 340° to give the corresponding *N*-(4- and 2-alkylphenyl)anilines; *N*-*n*-propyldiphenylamine gives both *C*-*n*-propyl and *C*-isopropyl products under identical conditions. The ratios of isomers produced indicate that carbonium ions participate in the formation of the *C*-isopropyl products, but that bimolecular alkyl transfer is involved in the other cases.

THE side-chain-to-nucleus migration of alkyl groups (usually at 250–300°) in *N*-alkylanilines, either as their hydrohalides (Hofmann-Martius rearrangement) or in the presence of metal salts as catalysts (Reilly-Hickinbottom modification), has received extensive investigation.^{2,3} However, much of the work on this type of reaction was carried out before modern analytical techniques became available, and the results have led to difficulties and controversy in mechanistic interpretation.²⁻⁵ For example, it was believed for many years that skeletal rearrangement of the migrating alkyl group occurs under the former conditions, but not in the Reilly-Hickinbottom modification,⁶ and the comparatively recent discovery that both 4-isopropylaniline and 4-*n*-propylaniline are formed when *N*-*n*-propylaniline is heated with metal salts⁷ has led to improved understanding of the mechanism involved.^{2,7}

We have successfully applied g.l.c. to the analysis of the products from the previously unreported Reilly-Hickinbottom rearrangement of *N*-alkyldiphenylamines in the presence of anhydrous cobalt(II) chloride. Preliminary attempts to effect rearrangement of *N*-methyl- and *N*-ethyl-diphenylamine during 24 h at 300° led mainly (>80%) to recovery of the starting material, but complete reaction of *N*-methyl-, *N*-ethyl-, *N*-*n*-propyl-, and *N*-isopropyl-diphenylamine occurs during 24 h at 340° in the presence of equimolar proportions of cobalt(II) chloride. The yields of the major products are summarised in the Table.

In each reaction, the major product is diphenylamine itself, but significant yields of rearrangement products, in which the migrating alkyl group appears at the 4- or 2-position, are also obtained. The formation of both *C*-*n*-propyl and *C*-isopropyl products, and also the detection of propene (6% yield), in the rearrangement of *N*-*n*-propyldiphenylamine are in accord with the suggestion^{2,7} that alkylation in the Reilly-Hickinbottom rearrangement proceeds *via* carbonium ions (Scheme 1 †),

† Cobalt forms a number of labile complexes of the general formula CoX_2A_2 (X = halogen, A = amine)⁸ and this stoichiometry may well apply to the complexes in Schemes 1 and 2, which are shown as 1 : 1 adducts for simplicity.

¹ Part II, J. M. Birchall and D. H. Thorpe, *J. Chem. Soc. (C)*, 1968, 2900.

² H. J. Shine, 'Aromatic Rearrangements,' Elsevier, Amsterdam, 1967, p. 249.

³ G. F. Grillot in 'Mechanisms of Molecular Migration,' ed. B. S. Thyagarajan, Wiley-Interscience, New York, vol. 3, p. 237.

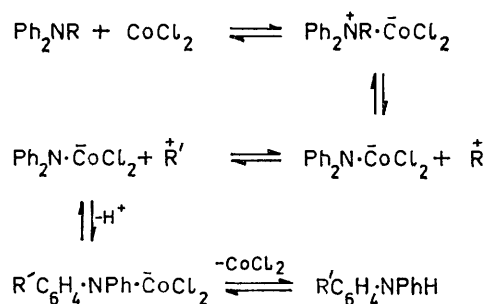
but the relative yields of 4- and 2-substituted diphenylamines do not support complete interpretation of the reactions on this basis.

Products (%) from the rearrangement of *N*-alkyldiphenylamines (Ph_2NR)

R	Ph_2NH	2- $\text{R}^n\text{C}_6\text{H}_4\cdot\text{NHPH}$	4- $\text{R}^n\text{C}_6\text{H}_4\cdot\text{NHPH}$
Me	43	4	23
Et	39	4	21
Pr ⁿ	44	1	9
Pr ⁱ	48		

R	2- $\text{R}^i\text{C}_6\text{H}_4\cdot\text{NHPH}$	4- $\text{R}^i\text{C}_6\text{H}_4\cdot\text{NHPH}$
Me		
Et		
Pr ⁿ	10	6
Pr ⁱ	12	10

Indeed, it seems that free carbonium ions are involved in the formation of only the *C*-isopropyl products, which are the only cases for which a predominance of 2-substitution occurs during the reaction.



SCHEME 1

In view of their well established lower stability, methyl, ethyl, and *n*-propyl cations should show a greater tendency towards a statistical proportion of 2-substitution than the more selective isopropyl cations. However, the observation that relatively little 2-substitution by primary alkyl groups occurs in the rearrangements suggests that truly bimolecular processes [see

⁴ E. D. Hughes and C. K. Ingold, *Quart. Rev.*, 1952, 6, 43.

