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REACTIONS IN ANHYDROUS HYDROGEN FLUORIDE

II. Aminomethylation of Aromatic Compounds*

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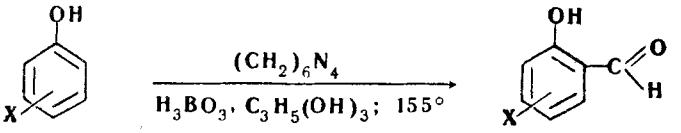
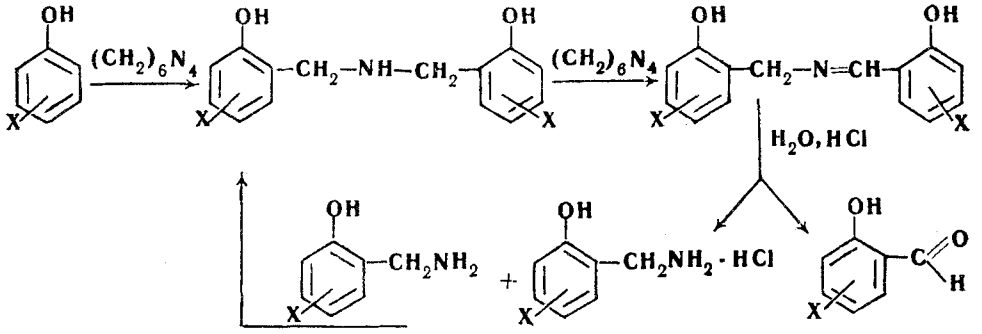
Symmetrical N-benzyl-substituted hexahydrotriazines (I), benzylamines, benzaldehydes, and diphenylmethanes are synthesized by reacting aromatic compounds with urotropine in anhydrous hydrogen fluoride. A mechanism for the reaction is suggested, and the hypothesis advanced that the primary products of Duff's reaction are type I compounds.

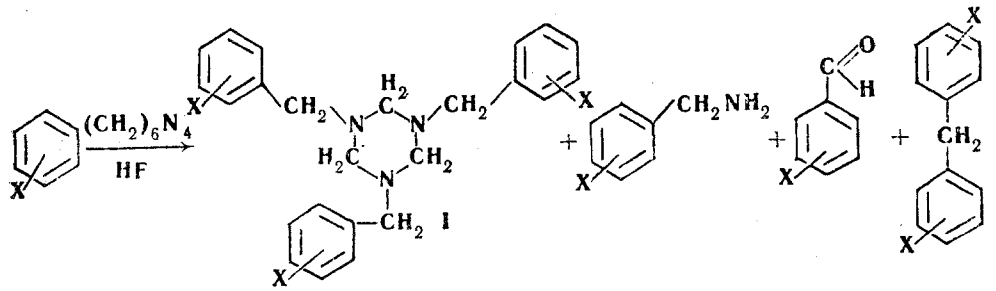
In 1941 Duff investigated the acid condensation of phenols with urotropine at elevated temperature. The main reaction products were o-hydroxy-substituted aromatic aldehydes [2]:



While attempting to determine the mechanism of this reaction, Duff established that reaction of urotropine with excess phenol gives the corresponding dibenzylamines. Oxidation of these amines with urotropine gives the aldehydes, the equations being [3]



When studying organic reactions in anhydrous hydrogen fluoride, we investigated the condensation of urotropine with benzene, toluene, m-xylene, and chlorobenzene. It was shown that, under quite mild conditions, urotropine readily condenses with m-xylene and toluene in anhydrous hydrogen fluoride (temperature 10-15° C, atmospheric pressure). In most cases the main condensation products are the corresponding symmetrical N-benzyl-substituted hexahydrotriazines I. Along with the latter were isolated the corresponding benzylamines, benzaldehydes, and diphenylmethane derivatives** :



* For Part I see [1].

