Electric Dipole Moments of Some Imidazolin-2(3*H*)-ones, Benzimidazol-2(3*H*)-ones, and Analogous Thiones

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The electric dipole moments of imidazolin-2(3*H*)-one, benzimidazol-2(3*H*)-one, their mono- and di-*N*-methyl derivatives, and of the analogous thiones have been determined for benzene and 1,4-dioxan solutions at 25 °C. The results are discussed in terms of tautomerism and molecular conformations.

THE saturated five-membered imidazolidine ring is unstable although imidazolin-2(3*H*)-ones, benzimidazol-2(3*H*)-ones, and their analogous thiones are stable. Provided the protons on both nitrogen atoms have not been substituted these compounds can exist in solution as an equilibrium mixture of tautomers; this is prevented by methylation of both nitrogen atoms but, in some cases, the other form can be isolated as its methyl ether or sulphide. From the electric dipole moments of these extreme forms and the average values for tautomeric mixtures it was hoped to be able to investigate the equilibria. Measurements have been made for benzene and 1,4-dioxan solutions since the latter solvent should change the equilibrium compositions by complexing with acidic protons in the solute molecules.

EXPERIMENTAL AND RESULTS

Preparation and Purification of Compounds.—The purification of both solvents has been described.[1] Dipole moment measurements were made immediately after the final purification of each compound. Imidazolin-2(3*H*)-one was prepared [2] by heating an equimolar mixture of ethylenediamine and urea in the presence of water as a moderater. The product was recrystallised from chloroform and from dioxan to a constant m.p. 134 °C. 1-Methylimidazolin-2(3*H*)-one was obtained in poor yield from imidazolin-2(3*H*)-one and dimethyl sulphate,[3] in sodium hydroxide solution. The product was evaporated to dryness, sublimed *in vacuo*, and the lower-melting portion of the sublimate recrystallised from ethyl acetoacetate and from benzene to a constant m.p. 113—114 °C. 1,3-Dimethylimidazolin-2(3*H*)-one, obtained from a 2 : 1 molar ratio of methyl toluene-*p*-sulphonate and imidazolin-2(3*H*)-one, was diluted with sodium ethoxide solution, filtered and fractionated, b.p. 94—95° at 11 mmHg. Benzimidazol-2(3*H*)-one, formed by condensing *o*-phenylenediamine with urea [4] in the presence of concentrated hydrochloric acid, was extracted with sodium hydroxide solution, acidified, filtered, and recrystallised from ethanol to a constant m.p. 315 °C. 1-Methylbenzimidazol-2(3*H*)-one, obtained from refluxing benzimidazol-2(3*H*)-one in 25% aqueous potassium hydroxide solution with dimethyl sulphate, was washed with water, filtered, sublimed *in vacuo*, and recrystallised from ethanol to a constant m.p. 194 °C. 1,3-Dimethylbenzimidazol-2(3*H*)-one was formed from excess of dimethyl sulphate and benzimidazol-2(3*H*)-one in potassium hydroxide solution. The pure product, obtained from light petroleum (b.p. 80—100 °C), had m.p. 107 °C. Benzimidazole was treated with phosphoryl chloride in the presence of HCl gas,[5] and the 2-chlorobenzimidazole formed heated with dimethyl sulphate, refluxed with sodium methoxide solution,[6] filtered, and the filtrate evaporated to dryness. The residue was mixed with water and the 2-methoxy-1-methylbenzimidazole recrystallised from aqueous methanol to a constant m.p. 44 °C.

Imidazoline-2(3*H*)-thiones were prepared by reacting ethylenediamine, or its methyl derivatives, with carbon disulphide in 95% ethanol, refluxing the resulting thiocarbamic acids with concentrated mineral acid and recrystallising the product to a constant m.p.[7] Thus were obtained imidazoline-2(3*H*)-thione, m.p. 198 °C; 1-methylimidazoline-2(3*H*)-thione, m.p. 132 °C; 1,3-dimethylimidazolidine-2(3*H*)-thione, m.p. 112 °C.

