

Configuration and Conformation of Acyl Derivatives of Hydroxylamine. Part 22.^{1a} Hydroxamoyl Chlorides. A Revision

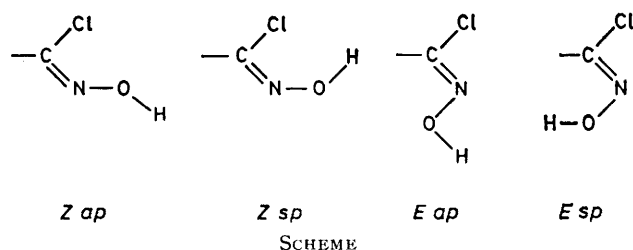
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The analysis of the i.r. spectra of hydroxamoyl chlorides (Ia—d) under different conditions points to the *Z*-configuration in solution, *i.e.* the same configuration as established previously in the crystalline state by *X*-ray measurements. The previous arguments favouring the *E*-configuration are thus rebutted. This conclusion is supported by empirical correlations of i.r. frequencies, ¹H and ¹³C n.m.r. chemical shifts, and by a revised analysis of dipole moments taking into account an aliphatic derivative and referring to the *O*-benzoyl derivatives (II) as model compounds. The original erroneous assignment was caused by the use of less efficient model compounds and by the low sensitivity of the dipole moments of (I) to the configuration.

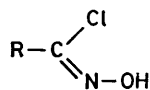
THE configuration on the C=N double bond of hydroxamoyl chlorides is a stereochemical problem which is still controversial.^{1b} In fact, although the *Z*-configuration of 4-nitrobenzohydroxamoyl chloride (Ic) in the solid state has been recently established by *X*-ray crystallography,² a change of configuration as well as an equilibrium between the *E*- and *Z*-forms cannot be excluded for the solution state, since both possibilities have been demonstrated for other imino-compounds.³ Previous approaches to this problem mainly based on dipole moment measurements have led to contradictory conclusions, the *E*-configuration being preferred by us,^{4,5} the *Z*-configuration by Lumbroso and his associates.⁶⁻⁸ The dipole moment approach, however, was considerably limited by the presence of two stereochemical problems, *i.e.* the configuration of the C=N bond and the conformation of the N-O bond, whose combination gives the four planar arrangements shown in the Scheme. While evidence supports the *ap* con-



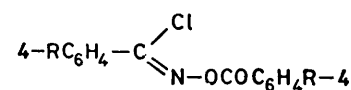
formation for the N-O bond for the majority of imino-compounds,⁹ including hydroxamoyl chlorides,⁴⁻⁷ dipole moment studies^{4,5,8} and other experimental approaches⁶ were equally inefficient in solving the problem of the configuration of the C=N bond. The *Z*-configuration has recently been established for the *O*-benzoyl derivatives (II) from a dipole moment study,¹ and the identical stereochemistry is likely to occur in the parent compounds (I).

The aim of the present paper is to investigate whether the configuration of hydroxamoyl chlorides (I) in solution is the same as established previously for the

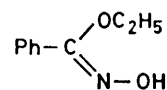
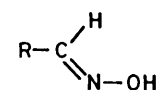
solid state.² The results from i.r. spectroscopy as well as some empirical correlations from ¹H and ¹³C n.m.r. spectroscopy, and a more extensive analysis of the dipole moments point uniformly to the same configura-



- a; R = C₆H₅
 b; R = 4-CH₃OC₆H₄
 c; R = 4-ClC₆H₄
 d; R = 4-NO₂C₆H₄
 e; R = 2,4,6-(CH₃)₃C₆H₂
 f; R = Bu^t



R = H or Cl



ation for compounds (I) under all conditions. Therefore, in contrast to our previous claim,^{4,5} we now assign the *Z*-configuration to compounds (I).