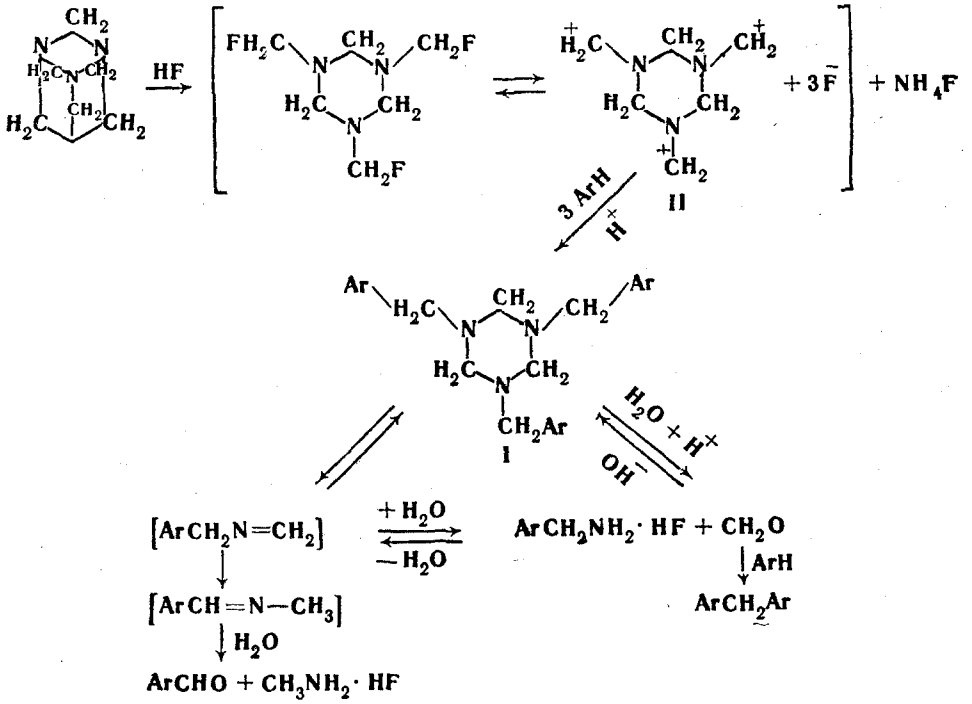
** The table gives the yields of the corresponding compounds.

The literature states [4] that, depending on the conditions, I can be hydrolyzed in acid media either to benzylamines or to benzaldehydes. Comparison of the results in the literature with ours leads to the view that the primary products of condensation of urotropine with phenols in the Duff reaction are I.

In a special experiment where I was in contact with hydrogen fluoride for a long time, to some extent the corresponding benzaldehydes and benzylamines were found to be formed, along with a considerable quantity of polymeric products. The relative instability of I in anhydrous hydrogen fluoride may explain formation of considerable amounts of p-chlorobenzaldehyde when chlorobenzene reacts with urotropine. This reaction can be effected only at 100° C; obviously, under such conditions, the initially formed hexahydrotriazines suffer further change. Our results are in agreement with those recently published by Denton and Sceschitzky [5], who prepared a number of aromatic aldehydes by condensing excess urotropine with aromatic hydrocarbons in the presence of polyphosphoric acid at elevated temperature.

Condensation of excess benzene with urotropine at 100° C gives, in addition to benzaldehyde, benzylamine, diphenylmethane, and dibenzylbenzene, up to 24% of a thermoreactive nitrogenous polymer. The IR spectrum of the latter shows the presence of substituted phenyl rings, and there is also considerable absorption in the 850 cm^{-1} region which in similar products, is ascribed to the $-CH_2-NH-CH_2$ group [6]. This falls in line with the results of a number of authors, who demonstrated the intermediate formation of dibenzylamines when preparing phenol-urotropine resins [7].

Formation of the above products can be explained by the following equations:



The initial part of the reaction is stepwise splitting of the urotropine in the acid to give symmetrical N,N',N"-tris (fluoromethyl)-hexahydrotriazine, which, in anhydrous hydrogen fluoride, exists in dissociation equilibrium with the triply charged ion II. (Formation of II was proved by Tada [8], who made a detailed study of the acid hydrolysis of urotropine). Subsequently there is electrophilic attack by II on the aromatic ring, to give I.

Experimental

Reaction of urotropine with m-xylene. A 140 ml steel reactor was cooled in ice-water, and charged with 80 g (4 mole) HF and 45.5 g (0.428 mole) m-xylene, and 15 g (0.107 mole) urotropine added with stirring over 20 min.* Stirring was continued for 5-6 hr longer, and the temperature gradually raised to room temperature. The products were left overnight. Next day the solution was poured into a polyethylene beaker, and the HF evaporated off. The oil remaining was treated with 150 ml water, and extracted with ether (3-4 extractions with 50-100 ml ether each time).

