322. *Physical Properties and Chemical Constitution. Part XXXVIII.* The Electric Dipole Moments of Aminopyridines and Aminoquinolines.*

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The electric dipole moments of the three aminopyridines and seven aminoquinolines have been determined by measuring the dielectric constants, specific volumes, and refractive indices of their solutions in pure benzene at 25·00°. The apparent moment of the amino-group, which is at an angle to the plane of the heterocyclic ring, has been calculated for each compound and the values obtained are discussed. They show a considerable variation.

The electric dipole moments of monosubstituted pyridines and quinolines have already been discussed in this series;[1-3] this communication extends the experimental data to amino-compounds. The amino-group has an appreciable mesomeric moment and differs from the substituents investigated previously in that its group moment is inclined at an angle to the plane of the heterocyclic ring. The group can rotate about the C–N bond[4] but the average group moment may be considered to lie in a plane perpendicular to that of the heterocyclic ring.[5] Investigations into the steric repression of mesomerism in amino-compounds[5,6] have demonstrated that the mesomeric moment can be large and would be expected to vary with the position of the substituent in the heterocyclic molecules. The interaction between group moments can also be large in amino-compounds.[6,7]

* Part XXXVII, *J.*, 1962, 4525.

1 Cumper, Vogel, and Walker, *J.*, 1956, 3621; Cumper and Vogel, *J.*, 1960, 4723.
2 Cumper, Redford, and Vogel, *J.*, 1962, 1176, 1183.
3 Cumper, Ginman, and Vogel, *J.*, 1962, 1188.
4 Grubb and Smyth, *J. Amer. Chem. Soc.*, 1961, **83**, 4873.
5 Smith, *J.*, 1961, 81.
6 Smith and Walshaw, *J.*, 1957, 4527.
7 Le Fèvre and Smith, *J.*, 1932, 2239.

Experimental and Results

The apparatus, experimental techniques, methods of calculation, and presentation of results are as described previously.[2,3] The measured properties of the benzene solutions are presented in Table 1 and the polarisation data and dipole moments (μ) in Table 2. 4-Aminopyridine is only sparingly soluble in benzene so that in spite of measuring a greater number of

Table 1.

Aniline

$100w_2$	ε_{12}	v_{12}	n_{12}
0·1009	2·2755	1·14429	1·49786
0·1285	2·2761	1·14423	1·49788
0·2747	2·2804	1·14399	1·49808
0·5901	2·2901	1·14348	1·49832
1·2037	2·3079	1·14244	1·49873
1·5612	2·3183	1·14181	1·49903
1·5751	2·3188	1·14178	1·49903

3-Aminopyridine

$100w_2$	ε_{12}	v_{12}	n_{12}
0·0873	2·2832	1·14423	1·49787
0·1614	2·2917	1·14400	1·49806
0·5773	2·3421	1·14280	1·49863
0·7240	2·3605	1·14237	1·49870
0·7264	2·3612	1·14235	1·49870
1·0458	2·3918	1·14147	1·49901
1·3261	2·4239	1·14066	1·49923

2-Aminoquinoline

$100w_2$	ε_{12}	v_{12}	n_{12}
0·0593	2·2755	1·14428	1·49753
0·1074	2·2778	1·14413	1·49763
0·1372	2·2792	1·14403	1·49763
0·1680	2·2808	1·14392	1·49771
0·2032	2·2817	1·14379	1·49780
0·2305	2·2835	1·14369	1·49782
0·2616	2·2846	1·14358	1·49788
0·3020	2·2865	1·14349	1·49791
0·3253	2·2874	1·14341	1·49793
0·3412	2·2886	1·14333	1·49796

4-Aminoquinoline

$100w_2$	ε_{12}	v_{12}	n_{12}
0·0247	2·2759	1·14437	1·49743
0·0463	2·2787	1·14424	1·49748
0·0763	2·2820	1·14399	1·49762
0·1136	2·2865	1·14407	1·49761
0·1342	2·2900	1·14398	1·49760
0·1595	2·2921	1·14390	1·49763
0·2086	2·2986	1·14371	1·49773
0·2383	2·3030	1·14359	1·49776
0·2800	2·3098	1·14344	1·49782