EXPERIMENTAL

M.p.s are uncorrected. I.r. spectra were recorded on a Perkin-Elmer model 621 spectrometer, with a precision of ± 0.5 cm⁻¹ (calibration with NH₃ and H₂O vapour); ¹H and ¹³C n.m.r. spectra (SiMe₄ as internal standard) were measured on Varian HA-100 and CFT-20 instruments operating at 100 and 20 MHz, respectively. U.v. spectra were recorded on a JASCO spectrometer model ORD/UV-5 for the concentration range 10⁻⁵—10⁻³M. The dipole moment measurements were carried out as previously described.¹

Hydroxamoyl chlorides (I) were obtained by chlorination of the corresponding oximes by the NOCl method as previously described.⁵ Benzohydroxamoyl chloride ⁷ (Ia) had m.p. 51—52 °C; ν (C₂H₂Cl₂) 480vw, 590s, 638vw, 670m, 690vs, 706sh, 762vs, 932s, 990vs, 1 025vw, 1 180vw, 1 195vw, 1 232vs, 1 245sh, 1 313vw, 1 335vw, 1 371m, 1 449m, 1 492m,

1 579w, 1 600m, 1 765vw, 3 000vw, 3 025vw, 3 040vw, 3 062m, 3 320br,m, and 3 555s cm^{-1} ; ν (KBr) 3 280s cm^{-1} ; λ (cyclohexane): 247 ($\log \epsilon$ 4.16) and 289sh (2.54) nm. 4-Methoxybenzohydroxamoyl chloride ⁷ (Ib) had m.p. 87—88 °C; ν ($\text{C}_2\text{H}_2\text{Cl}_2$) 515vw, 589m, 598m, 620vw, 659w, 935s, 988s, 1 014w, 1 039s, 1 100vw, 1 119w, 1 178vs, 1 238sh, 1 465m, 1 510vs, 1 573w, 1 600vs, 2 300w, 2 335m, 2 840m, 2 915vw, 2 940w, 2 960w, 3 005w, 3 380br,w, and 3 560s cm^{-1} ; ν (KBr) 3 350s cm^{-1} ; δ (CDCl_3) 3.84 (3 H, s, OCH_3), 6.92 (2 H, d, $J_{3,5}$ 9 Hz), 7.78 (2 H, d, $J_{2,6}$ 9 Hz), and *ca.* 8.4 (1 H, s, OH); δ (CCl_4) 3.82, 6.86, 7.75, and 7.95; δ (Me_2CO ; 37 °C) 3.82, 6.96, 7.76, and 11.05; δ (Me_2CO ; -60 °C) 3.84, 7.04, 7.82, and 11.90; λ (cyclohexane) 211sh ($\log \epsilon$ 4.25), 265 (4.32), and 296 ($\log \epsilon$ 3.30) nm. 4-Chlorobenzohydroxamoyl chloride ⁷ (Ic) had m.p. 88—89 °C; ν ($\text{C}_2\text{H}_2\text{Cl}_2$) 514s, 590s, 622w, 716w, 731w, 833w, 941vs, 998vs, 1 021s, 1 100vs, 1 184m, 1 230s, 1 240s, 1 249s, 1 306vw, 1 376vw, 1 401s, 1 492vs, 1 520vw, 1 600s, 1 609m, 1 703s, 1 910vw, 2 850vw, 2 920vw, 3 040w, 3 350br,m, and 3 560s cm^{-1} ; ν (KBr) 3 300s cm^{-1} ; δ (CDCl_3) 7.34 (2 H, d, $J_{3,5}$ 9 Hz), 7.74 (2 H, d, $J_{2,6}$ 9 Hz), and 8.41 (1 H, s, OH); λ (cyclohexane) 218sh, (log ϵ 4.03), 256 (4.21), and 284sh (3.15), 292 (2.72) nm. 4-Nitrobenzohydroxamoyl chloride ⁷ (Id) had m.p. 124—125 °C; ν (CHCl_3) 498w, 598m, 665w, 690m, 710vw, 853vs, 860s, 940s, 1 001s, 1 113w, 1 181vw, 1 220br,s, 1 247s, 1 273vw, 1 295vw, 1 319vw, 1 340sh, 1 353vs, 1 374m, 1 404w, 1 440vw, 1 490w, 1 526vs, 1 555vw, 1 590m, 1 599sh, 1 680vw, 1 795vw, 1 930vw, 2 860vw, 2 950vw, 3 015m, 3 080vw, 3 110vw, 3 350br,w, and 3 550s cm^{-1} ; ν (KBr) 3 280s cm^{-1} ; δ (CDCl_3) 8.03 (2 H, d, $J_{2,6}$ 9 Hz), 8.27 (2 H, d, $J_{3,5}$ 9 Hz), and 8.36 (1 H, s, OH); δ (CD_3SOCD_3) 8.00 (2 H, d, $J_{2,6}$ 9 Hz), 8.25 (2 H, d, $J_{3,5}$ 9 Hz), and 12.81 (1 H, s, OH); λ (methanol) 219 ($\log \epsilon$ 4.03), 294 (4.22) nm. 2,4,6-Trimethylbenzohydroxamoyl chloride ¹⁰ (Ie) had m.p. 72 °C, δ (Me_2CO ; 37 °C) 2.21 (6 H, s, 2CH_3), 2.25 (3 H, s, CH_3), 6.89 (2 H, s, ArH), and 11.02 (1 H, s, OH), the signals at δ 2.21—6.89 remain unchanged in the range -80 to +37 °C.