The acid ether extracts were neutralized with $NaHCO_3$ solution, filtered, and dried over $MgSO_4$. After distilling

* The order in which the urotropine and m-xylene were added did not affect the outcome of the reaction.

off the ether, the residue was vacuum-distilled, to give:

2,4-Dimethylbenzaldehyde, 1 g bp 89° (8 mm), n_D^{20} 1.5481, PMR spectrum:* δ(o-CH_3) 2.5; δ(p-CH_3) 2.3; δ $\left(-C\begin{matrix}O\\ \|\\ H\end{matrix}\right)$ 9.5. The literature gives [9] bp 114° C (20 mm). 2,4-Dinitrophenylhydrazone, mp 219–220° C (ex toluene); the literature gives [10] mp 221–222° C. Found: N 17.78, 17.80%. Calculated for $C_{15}H_{14}N_4O_4$: N 17.83%.

Products of Reaction of Urotropine with Aromatic Compounds

Aromatic compound	Yields, weight %			
	Hexahydrotriazine	Benzylamine	Diphenylmethane	Benzaldehyde
m-Xylene	59.1	21.8	7.9	2.5
Toluene	49.1	2.7	7.6	4.1
Chlorobenzene	5.3	Trace	19.4	25.0
Benzene	Trace	5.7	3.7**	11.7

*Calculated on the urotropine

**Alone with 11% dibenzylbenzene.

2,2',4,4'-Tetramethyldiphenylmethane, 3 g, bp 145° (3 mm), n_D^{20} 1.5662, PMR spectrum: δ(o,p-CH_3) 2.7; δ(−CH_2−) 4.3. The literature gives [11] bp 140–142° (3 mm), n_D^{15} 1.5635. Found: C 90.56, 90.73; H 8.95, 8.88%. Calculated for $C_{17}H_{20}$: C 91.01; H 8.99%.

The aqueous layer was made alkaline with 40% NaOH solution, extracted with ether, the solid filtered off, and the liquid dried over $MgSO_4$. After distilling off the solvent, the amine was vacuum-distilled, and the residue crystallized. The following were obtained:

2,4-Dimethylbenzylamine, 9.5 g bp 96° (8 mm), n_D^{20} 1.5378, PMR spectrum: δ(−CH_2−) 3.7; δ(o-CH_3) 2.4; δ(p-CH_3) 2.3; δ(−NH_2) 1.3. The literature gives [12] bp 218–219° C. Hydrochloride: mp 213° C (ex EtOH). The literature gives [12]: mp 212° C. Found: C 62.92, 62.86; H 8.26, 8.30: Cl 21.46, 21.20; N 8.04, 7.88%. Calculated for $C_9H_{13}N \cdot HCl$: C 62.97; H 8.22; Cl 20.65; N 8.16%.

N,N',N"-Tris(2,4-dimethylbenzyl) hexahydrotriazine, 28 g, mp 80°C, (ex EtOH). PMR spectrum: δ(Ar−CH_2−N<) 3.8; δ(=N−CH_2−N=) 3.6; δ(o,p-CH_3) 2.5. Found: C 81.29, 81.17; H 8.87, 8.78; N 9.07, 9.32%; mol. wt. 401, 4.12. (cryoscopic in benzene). Calculated for $C_{30}H_{39}N_3$: C 81.59; H 8.90; N 9.51%; mol. wt. 441.

Reaction of urotropine with toluene. Under conditions similar to those used in the preceeding experiment, from 15 g (0.107 mole) urotropine and 39.4 g (0.428 mole) toluene in 80 g (4 mole) HF, the products were:

p-Methylbenzaldehyde, 1.6 g, bp 60.5° (3 mm), n_D^{20} 1.5466, PMR spectrum: δ(p-CH_3) 2.3; δ $\left(-C\begin{matrix}O\\ \|\\ H\end{matrix}\right)$ 9.8. The literature gives [13] bp 98–100° (20 mm); n_D^{16} 1.547. 2,4-Dinitrophenylhydrazone mp 232° (washed with EtOAc). The literature [14] gives mp 233–234° C. Found: N 18.29, 18.55%. $C_{14}H_{12}N_4O_4$: N 18.66%.