⁵ M. J. S. Dewar, in 'Molecular Rearrangements,' ed. P. de Mayo, Interscience, New York, 1963, part 1, p. 310.

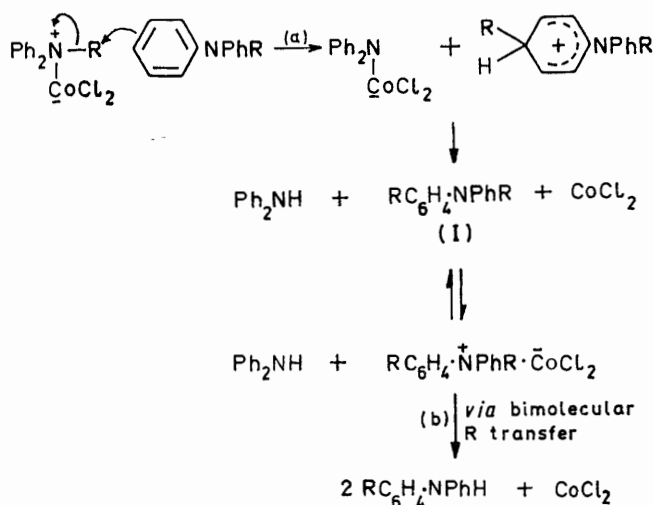
⁶ W. J. Hickinbottom, *J. Chem. Soc.*, 1932, 2396.

⁷ M. J. Molera, J. M. Gamboa, M. del Val Cob, and N. Ortin, *Anales real Soc. españ. Fis. Quim.*, 1963, 59B, 379.

⁸ G. B. Bokai, T. I. Malinovskii, and A. V. Ablov, *Kristallografiya*, 1956, 1, 49.

step (a), Scheme 2] are responsible for the alkyl migration in these cases.*

Bimolecular alkyl transfer to the 2-position would be expected to be subject to steric hindrance to a far greater extent than the corresponding substitution by a



SCHEME 2

carbonium ion, thus accounting for the pronounced differences in the isomer distributions produced by the two mechanisms.

It might be expected that at least some of the *N*-alkyl-*N*-(4-alkylphenyl)aniline (I), produced as an intermediate in Scheme 2, would survive the reaction,⁹ but careful examination of the products from the rearrangement of *N*-methyldiphenylamine did not reveal the presence of either *N*-methyl-*N*-(*o*- or *p*-tolyl)aniline. However, an appreciable amount of diphenylamine is present at the end of this reaction and complete conversion of the dimethyl compounds *via* step (b) would account for the absence of intermediates of this type. In accord with this suggestion, a separate experiment, in which an equimolar mixture of diphenylamine and *N*-methyl-*N*-(*p*-tolyl)aniline was heated with cobalt chloride at 340° for 24 h, resulted in complete conversion of the dimethyl compound into (mainly) *N*-(*o*- and *p*-tolyl)aniline.

Each of the experiments described here yielded small amounts of a number of by-products, some of which were identified by their chromatographic retention times (see Experimental section). The formation of these compounds by degradation at the high reaction temperature involved is not difficult to rationalise.

EXPERIMENTAL

All rearrangement reactions were carried out in sealed tubes in the absence of air. Analysis by g.l.c. was carried

* A similar scheme was proposed by Dewar⁵ for the Reilly-Hickinbottom rearrangement in the aniline series before the discovery that isomerisation can occur with the larger alkyl groups.⁷

out with a Pye P104 Chromatograph, fitted with a flame-ionisation detector; columns (2 m × 5 mm i.d.) were packed with 10% by weight of polyethylene glycol adipate on Celite and were maintained at 181° with a carrier-gas flow (N_2) of ca. 50 ml min⁻¹. For quantitative calibration in each case standard mixtures of the appropriate reference compounds were used.

Reference Compounds.—*N*-(*o*-Tolyl)aniline was obtained¹⁰ from *N*-*o*-tolylanthranilic acid. *N*-(4-Methyl-, 2-ethyl-, and 4-ethyl-phenyl)aniline were obtained by Goldberg reactions from the corresponding 2- or 4-alkylacetanilide and bromobenzene;¹¹ the same method was used to prepare *N*-(2- and 4-isopropylphenyl)aniline, previously obtained by other routes,^{12,13} and the new *N*-(2-*n*-propylphenyl)aniline (Found: C, 85.3; H, 8.6; N, 6.4. $C_{15}H_{17}N$ requires C, 85.3; H, 8.4; N, 6.2%), m.p. 60–61° (white needles from aqueous ethanol) [*N*-acetyl derivative (Found: C, 80.7; H, 7.7; N, 5.5. $C_{17}H_{19}NO$ requires C, 80.6; H, 7.5; N, 5.5%), b.p. 152–153° at 0.4 mmHg, n_D^{20} 1.6093]. *N*-(4-*n*-Propylphenyl)aniline was prepared from 1-bromo-4-*n*-propylbenzene and acetanilide, starting materials which are easier to obtain than the 4-*n*-propylacetanilide used by Takada and Nishimura.¹¹ All previously described compounds gave correct elemental analyses and had physical constants in agreement with reported data.