Benzimidazole-2(3*H*)-thione was obtained by reacting *o*-phenylenediamine with potassium ethyl xanthante and treating the product with dilute acid [8] and recrystallising from 95% ethanol to a constant m.p. 304 °C. Derivatives of this thione were prepared by the methods of Futaki.[9] 2-Methylthiobenzimidazole, m.p. 20 °C; 1-methylbenzimidazole-2(3*H*)-thione, m.p. 191 °C; 1-methyl-2-methylthiobenzimidazole, m.p. 57—57·5 °C; 1,3-dimethylbenzimidazole-2(3*H*)-thione, m.p. 152 °C.

Physical Measurements.—For each solute appropriate measurements were made as described previously [10] upon dilute solutions in the relevant solvent at 25·0 °C. Electric permittivities, specific volumes, and refractive indices are given in SUP No. 20514 (5 pp.).† Table 2 lists the slopes of the graphs of electric permittivity (α), specific volume (β), and refractive index squared (γ) against weight fraction w_2, together with the polarisation data and dipole moments (μ) computed by the standard methods.[10]

When the plot of electric permittivity against weight fraction was not linear the points were fitted to an equation of the form $\varepsilon = \varepsilon + \alpha w_2 + \alpha' w_2^2$ and the limiting gradient at infinite dilution (α) employed to calculate the dipole moment. The solubilities of imidazolin-2(3*H*)-one in benzene and of imidazoline-2(3*H*)-thione in 1,4-dioxan solution restricted the maximum weight fractions in these

† See note about Supplementary Publications in Notice to Authors No. 7 in *J. Chem. Soc.* (*A*), 1970, Issue No. 20 (items less than 10 pp. are supplied as full size copies).

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TABLE 1

Polarisation data and dipole moments in mixed benzene–1,4-dioxan solution

Compound	% Benzene	Maximum $10^6 w_2$	α	α'	β	γ	P_T (cm^3)	R_D (cm^3)	μ (D)
Benzimidazol-2(3*H*)-one	79·99	265	$4{\cdot}24_5$	4870	−0·312		120		2·0
	60·26	497	$5{\cdot}56_3$	7300	−0·152		131:2		2·15
	39·50	832	$5{\cdot}01_9$		−0·270		142·5		2·29
	20·03	1342	$5{\cdot}51_7$		−0·388		149·4		2·35
	0·00	2266	$6{\cdot}03_4$		−0·289	−0·556	159·6	36·51	2·46
Imidazoline-2(3*H*)-thione	79·99	496	$29{\cdot}7_6$		−0·620		572·4		5·16
	60·26	1028	$32{\cdot}3_6$		−0·445		609·7		5·33
	39·50	2014	$34{\cdot}7_0$	−530	−0·390		633·6		5·43
	20·03	2930	$36{\cdot}9_8$	−1000	−0·282		661·5		5·56
	0·00	718	$39{\cdot}8_5$	−2900	−0·416		686·7	(29·7)	5·67
Benzimidazole-2(3*H*)-thione	80·26	1794	$12{\cdot}3_2$		−0·450	0·859	368·8	50·80	3·93
	60·16	5852	$13{\cdot}2_1$	−78	−0·411	0·771	384·3	49·65	4·05
	41·73	10,081	$13{\cdot}9_0$	−55	−0·341	0·821	395·4	51·55	4·10
	19·91	12,602	$14{\cdot}5_8$	−32	−0·320	0·811	400·4	49·57	4·14
	0·00	11,939	$14{\cdot}9_0$		−0·272	0·826	398·8	49·22	4·14