2,2-Dimethylpropionohydroxamoyl Chloride ¹¹ (If).—A solution of NOCl (2 g) in anhydrous ethyl ether (15 ml) cooled at 0 °C was added under stirring to a solution of 2,2-dimethylpropanal oxime (2 g) in the same solvent (20 ml). The mixture was allowed to warm to room temperature and left aside until the solvent had completely evaporated. The oil residue, treated with light petroleum and charcoal, gave on cooling in an acetone- CO_2 bath, a solid, m.p. 32—33 °C. The product is highly lachrimatory and a powerful skin irritant; dipole moment data (benzene; 25 °C) α 4.25, β -0.165, P_2^0 147.9 cm^3 , R_D 34.4 cm^3 (calculated from increments with the value ¹² of 6.39 cm^3 for the unconjugated =NOH group), μ (5%), 2.34 D, μ (15%) 2.30 D.

Benzaldoximes (III) were prepared from the corresponding aldehydes by the hydroxylamine hydrochloride-sodium hydroxide method.¹³ The reaction gave almost pure *Z*-isomers (OH *cis* to aryl). The *E*-isomers were obtained from the *Z*-forms by the hydrochloride method¹⁴ and purified by column chromatography (silica; ethyl ether-light petroleum 1:1). M.p.s of the pure *E*- and *Z*-compounds (t.l.c.: silica; ethyl ether-light petroleum 1:1) were identical to those from the literature.¹⁵

(*E*)-Benzaldoxime had m.p. 30 °C; ν (cyclohexane) 459w, 510m, 646m, 691s, 755s, 872m, 950m, 973s, 1 076w, 1 102vw, 1 160vw, 1 178vw, 1 211m, 1 290w, 1 306m, 1 318sh, 1 490w, 1 501w, 1 579vw, 1 600vw, 1 632w, 3 330m, and 3 600m cm^{-1} ; ν (KBr) 3 300m cm^{-1} ; λ (cyclohexane) 250