6-Aminoquinoline

$100w_2$	ε_{12}	v_{12}	n_{12}
0·0836	2·2790	1·14414	1·49773
0·1470	2·2842	1·14392	1·49773
0·2413	2·2921	1·14361	1·49800
0·3959	2·3048	1·14306	1·49830
0·4348	2·3087	1·14295	1·49848
0·7464	2·3346	1·14188	1·49891
0·9088	2·3490	1·14131	1·49921

8-Aminoquinoline

$100w_2$	ε_{12}	v_{12}	n_{12}
0·1097	2·2742	1·14412	1·49785
0·2534	2·2761	1·14360	1·49807
0·3252	2·2776	1·14333	1·49822
0·4213	2·2789	1·14306	1·49840
0·4701	2·2797	1·14290	1·49859
0·5946	2·2811	1·14244	1·49868
0·8314	2·2843	1·14175	1·49904

2-Aminopyridine

$100w_2$	ε_{12}	v_{12}	n_{12}
0·0926	2·2772	1·14420	1·49772
0·4074	2·2932	1·14340	1·49783
0·4301	2·2947	1·14333	1·49784
0·6428	2·3054	1·14280	1·49801
0·9783	2·3228	1·14195	1·49827
1·2861	2·3390	1·14117	1·49862
1·6971	2·3606	1·14009	1·49898

4-Aminopyridine

$100w_2$	ε_{12}	v_{12}	n_{12}
0·00517	2·2731	1·14442	1·49773
0·00909	2·2738	1·14440	1·49776
0·01328	2·2742	1·14437	1·49775
0·02271	2·2762	1·14435	1·49775
0·03504	2·2782	1·14432	1·49775
0·03720	2·2784	1·14428	1·49773
0·04523	2·2800	1·14427	1·49772
0·05595	0·2823	1·14427	1·49772
0·06209	2·2833	1·14425	1·49769

3-Aminoquinoline

$100w_2$	ε_{12}	v_{12}	n_{12}
0·0595	2·2767	1·14424	1·49769
0·1308	2·2829	1·14395	1·49783
0·3340	2·2972	1·14329	1·49826
0·4216	2·3046	1·14303	1·49836
0·5942	2·3167	1·14240	1·49862
1·0160	2·3486	1·14094	1·49936
1·2435	2·3677	1·14013	1·49975

5-Aminoquinoline

$100w_2$	ε_{12}	v_{12}	n_{12}
0·1372	2·2854	1·14399	1·49786
0·2349	2·2950	1·14360	1·49807
0·3749	2·3088	1·14311	1·49824
0·5972	2·3310	1·14235	1·49857
0·8510	2·3558	1·14155	1·49898
1·1234	2·3848	1·14054	1·49962
1·2831	2·4019	1·13996	1·49962

7-Aminoquinoline

$100w_2$	ε_{12}	v_{12}	n_{12}
0·0982	2·2774	1·14412	1·49771
0·1816	2·2823	1·14383	1·49779
0·3503	2·2931	1·14323	1·49818
0·3811	2·2938	1·14315	1·49819
0·8283	2·3194	1·14178	1·49894
0·9934	2·3299	1·14116	1·49919
1·1538	2·3402	1·14075	1·49944

TABLE 2.

Compound	α	β	$_\infty P_2$ (cm.^{3})	R_D (cm.^{3})	$_oP$ (cm.^{3})	μ (D)	Previous values for C_6H_6 solns.
Aniline	2·93$_2$	−0·168$_0$	77·44	30·63	47·82	1·53	1·51—1·54,[a] 1·53[b]
2-Aminopyridine ...	2·36$_3$	−0·256$_8$	116·9	28·89	88·0	2·08	2·17,[c] 2·06,[d] 2·04[e]
3-Aminopyridine ...	11·4$_4$	−0·285$_4$	226·6	29·50	197·1	3·11	3·19,[c] 3·12[e]
4-Aminopyridine ...	18·0$_3$	−0·388$_4$	340·4	30·15	310·2	3·90	3·79,[c] 3·97[d] 3·95[e]
2-Aminoquinoline ...	4·50$_9$	−0·320$_2$	157·6	47·12	110·5	2·33	
3-Aminoquinoline ...	7·47$_7$	−0·346$_2$	237·0	47·99	189·0	3·04	
4-Aminoquinoline ...	12·5$_0$	−0·354$_6$	272·8	47·04	324·8	3·99	3·97[f]
5-Aminoquinoline ...	10·0$_4$	−0·345$_3$	506·5	48·06	254·4	3·56	
6-Aminoquinoline ...	8·46$_1$	−0·347$_0$	263·7	48·58	215·2	3·24	
7-Aminoquinoline ...	5·81$_8$	−0·322$_6$	193·1	48·13	144·9	2·66	
8-Aminoquinoline ...	1·41$_3$	−0·331$_0$	73·26	48·20	25·06	1·11	