***N*-Methyl-*N*-tolylanilines.**—*N*-(*o*-Tolyl)aniline (9.15 g, 50 mmol), dimethyl sulphate (12.60 g, 100 mmol), and anhydrous potassium carbonate (10 g) were heated under reflux on a boiling water bath for 2 h. The melt was treated with aqueous 4*M*-hydrochloric acid (35 ml), and the mixture was then basified with aqueous 2*M*-sodium hydroxide (50 ml). The free bases were extracted with light petroleum (b.p. 60–80°), and distillation gave *N*-methyl-*N*-(*o*-tolyl)aniline (6.70 g, 68%) (Found: C, 85.5; H, 7.4; N, 7.3. $C_{14}H_{15}N$ requires C, 85.2; H, 7.7; N, 7.1%), as an oil, b.p. 126–128° at 0.6 mmHg, n_D^{20} 1.6015. A similar reaction with *N*-(*p*-tolyl)aniline (18.30 g) gave *N*-methyl-*N*-(*p*-tolyl)aniline (14.80 g, 75%) (Found: C, 85.2; H, 7.8; N, 7.2%), b.p. 114° at 0.3 mmHg, n_D^{20} 1.6092.

Rearrangement Reactions.—(a) *N*-Methyldiphenylamine. The *N*-methyl compound (5.00 g, 26.7 mmol) (from dimethyl sulphate)¹⁴ and anhydrous cobalt(II) chloride (3.48 g, 26.8 mmol) were heated at 340° for 24 h. No gaseous products were obtained, and the violet involatile products were warmed with aqueous 4*M*-ammonia (100 ml). The mixture was filtered to leave a black, carbonaceous residue (2.39 g), which could not be purified. The ammoniacal solution was extracted with benzene (3 × 50 ml), and the combined extracts were washed with water (2 × 25 ml), dried (Na_2SO_4), and evaporated to give a dark brown oil (3.91 g). Analysis of the oil by g.l.c. showed it to contain (in order of elution; yields in parentheses) aniline (1%), *o*- and *p*-toluidine (1%), biphenyl (3%), 4-methylbiphenyl (2%), 4,4'-dimethylbiphenyl (1%), *N*-(*o*-tolyl)aniline (4%), diphenylamine (43%), and *N*-(*p*-tolyl)aniline (23%); six other minor components were not identified, but no *N*-methyldiphenylamine or *N*-methyl-*N*-(*o*- or *p*-tolyl)aniline

⁹ Cf. W. J. Hickinbottom, *J. Chem. Soc.*, 1937, 1119.

¹⁰ S. P. Massie and P. K. Kadaba, *J. Org. Chem.*, 1956, **21**, 347.

¹¹ A. Takada and H. Nishimura, *Chem. and Pharm. Bull. (Japan)*, 1962, **10**, 1.

¹² R. Stroh, J. Ebersberger, H. Haberland, and W. Hahn, *Angew. Chem.*, 1957, **69**, 124.

¹³ D. Craig, *J. Amer. Chem. Soc.*, 1938, **60**, 1458.

¹⁴ C. S. Gibson and D. C. Vining, *J. Chem. Soc.*, 1923, **123**, 831.

was present. Distillation of the oil then yielded a pale green distillate (3.32 g), b.p. 110–140° at 1.5 mmHg, and left an intractable black solid (0.58 g). The distillate was chromatographed on alumina (Spence Grade H): elution with light petroleum (b.p. 60–80°) gave diphenylamine (1.80 g), m.p. (from aqueous ethanol) and mixed m.p. 53°; elution with benzene gave *N*-(*p*-tolyl)aniline (0.95 g), m.p. (from aqueous ethanol) and mixed m.p. 89°, both identified by i.r. spectroscopy; and further elution with benzene gave impure *N*-(*o*-tolyl)aniline (0.29 g), identified by i.r. spectroscopy and shown by g.l.c. to contain traces of the *p*-tolyl isomer and of other impurities.