($\log \epsilon$ 4.21), 281 (3.14), 283sh (3.11), 291 (2.98) nm. (*Z*)-Benzaldoxime had m.p. 128—129 °C; ν (cyclohexane) 510w, 580m, 600vw, 645vw, 692m, 844w, 870m, 895sh, 940sh, 950s, 1 033vw, 1 078vw, 1 160vw, 1 189w, 1 265w, 1 303w, 1 320w, 1 365w, 1 430m, 1 492w, 1 578w, 1 596w, 1 640w, 2 920w, 3 270m, and 3 580m cm^{-1} ; ν (KBr) 2 790m, 2 810m, and 3 170m cm^{-1} ; λ (cyclohexane) 240 ($\log \epsilon$ 4.26), 278sh (3.02), and 288 (2.82) nm. (*E*)-4-Methoxybenzaldoxime had m.p. 65 °C; ν (KBr) 434vw, 492w, 516w, 569m, 684m, 800w, 833s, 861w, 904m, 923vw, 951s, 969sh, 1 010vw, 1 028s, 1 116w, 1 152sh, 1 176s, 1 198w, 1 262s, 1 301m, 1 315sh, 1 352m, 1 368w, 1 411m, 1 443sh, 1 451m, 1 506s, 1 569w, 1 599s, 1 646w, 2 800m, 2 840m, 3 005m, 3 070m, and 3 170m cm^{-1} ; λ (cyclohexane) 215 ($\log \epsilon$ 4.30), 221sh (4.12), 254sh (4.23), 264 (4.36), 271sh (4.32), 290 (3.68), and 301 (3.44) nm. (*Z*)-4-Methoxybenzaldoxime had m.p. 132—133 °C; ν (KBr) 421vw, 453w, 491vw, 527sh, 533m, 592m, 700w, 750vw, 810sh, 820sh, 829s, 839m, 849w, 878m, 929sh, 942m, 958sh, 966s, 1 012sh, 1 030s, 1 111m, 1 171s, 1 185sh, 1 213sh, 1 254s, 1 301sh, 1 310s, 1 320m, 1 370vw, 1 420m, 1 441m, 1 459m, 1 468m, 1 515s, 1 573m, 1 608s, 1 620sh, 2 840m, 2 900m, 2 940m, 2 965m, 3 005m, 3 050m, 3 075m, and 3 320m cm^{-1} (in $\text{C}_2\text{H}_2\text{Cl}_2$ solution the compound rearranges rather quickly to the stereoisomer); λ (cyclohexane) 212 ($\log \epsilon$ 4.27), 217sh (4.13), 261 (4.37), 282sh (3.62), and 293 (3.19) nm. (*E*)-4-Chlorobenzaldoxime had m.p. 110—111 °C; λ (cyclohexane) 205sh ($\log \epsilon$ 4.36), 208 (4.40), 214 (4.38), 219 (4.20), 259 (4.35), 287 (3.36), and 297 (3.20) nm. (*Z*)-4-Chlorobenzaldoxime had m.p. 145—146 °C; λ (cyclohexane) 206 ($\log \epsilon$ 4.39), 211 (4.34), 217 (4.12), 250 (4.37), 283sh (3.43), and 292 (2.75) nm. (*Z*)-4-Nitrobenzaldoxime had m.p. 133 °C; ν (CHCl_3) 425m, 484m, 503w, 573w, 625vw, 691m, 843s, 854s, 881w, 903vw, 941m, 967s, 1 018vw, 1 100sh, 1 112m, 1 180w, 1 266s, 1 297sh, 1 301w, 1 314sh, 1 319sh, 1 326w, 1 349vs, 1 380sh, 1 402w, 1 410w, 1 420w, 1 497w, 1 526vs, 1 598sh, 1 601m, 1 624vw, 2 860vw, 2 870vw, 3 080w, 3 320w, and 3 575m cm^{-1} ; ν (KBr) 3 300m cm^{-1} ; δ (CD_3SOCD_3) 7.79 (2 H, d, $J_{2,6}$ 9 Hz), 8.16 (2 H, d, $J_{3,5}$ 9 Hz), and 8.17 (1 H, s, OH); λ (methanol) 222 ($\log \epsilon$ 4.02) and 300 (4.13) nm.

(*E*) and (*Z*)-Ethyl benzohydroximates (IV), were prepared and purified as described.¹⁶

Calculations.—The theoretical dipole moments were calculated from the bond moments previously employed.⁵ The bond angles were slightly modified on the basis of the new crystallographic data: ² C=C=N 121 (*Z*-configuration) or 130° (*E*-configuration), C-C-Cl 118 (*Z*) or 115° (*E*), C=N-O 115°, N-O-H 105°.

RESULTS AND DISCUSSION

I.r. Spectra.—In the crystalline state all hydroxamoyl chlorides (Ia—d) showed an OH band in the range 3 280—3 350 cm^{-1} , a feature which is present also in aromatic *E*- (*trans* aryl) aldoximes,^{17,18} whereas *Z*- (*cis* aryl) isomers absorb between 3 150 and 3 180 cm^{-1} . Such a difference has been ascribed¹⁸ to different types of intermolecular associations through hydrogen bonds.¹⁹ Since this behaviour is determined by a variety of factors, it is difficult to predict how it is affected by the substitution of Cl for H. This prevents the OH frequencies being used as a direct stereochemical probe of compounds (I). However, when the *Z*-configuration of (Id) is established,² then the uniformity of i.r. spectra

implies that the remaining hydroxamoyl chlorides (I) in the crystalline state are also *Z*-isomers.