[a] Measurements prior to 1948 from Wesson "Tables of Electric Dipole Moments," Massachusetts Inst. Technol., 1948. [b] Few and Smith, *J.*, 1949, 753. [c] Goethals, *Rec. Trav. chim.*, 1935, **54**, 299; Goethals and Wibaut, *ibid.*, 1954, **73**. 35. [d] Rogers, *J. Phys. Chem.*, 1956, **60**, 125. [e] Barassin and Lumbroso, *Bull. Soc. chim. France*, 1961, 492. [f] Edgerley, quoted by Short, *J.*, 1952, 4584.

solutions the moment we report for this molecule is of a lower accuracy than for the other amino-compounds. Aniline has been studied for purposes of comparison.

Preparation of Pure Compounds.—Each compound was extensively purified immediately before its dipole moment was determined. The infrared and ultraviolet spectra of these compounds, their m. p.s and also those of their derivatives were in good agreement with published data where available.

Aniline. A sample of AnalaR aniline (Hopkin and Williams) was fractionated, converted into its acetyl derivative and recrystallised from water to a constant m. p. of 114°; the regenerated aniline, fractionated twice, had b. p. 184·5°/750 mm., n_D^{20} 1·58563, d_4^{20} 1·0220.

2-*Aminopyridine.* 2-Aminopyridine (Hopkin and Williams) was purified by recrystallising it from light petroleum (b. p. 40—60°) to a constant m. p. of 58·5°.

3-*Aminopyridine.* 3-Aminopyridine (Fluka) was purified by recrystallising it successively from chloroform and from benzene to a constant m. p. of 64·5°.

4-*Aminopyridine.* 4-Aminopyridine (Fluka) was purified by recrystallising it from a benzene–alcohol mixture to a constant m. p. of 159°.

2-*Aminoquinoline.* (i) Sodamide, from sodium (37·5 g.) and liquid ammonia (1 l.), was heated with xylene (300 ml.), and dry quinoline (100 ml.; b. p. 104°/12 mm.) added during 1½ hr. The excess of sodamide was decomposed with water (500 ml.), and concentrated hydrochloric acid (100 ml.) was added to dissolve solids. The acid layer was made alkaline with sodium hydroxide, and the 2-aminoquinoline extracted with ether. The extract was dried and the ether evaporated. The product (32 g.) was fractionally distilled (b. p. 182—183°/18 mm.) and recrystallised from benzene to give plates (constant m. p. 129—130°) (Found: C, 74·8; H, 5·7; N, 19·9. Calculated for $C_9H_8N_2$: C, 75·0; H, 5·6; N, 19·4%). The picrate had m. p. 266—267°.

(ii) 2-Chloroquinoline [2] (10 g.; b. p. 148°/15 mm.) and phenol (55 g.) were refluxed and dry ammonia gas passed through the mixture for 12 hr. The 2-aminoquinoline, isolated as detailed below under 4-aminoquinoline, was dried in a vacuum desiccator and recrystallised from benzene to a constant m. p. of 129·5—130·5° (3 g.). The picrate had m. p. 266°.

3-*Aminoquinoline.* 3-Aminoquinoline (Eastman-Kodak) was recrystallised from benzene to give needles, constant m. p. 93·5°.

4-*Aminoquinoline.* Backeberg and Marais's method [8] was used in which 4-chloroquinoline [2] (2·5 g., b. p. 81°/0·5 mm.) and phenol (10 g.) are refluxed on an oil bath and dry ammonia gas bubbled through the mixture. Water was added and the phenol removed by steam distillation. 4-Aminoquinoline was precipitated with sodium hydroxide and separated from ethanol as the monohydrate, m. p. 69—70° (2·1 g.). After drying and recrystallisation from benzene, the anhydrous compound had m. p. 156—157°. The picrate softened at 274° and melted at 281°.