(b) *N*-Ethylidiphenylamine. The *N*-ethyl compound (5.00 g, 25.4 mmol) (from diethyl sulphate)¹⁵ and cobalt(II) chloride (3.30 g, 25.4 mmol) were heated at 340° for 24 h. Extraction of the products as in (a) gave a black residue (2.74 g) and a brown oil (3.87 g). G.l.c. showed the latter to contain aniline (2% yield), biphenyl (1%), *N*-(2-ethylphenyl)aniline (4%), diphenylamine (39%), *N*-(4-ethylphenyl)aniline (21%), and traces of eleven other components. Distillation of the oil gave a fraction (3.02 g), b.p. 110–136° at 0.2 mmHg, which was separated by liquid-phase chromatography on alumina and gave diphenylamine (1.39 g), *N*-(4-ethylphenyl)aniline (0.90 g), m.p. and mixed m.p. 85°, and substantially pure *N*-(2-ethylphenyl)aniline (0.33 g), identified by i.r. spectroscopy and g.l.c.

(c) *N*-*n*-Propylidiphenylamine. The *N*-*n*-propyl compound (5.00 g, 23.2 mmol) (from *n*-propyl iodide)¹⁵ and cobalt(II) chloride (3.00 g, 23.2 mmol) were heated at 340° for 24 h and yielded propene (0.49 g, 6%) [Found: *M* (Regnault), 41.8. Calc. for C₃H₆: *M*, 42.0], identified by i.r. spectroscopy, as the only volatile product. Extraction of the products as before gave a black residue (2.62 g) and a brown oil (3.66 g), the latter being shown by g.l.c. to contain aniline (2% yield), biphenyl (2%), *N*-(2-isopropylphenyl)aniline (10%), diphenylamine (44%), *N*-(2-*n*-propylphenyl)aniline (1%), *N*-(4-isopropylphenyl)aniline (6%), *N*-(4-*n*-propylphenyl)aniline (9%), and traces of eight unidentified components. Distillation of the brown oil, followed by chromatography of the distillate (3.23 g; b.p. 124–158° at 0.2 mmHg) on alumina gave pure diphenyl-

amine (1.44 g) and a yellow oil (1.43 g), which could not be purified further by this method and was shown by g.l.c. to be a mixture of *N*-(2-isopropyl-, 4-isopropyl-, and 4-*n*-propyl-phenyl)anilines.

(d) *N*-Isopropylidiphenylamine. Analysis by g.l.c. of the brown oil (4.15 g) obtained by the reaction of *N*-isopropylidiphenylamine (5.00 g, 23.2 mmol) (from isopropyl iodide)¹⁵ with cobalt(II) chloride (3.00 g, 23.2 mmol) at 340° for 24 h showed it to contain aniline (2% yield), biphenyl (3%), *N*-(2-isopropylphenyl)aniline (12%), diphenylamine (48%), *N*-(4-isopropylphenyl)aniline (10%), and traces of 12 unidentified components; no *N*-(2-*n*-propyl- or 4-*n*-propylphenyl)aniline was detected. The brown oil yielded a pale green distillate (3.36 g), b.p. 110–124° at 0.05 mmHg, and liquid-phase chromatography on alumina gave pure diphenylamine (1.76 g), *N*-(4-isopropylphenyl)aniline (0.38 g), m.p. and mixed m.p. 71–72°, and *N*-(2-isopropylphenyl)aniline (0.71 g), identified by i.r. spectroscopy and g.l.c.

Reaction of N-Methyl-N-(p-tolyl)aniline and Diphenylamine with Cobalt(II) Chloride.—*N*-Methyl-*N*-(*p*-tolyl)aniline (2.46 g, 12.5 mmol), diphenylamine (2.11 g, 12.5 mmol), and anhydrous cobalt(II) chloride (3.28 g, 25.0 mmol) were heated at 340° for 24 h. G.l.c. of the brown oil (3.85 g) obtained by the usual extraction procedure showed it to contain aniline (0.08 g), *o*- and *p*-toluidine (0.04 g), biphenyl (0.08 g), 4-methylbiphenyl (0.08 g), 4,4'-dimethylbiphenyl (0.04 g), *N*-(*o*-tolyl)aniline (0.12 g, 0.7 mmol), diphenylamine (1.73 g, 82% recovery), *N*-(*p*-tolyl)aniline (1.31 g, 7.2 mmol), and seven minor unidentified components. No *N*-methyl-*N*-(*o*- or *p*-tolyl)aniline was present. Distillation, liquid-phase chromatography, and crystallisation from aqueous ethanol gave diphenylamine (1.54 g), *N*-(*p*-tolyl)aniline (1.27 g), and *N*-(*o*-tolyl)aniline (*ca.* 0.1 g), identified by mixed m.p., i.r. spectroscopy, and/or g.l.c.

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¹⁵ J. Forrest, D. A. Liddell, and S. H. Tucker, *J. Chem. Soc.*, 1946, 454.