The i.r. spectra of compounds (Ia—d) in solution (tetrachloromethane, dichloromethane, benzene, acetone, dimethyl sulphoxide) appeared simpler than in the solid state owing to the absence of crystal splitting and all showed similar changes of band intensities and frequencies. The largest differences occurred in the OH stretching region, whereas these were less significant in the region 1 200—1 300 cm^{-1} (OH in-plane bending). Moreover, the spectra of (Ia—d) showed a new band near 590 cm^{-1} , whereas a band at 700 and a shoulder at 525 cm^{-1} are present in the crystal, had disappeared; this behaviour made a change of configuration between the two phases a real possibility. Moreover, a detailed analysis of the i.r. spectra of (*E*)- and (*Z*)-4-methoxy-

Another indication in favour of the *Z*-configuration can be derived from the out-of-plane C—H deformation frequencies.^{3,21,22} For monosubstituted benzenes having the *cis*- C_6H_5 configuration, these frequencies lie in the range 698—702 cm^{-1} , while for the *trans*- C_6H_5 isomers they lie between 691 and 695 cm^{-1} ; ^{1,3} for 4-chlorophenyl derivatives the ranges are ²¹ 824—829 (*cis*- $\text{C}_6\text{H}_4\text{Cl}$) and 833—839 cm^{-1} (*trans*- $\text{C}_6\text{H}_4\text{Cl}$). This points to the *Z*-configuration for compounds (I) since the C—H frequencies at 690 cm^{-1} for (Ia) and 833 cm^{-1} for (Ic) are those expected for the *trans*-aryl configuration. However, the limits of this approach appear evident if it is applied to aromatic oximes: the C—H frequencies of both *E*- and *Z*-benzaldoximes lie at 691 cm^{-1} , while for both 4-chlorobenzaldoximes they are in the region which corresponds to *cis*- $\text{C}_6\text{H}_4\text{Cl}$ (*E* 825, *Z* 827 cm^{-1}).

TABLE I

¹H N.m.r. chemical shifts (δ , from tetramethylsilane) of the *ortho*-hydrogens of the benzene ring of benzohydroxamoyl chlorides (I) and some model compounds

	Substituent			
	4-OCH ₃	4-Cl	4-NO ₂	H
(<i>Z</i>)-Benzohydroxamoyl chloride (<i>trans</i> C_6H_5) ^a	7.78	7.74	8.03	
(<i>E</i>)-Benzaldoxime (<i>trans</i> C_6H_5) ^b	7.56	7.54	7.86	
$\Delta\delta$ (H \rightarrow Cl)	0.22	0.20	0.17	
(<i>Z</i>)-Benzaldoxime (<i>cis</i> C_6H_5) ^b	8.00	7.98	8.35	
$\Delta\delta$ (<i>E</i> \rightarrow <i>Z</i>)	0.44	0.44	0.49	
(<i>Z</i>)- <i>O</i> -Methylbenzohydroxamoyl chloride (<i>trans</i> C_6H_5) ^c	7.80	7.74	8.10	
$\Delta\delta$ (NOH \rightarrow NOCH ₃)	0.01	0.00	0.07	
(<i>E</i>)- <i>O</i> -Methylbenzohydroxamoyl chloride (<i>cis</i> C_6H_5) ^c	7.82	7.75	8.00	
$\Delta\delta$ (<i>E</i> \rightarrow <i>Z</i>)	-0.02	-0.01	0.10	
Benzoyl chloride		7.74 ^d		8.07 ^e
Benzaldehyde		8.03 ^d		7.81 ^e
$\Delta\delta$ (H \rightarrow Cl)		0.29		0.26

^a In CDCl_3 . ^b In THF. ^c In CDCl_3 the configuration was reversed with respect to that in ref. 28. ^d In CCl_4 . ^e In CDCl_3 .