TABLE 2

Polarisation data and experimental and calculated dipole moments at 25·0 °C

Compound	α	α'	β	γ	P_T (cm^3)	R_D (cm^3)	μ_{exp} (D)	μ_I	μ_{IIa}	μ_{IIb}
Benzene solution										
Imidazolidin-2-one	$19{\cdot}5_2$	−10,900	−0·764		325·7	(21·1)	3·86	2·15	0·96	2·79
	$12{\cdot}8_8$				218·2		3·1			
1-Methylimidazolin-2(3*H*)-one	$14{\cdot}9_2$	−935	−0·213	0·043	309·1	27·95	3·72	2·33	0·87	3·15
1,3-Dimethylimidazolin-2(3*H*)-one	$6{\cdot}21_1$		−0·169	−0·151	166·4	29·35	2·58	2·44		
Benzimidazol-2(3*H*)-one					(115)	(36·9)	(1·9)	2·15	0·96	2·79
1-Methylbenzimidazol-2-(3*H*)-one	$2{\cdot}64_3$	−145	−0·421		105·5	(41·7)	1·77	2·33	0·87	3·15
1,3-Dimethylbenzimidazol-2(3*H*)-one	$4{\cdot}34_8$		−0·311	0·243	172·9	47·11	2·49	2·44		
2-Methoxy-1-methylbenzimidazole	$5{\cdot}48_4$		−0·294	0·235	208·3	47·69	2·80		0·91	2·80
Imidazoline-2(3*H*)-thione					(550)	(29·7)	(5·0)	2·49	1·50	2·40
1-Methylimidazoline-2(3*H*)-thione	$21{\cdot}3_4$	−395	−0·356	0·368	493·4	35·02	4·74	2·66	1·59	2·68
1,3-Dimethylimidazoline-2(3*H*)-thione	$23{\cdot}1_8$		−0·307	0·255	599·1	38·30	5·24	2·78		
Benzimidazole-2(3*H*)-thione					(348)	(49·5)	(3·8)	2·49	1·50	2·40
1-Methylbenzimidazole-2(3*H*)-thione	$6{\cdot}71_1$		−0·405	0·489	243·4	50·90	3·07	2·66	1·59	2·68
1,3-Dimethylbenzimidazole-2(3*H*)-thione	$10{\cdot}3_9$		−0·347	0·477	388·5	57·86	4·04	2·78		
2-Methylthiobenzimidazole	$4{\cdot}69_9$	−120	−0·521	0·562	175·6	47·61	2·50		1·04	2·57
	$4{\cdot}57_4$				171·7		2·5			
1-Methyl-2-methylthiobenzimidazole	$4{\cdot}15_6$		−0·341	0·378	181·9	54·07	2·51		1·06	3·00
1,4-Dioxan solution										
Imidazolin-2(3*H*)-one	$23{\cdot}5_1$	−500	−0·275	0·275	336·9	19·42	4·02 [a]			
1-Methylimidazolin-2(3*H*)-one	$21{\cdot}7_3$	−200	−0·107	0·204	383·1	25·60	4·18			
1,3-Dimethylimidazolin-2(3*H*)-one	$7{\cdot}41_6$		0·073	0·053	173·7	31·37	2·64			
Benzimidazol-2(3*H*)-one	$6{\cdot}03_4$		−0·289	0·556	159·6	36·51	2·46			
1-Methylbenzimidazol-2(3*H*)-one	$5{\cdot}52_9$	−20	−0·182	0·546	168·6	44·02	2·49			
1,3-Dimethylbenzimidazol-2(3*H*)-one	$5{\cdot}03_5$		−0·092	0·433	175·5	48·47	2·51			
2-Methoxy-1-methylbenzimidazole	$6{\cdot}71_2$		−0·084	0·381	220·7	47·72	2·91			
Imidazolin-2(3*H*)-thione	$39{\cdot}8_5$	−2900	−0·416		686·7	(29·7)	5·67 [b]			
	$37{\cdot}7_2$				651		5·52			
1-Methylimidazoline-2(3*H*)-thione	$32{\cdot}9_5$	−99	−0·165	0·441	657·4	33·09	5·53			
1,3-Dimethylimidazoline-2(3*H*)-thione	$28{\cdot}9_5$		−0·082	0·438	654·0	39·72	5·48			
Benzimidazole-2(3*H*)-thione	$14{\cdot}9_0$		−0·272	0·826	398·8	49·22	4·14			
1-Methylbenzimidazole-2(3*H*)-thione	$13{\cdot}5_7$	25	−0·228	0·757	402·1	53·56	4·15			
1,3-Dimethylbenzimidazole-2(3*H*)-thione	$12{\cdot}5_0$		−0·150	0·681	409·1	59·19	4·16			
2-Methylthiobenzimidazole	$7{\cdot}15_9$	16	−0·179	0·618	231·1	51·46	2·99			
1-Methyl-2-methylthiobenzimidazole	$5{\cdot}19_5$		−0·153	0·559	194·5	55·10	2·58			