Dimethyldiphenylmethane, 2.4 g, bp 117° C (2 mm), GLC showed it to be a mixture of o- and p-isomers, PMR spectrum δ(o-,p-CH_3) 2.3 δ(−CH_2−) 4.0. Found: C 91.63, 91.50; H 8.32, 8.25%. Calculated for $C_{15}H_{16}$: C 91.78; H 8.22%.

p-Methylbenzylamine, 1 g bp 63° (3 mm), n_D^{20} 1.5362, PMR spectrum: δ(−CH_2−) 3.8; δ(p-CH_3) 2.5; δ(−NH_2)

* The PMR was investigated with a TsLA-5535 spectrometer, working frequency 40 Mcps, and with proton stabilization of resonance conditions. Sealed tubes were used. For the solids the solvent was CCl_4, and the internal standard was benzene. Chemical shifts were measured by the side bands method and by precalibration. The chemical shifts are given on the δ scale (zero on tetramethylsilane, shifts with a weak field reckoned positive). The authors express their great thanks to E. I. Fedin and P. V. Petrovskii for determining the PMR spectra.

1.6. The literature [15] gives bp84-85° (10 mm), n_D^{20} 1.5375.

N,N',N"-Tris (p-methylbenzyl) hexahydrotriazine, 21 g, mp 138° C (ex benzene), PMR spectrum: δ (Ar–CH_2–N=) 3.7; δ (=N–CH_2–N=) 3.5; δ (p-CH_3) 2.5. The literature gives [16] mp 132-133° C. Found: C 81.45, 81.35; H 8.43, 8.33; N 10.43, 10.30%, mol. wt. 408 (cryoscopic in benzene). Calculated for $C_{27}H_{33}N_3$: C 81.16; H 8.32; N 10.52%; mol. wt. 400.

Reaction of urotropine with chlorobenzene. A mixture of 80 g HF, 15 g (0.107 mole) urotropine and 48.4 g (0.428 mole) chlorobenzene was agitated in a steel bomb at 100° C for 5 hr, and the products worked up in the usual way to give:

p-Chlorobenzaldehyde, 11.6 g mp 46-47° C (ex n-heptane), PMR spectrum δ (–C(=O)H) 9.8. The literature gives [17] mp 47.2° C. 2,4-Dinitrophenylhydrazone mp 260° C (ex m-xylene). The literature gives [18] mp 262-263° C (decomp). Found: N 17.73, 17.47%. Calculated for $C_{13}H_9ClN_4O_4$: N 17.52%.

Dichlorophenylmethane (mixture of o- and p-isomers), 7.3 g, bp 150.5-152.5° (2 mm), n_D^{20} 1.5959, PMR spectrum: δ (–CH_2–) 4.1; 3.9. Found: C 65.69, 65.62; H 4.42, 4.39; Cl 28.34, 28.16%. Calculated for $C_{13}H_{10}Cl_2$: C 65.84; H 4.25; Cl 29.90%.

N,N',N"-Tris (chlorobenzyl) hexahydrotriazine (mixture of isomers), 2.5 g bp 130-150° C (5 mm); PMR spectrum: δ (Ar–CH_2–N=) 3.7; δ (=N–CH_2–N=) 3.5. Found: C 62.59, 62.74; H 5.22, 5.26; Cl 22.77, 22.69%. Calculated for $C_{24}H_{24}Cl_3N_3$: C 62.55; H 5.25; Cl 23.08%.

Reaction of urotropine with benzene. A mixture of 80 g HF, 15 g (0.107 mole) urotropine, and 33.4 g (0.428 mole) benzene was agitated for 5 hr at 70-90° C in a steel bomb, and the products worked up as described for the reaction with m-xylene, to give:

Benzaldehyde, 4 g bp 38° C (3 mm); 2,4-dinitrophenylhydrazone: mp 234° C (ex EtOAc), undepressed mixed mp with an authentic specimen.

Diphenylmethane, 1 g, bp 96° (2 mm), n_D^{20} 1.5741, PMR spectrum: δ (–CH_2–)4.1. GLC showed it to be an azeotrope containing 10% benzaldehyde.

Dibenzylbenzene (mixture of isomers), 3 g mp 79° C (ex EtOH), PMR spectrum: δ (–CH_2–) 4.2. Found: C 92.54, 92.37; H 6.64, 6.90%. Calculated for $C_{20}H_{18}$: C 92.98; H 7.02%.

Benzylamine, 2 g, bp 80-100° (20 mm), n_D^{20} 1.5449, PMR spectrum: δ (–CH_2–) 3.7; δ (–NH_2) 1.8. The literature gives [19] 185° (767 mm), n_D^{20} 1.54380.

The insoluble product obtained on making the aqueous solution alkaline was carefully washed with water and ether. Yield of polymer 10 g. IR spectrum: 695, 735, 800, 850 cm^{-1}.

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