5-*Aminoquinoline.* 5-Nitroquinoline [2] (8·6 g., m. p. 71°) in ethanol (200 ml.) was reduced in a Towers low-pressure hydrogenator with 10% palladium on charcoal (2·5 g., 10% Pd) as catalyst. The solvent was removed and the residue crystallised successively from ethanol and from benzene to a constant m. p. (1·6 g.; 107·5—108·5°) (Found: C, 75·3; H, 5·7; N, 19·2. Calculated for $C_9H_8N_2$: C, 75·0; H, 5·6; N, 19·4%). The picrate had m. p. 218—219°.

[8] Backeberg and Marais, *J.*, 1942, 381.

6-*Aminoquinoline*. 6-Nitroquinoline [2] (m. p. 152°) was reduced with tin and hydrochloric acid. Purification was by recrystallisation from benzene to yield deep yellow needles (m. p. 116°). Dilute solutions had a deep blue fluorescence.

7-*Aminoquinoline*. 7-Nitroquinoline [2] (m. p. 133°) in acetone was reduced in a hydrogenator using platinum oxide catalyst. The solution was filtered, the solvent removed, and the product recrystallised from benzene to give the monohydrate, m. p. 74°. After drying and recrystallisation from anhydrous benzene, the compound had m. p. 93—94°. The orange needles showed little fluorescence in solution.[9] The picrate had m. p. 235—237°.

8-*Aminoquinoline*. Dewar and Mole's method [10] was employed in which 8-nitroquinoline [2] (m. p. 88—89°) in ethanol solution is reduced with hydrazine hydrate by using palladium on charcoal as catalyst. The 8-aminoquinoline was recrystallised from ethanol to a constant m. p. (64—65°). The light yellow needles formed an orange picrate [m. p. 204—205° (decomp.)].

Discussion

It has been suggested that part of the 2- and the 4-aminopyridine might exist in an imino-form in solution. Evidence from measurements of dipole moments, basicities, and infrared spectra [11-13] however indicates that this is unlikely. In 8-aminoquinoline the amino-hydrogen atoms probably do interact with the heterocyclic nitrogen atom, but only the amino-form is considered to contribute to the dipole moment of the other compounds studied.

The geometrical structure of pyridine is well established [14] and that of quinoline was discussed in an earlier paper.[2] The amino-substituent can normally rotate about the N–C bond [4] but there is a tendency for the conformation in which the amino-group is as nearly coplanar as possible with the ring to predominate because in this position the interaction between the lone pair electrons on the nitrogen atom and the π-electrons in the ring is a maximum. The direction of the amino-group moment is consequently inclined to the plane of the heterocyclic ring. Smith,[5] who analysed the dipole moments of several amines, concluded that an amino-group attached to a benzene ring has an apparent moment of 1·53 D inclined at an angle of 48·5° to the plane of the aromatic ring; the component moment perpendicular to the ring being 1·15 D and that along the N–C bond 1·01 D. A substantial contribution towards the dipole moment arises through conjugation between the amino-group and the ring—Smith suggests that this mesomeric moment might be 1·67 D in aniline. This mesomeric moment will be somewhat different in aminopyridines and aminoquinolines which will consequently have slightly different values for the angle and component moments quoted above.

The apparent moments of the amino-group, relative to that of a C–H (*i.e.*, $\mu_{C-NH_2}-\mu_{C-H}$) bond and not corrected for any effect of the solvent, are listed in Table 3 for the molecules under discussion. These have been obtained by vector analysis of the dipole moments, taking those of pyridine and quinoline to be 2·21 D[1] and 2·15 D[2] (taken to be in the C_4–N direction) respectively in benzene solution, and for the conformation in which a line passing through the amino-hydrogen atoms is parallel to the ring.*

The values listed under μ_1 were calculated on the assumption that the component of the group moment perpendicular to the plane of the ring is 1·15 D, and for μ_2 that the group moment is inclined at 48·5° to the plane of the ring, as discussed above for aniline.

Neither assumption can be strictly correct and the actual group moments probably lie

* The same group moments would be obtained if instead of this fixed conformation there was completely free rotation about the C–N bond.