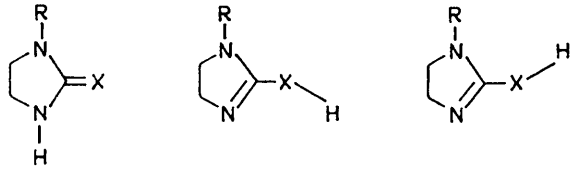
Values enclosed in parentheses could not be obtained by direct measurement because of low solubility (see Table 1). Literature values [a] 3·94 [11]; [b] 5·52. [12]

cases to 0·0007 and consequently the values quoted in Table 2 for α' are not meaningful. The dipole moments computed from a linear plot (also given in Table 2) may be the more reliable results. Three solutes, imidazoline-2(3*H*)-thione, benzimidazol-2(3*H*)-one, and benzimidazole-2(3*H*)-thione were not sufficiently soluble to be studied in benzene but measurements were made in mixed benzene–dioxan solvents and the dipole moments obtained (Table 1) were extrapolated to give values for solution in pure benzene.

DISCUSSION

In analysing the dipole moments of the compounds which possess a free *N*-hydrogen atom several features must be kept in mind.

(a) The keto form (I) may enolise to give (IIa) and/or (IIb). It is most unlikely that there is free rotation



about the C–X single bond in the enolised forms since the system has a minimum energy when the *p*-type orbitals of the O(or S), C, and two N atoms are parallel. By analogy with the conformations of carboxylic acids, esters, and amides [13] (IIa) would be expected to possess a lower energy than (IIb) and be the predominant form. This tautomerism is less likely in the thiones.

(b) In the crystalline state there is a strong intermolecular association, by hydrogen bonding, between the molecules since their m.p.s are considerably greater than for the 1,3-dimethyl derivatives. Irrespective of whether the molecules are in the keto or enol forms hydrogen bonding could also cause association to take place in solution, but at the lowest concentrations employed in this investigation this is unlikely to be extensive. When α' in Tables 1 and 2 is zero or small, it is reasonable to disregard any effect of solute association on the measured dipole moment; when α' is substantial, association is occurring and the reported dipole moment for the monomer may be in error.

(c) In 1,4-dioxan solution these solutes form hydrogen bonds to the solvent molecules and this reduces any tendency to solute association. The increment in dipole moment resulting from such complex formation is *ca.* 0·1—0·4 D for substituted pyrroles [14] and for various toluidines and aminopyridines.[15]

It is difficult to predict reliable values for the dipole moments of the compounds under consideration because of uncertainties about the bond moments to nitrogen atoms. Accepting the bond moments quoted by Cumper,[16] and taking that of the C=N bond [17] as 1·40 and C=S as 2·67 D,* then for the three structures given above the calculated moments are given in Table 2. Bond angles have not been determined for these molecules; those assumed were based upon the structure of caffeine [19] *viz.* $\widehat{NCN} = 112$, $\widehat{CNC} = 106$, and CNH=$\widehat{CNCH_3} = 127°$.

Thiones and Sulphides.—The electric permittivities of solutions of the benzimidazole-2(3*H*)-thiones are linear with weight fraction so it seems unlikely that association is occurring to any extent at the concentrations employed. The same is true for 1,3-dimethylimidazoline-2(3*H*)-thione but the 1-methyl and probably also the unmethylated imidazoline-2(3*H*)-thiones have negative values for α' indicating some association into a complex of lower dipole moment.

The 1,3-dimethyl derivatives must have structure (I) but their dipole moments are substantially greater than the predicted values of *ca.* 2·8 D; electronic charge must have passed from the nitrogen atoms towards the sulphur atom. The addition of the benzene ring reduces the dipole moments by *ca.* 1·2 D, whereas for the corresponding ketones the difference is only 0·1 D. This requires a flow of charge into the aromatic ring but the difference between thiones and ketones is too large for it to be due entirely to an electronegativity effect. Perhaps the vacant 3*d* orbitals of the sulphur atom are involved in accepting the electronic charge from each nitrogen atom, particularly in the imidazoline-2(3*H*)-thiones where there is no competition from the aromatic ring. The other unexpected feature with these two compounds is the substantial differences (0·12 and 0·24 D) between the measurements made in the two solvents. When there is no possibility of hydrogen bonding to dioxan the normal solvent effect is much less (*cf.* 0·02 and 0·06 D for the corresponding keto-compounds). Apparently the sulphur atom interacts with one of the solvents.

In dioxan solutions the parent thiones and their two methylated derivatives have virtually the same dipole moments (Figure). It is unlikely that enolisation is taking place to any significant extent; the thione form (I) would of course be stabilised by hydrogen bonding to dioxan molecules. The anticipated increase

* Assumed to be 0·34 D greater than for C=O, this being the difference between the dipole moments of urea (4·59 D) and thiourea (4·93 D).[18]

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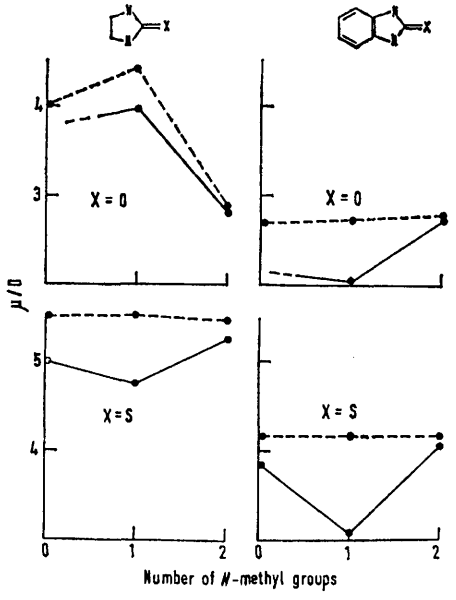
in dipole moment on methylation (Table 2) must be offset by the decrease in the dioxan increment from bonding to the *N*-hydrogen atoms.

In benzene solution the monomethyl derivatives have appreciably lower dipole moments which must



Dipole moments of imidazolin-2(3*H*)-ones, benzimidazol-2(3*H*)-ones and their thione analogues as a function of the number of *N*-methyl groups in benzene (——) and dioxan (– – –) solution

arise from partial enolisation to (IIa). Enolisation appears to be greater, and association less, in 1-methylbenzimidazole-2(3*H*)-thione than in 1-methylimidazoline-2(3*H*)-thione. The unsubstituted parent compounds have intermediate dipole moments implying that little enolisation has taken place.

The two sulphides, 2-methylthiobenzimidazole and 1-methyl-2-methylthiobenzimidazole have dipole moments of about 2·5 D in benzene solution with dioxan increments of 0·49 (augmented by hydrogen bonding) and 0·07 D respectively. These are close to the calculated values for structure (IIb) but, in view of the very low calculated moments for the 1,3-dimethylthiones, their conformations are probably that of (IIa). A dipole moment of 2·50 for the thiol and one of 4·0 D for the thione form of 1-methylbenzimidazole-2(3*H*)-thione requires a thione : thiol ratio of 2·0 to give the experimental result for this compound in benzene solution.

Ketones and Ethers.—From the Figure it is evident that the behaviour of the benzimidazol-2(3*H*)-ones is very similar to that of the thiones discussed above. In dioxan solution there is little, if any, enolisation or association and the magnitude of their dipole moments are as anticipated from the vector addition of group moments. The parent benzimidazol-2(3*H*)-one has a lower dipole moment in benzene solution, indicating some enolisation to (IIa), and it associates fairly strongly to give a complex of lower dipole moment. The introduction of a single methyl group increases the extent of enolisation but decreases the association in benzene solution.

The imidazolin-2(3*H*)-ones behave differently. The dimethylated derivative has a dipole moment only 0·1 D greater than the corresponding benzimidazol-2(3*H*)-one. However, the parent compound and 1-methylimidazolin-2(3*H*)-one have larger dipole moments and associate readily in solution, particularly in benzene, to form complexes with lower dipole moments. The dipole moments reported in Tables 1 and 2 and in the Figure for these two compounds are probably in error because of this marked association but if the increase in moment is correct then appreciable enolisation must have occurred to give structure (IIb), which is normally the less stable form. The ether, 2-methoxy-1-methylbenzimidazole has a dipole moment of 2·80 D in benzene solution indicating that it exists substantially in the same (IIb) form.

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