9 Hamer, *J.*, 1921, **119**, 1432.
10 Dewar and Mole, *J.*, 1956, 2556.
11 Lies and Curran, *J. Amer. Chem. Soc.*, 1945, **67**, 79; Angyal and Angyal, *J.*, 1952, 1461.
12 Albert, Goldacre, and Phillips, *J.*, 1948, 2240; see also McDaniel and Brown, *J. Amer. Chem. Soc.*, 1955, **77**, 3756.
13 Angyal and Werner, *J.*, 1952, 2911; Goulden, *J.*, 1952, 2939.
14 Bak, Hansen-Nygaard and Rastrup-Andersen, *Mol. Spectroscopy*, 1958, **2**, 361; cf. Cumper, *Trans. Faraday Soc.*, 1958, **54**, 1266.

TABLE 3.

Compound	μ_1 (D)	μ_2 (D)	π-Electron charge	pK_a *
2-Aminopyridine	—†	1·01	+0·021	6·86
3-Aminopyridine	1·59	1·61	+0·005	5·98
4-Aminopyridine	1·90	2·06	+0·020	9·17
2-Aminoquinoline	2·36	1·95	+0·032	7·34
3-Aminoquinoline	1·57	1·58	+0·000	4·95
4-Aminoquinoline	2·03	2·23	+0·027	9·17
5-Aminoquinoline	1·68	1·75	+0·004	5·46
6-Aminoquinoline	1·78	1·85	+0·001	5·63
7-Aminoquinoline	2·95	2·50	+0·006	6·65
8-Aminoquinoline	—†	—†	−0·003	3·99

* pK_a value for pyridine is 5·23 and for quinoline 4·94.
† The solutions from the quadratic equation in these cases are imaginary.

between μ_1 and μ_2; the relative order of the group moments for 2- and 4-aminoquinoline is reversed in the two series. No allowance has been made for any difference in the solvent effect with the various isomers.

There are several reasons why the group moment of a substituent is not constant in the compounds investigated; some of these were discussed in Part XXXIII.[2] The dipole moment of α-naphthylamine [5] (1·50 D) is only slightly lower than that of aniline (1·53 D) but β-naphthylamine [15] (1·77 D) possesses a substantially greater moment arising from an enhanced mesomeric moment and a polarisation of the unsubstituted ring. The amino-group moments in 2-, 3-, 6-, and 7-aminoquinoline would be increased for the same reasons. The extent of conjugation, and with it the mesomeric moment, also varies between the isomers. Infrared spectral studies [13] for example indicate that conjugation in the amino-pyridines increases in the order $3 < 2 < 4$. The substituent reduces the electronegativity of the carbon atom to which it is attached and this lowers the apparent group moment for the 2- and the 7-position in quinoline, increases it for the 3- and the 6-position and increases it still further for the 4-, 5-, and 8-isomers.[2] Another important factor is the π-electron charge on the substituted carbon atom of the parent molecule; one estimate of these charges [3] is given in Table 3. The relatively high charges on carbon-2 and carbon-4 in particular would increase the amino-group moment in these positions. Finally the primary moment of the heterocyclic molecule, located near its nitrogen atom,[16] will polarise the amino-substituent; this is greatest for 2-aminopyridine and 2- and 8-aminoquinoline where it lowers the group moments.

The relative order of the amino-group moment in the compounds investigated is consequently difficult to predict since it is determined by several factors. Similar factors affect the basic strength of these compounds and there seems to be a rough correlation for most of the compounds between the pK_a values [12] of these compounds in water and the amino-group moments (Table 3). The pK_a values also depend upon the nature of the protonated molecules so this comparison is not completely valid, particularly for 2-amino-pyridine and 2- and 8-aminoquinoline.

The group moment in 7-aminoquinoline and its pK_a value are unexpectedly great; it is interesting that the methyl-group moment in 7-methylquinoline is also greatly different from that in the other methylquinolines.[2] No group moment can be calculated for 8-aminoquinoline because of the interaction between an amino-hydrogen atom and the lone-pair electrons of the heterocyclic nitrogen atom. This interaction, which is confirmed by analysis of the infrared spectra,[17] would alter the magnitude and direction of the resultant dipole moment in this molecule.

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[15] Wassiliew and Syrkin, *Acta Physicochim. U.R.S.S.*, 1941, **14**, 414; *J. Phys. Chem.*, *U.S.S.R.*, 1941, **15**, 254.
[16] Brown and Heffernan, *Austral. J. Chem.*, 1957, **10**, 493; Cumper, *Chem. and Ind.*, 1958, 1628.
[17] Short, *J.*, 1952, 4584.