benzaldoxime and (*E*)-4-nitrobenzaldoxime under different conditions, revealed that the i.r. spectra of (Ia—d) in the solid state and in solution are more different than those of oximes (see particularly the 590 cm^{-1} band). Nevertheless, the differences are considerably smaller compared to those between *E*- and *Z*-stereoisomers of oximes (see the region below 880 cm^{-1}). This suggested that the observed changes in the case of hydroxamoyl chlorides (I) were merely due to the change of phase rather than stereochemistry. Their relation to intermolecular hydrogen bonds was confirmed by observations on deuteriated compounds. Upon deuteration, not only the expected changes in the regions of O—H stretching and O—H bending frequencies were observed but also the band at 590 cm^{-1} was present in the crystal as well as in solution. Thus, the latter band can be due, in our opinion, only to coupling of the O—H out-of-plane bending mode with another unidentified mode (possibly C=N twisting²⁰) in the crystalline state only. Thus, it is understandable that this coupling is broken by deuteration and in solution as well. Hence, hydroxamoyl chlorides (Ia—d) have the identical *Z*-configuration for the C=N bond in solution and in the solid state. Appreciable changes could not be detected in ¹H n.m.r. spectra of (Ib) and (Ie) in the temperature range from -80 to +37 °C.

Other spectroscopic correlations^{13,23,24} which have been devised for aromatic aldoximes, appear not be applicable to hydroxamoyl chlorides.

¹H N.m.r. Spectra.—The analysis of ¹H n.m.r. spectra of compounds (I) was focused on the resonances of the hydroxylic hydrogen in DMSO²⁵ and of the *ortho*-hydrogens of the benzene ring.¹

Some observations on the OH resonances of benzohydroxamoyl chlorides and model compounds led the *Z*-configuration for (I) to be preferred.⁶ From 'anti'-2-hydroxyiminoacetohydroxamoyl chloride²⁶ (OH *cis* to Cl) and *E*-aldoximes (OH *cis* to H), the effect of substitution of Cl for H *cis* to OH was determined to be 1.08 p.p.m. On the other hand, using as reference compound the 'amphi'-2-hydroxyiminoacetohydroxamoyl chloride which possesses the *E*-configuration (OH *trans* to Cl),²⁶ it can be calculated that the substitution H \rightarrow Cl combined with a configurational change implies $\Delta\delta$ 0.7 p.p.m. The difference of 1.19 p.p.m. found⁶ between the OH resonances of benzohydroxamoyl chloride (Ia) and (*E*)-benzaldoxime indicates retention of configuration upon substitution of Cl for H and therefore that OH is *cis* to Cl. Consistent with this finding, a comparison between 4-nitrobenzohydroxamoyl chloride (Id) and (*E*)-4-nitrobenzaldoxime gives $\Delta\delta$ 1.11 p.p.m. The above conclusions, however, should be regarded as

care since the correlation is empirical in character and has not been tested for a large series of compounds. Moreover the configurations of stereoisomeric 2-hydroxyiminoacetohydroxamoyl chlorides²⁶ are not quite certain.

The resonance of the *ortho*-hydrogens of the benzene ring has confirmed¹ the *Z*-configuration assigned to *O*-benzoylhydroxamoyl chlorides (II) and is also useful in

carbon resonances shifted upfield with respect to those of (*Z*)- and (*E*)-benzaldoximes. A similar shielding effect due to substitution of H by Cl occurs in benzoyl chloride³¹ (C=O δ 168.7 p.p.m.) with respect to benzaldehyde (C=O δ 190.7 p.p.m.). The upfield shifts of hydroxamoyl chlorides (Ia–d) are uniformly larger with respect to (*E*)-benzaldoximes ($\Delta\delta$ 11–12.5 p.p.m.) than

TABLE 2
¹³C N.m.r. chemical shifts [δ (p.p.m.) from tetramethylsilane in [²H₆]DMSO for hydroxyamoyl chlorides (I), oximes (III), and hydroximates (IV)]

X	(Z)-(III)			(I)		(E)-(III)		
	C(1)	C–H	$\Delta\delta(\text{CH} - \text{CCl})$	C(1)	C–Cl	$\Delta\delta(\text{CH} - \text{CCl})$	C(1)	C–H
OCH ₃	123.9	143.9	9.1	124.7	134.8	12.5	125.3	147.3
H	131.3	144.9	9.7	132.4	135.2	14.1	129.8	149.3
Cl	133.5	143.1	7.7	134.9	135.4	11.3	133.4	146.7
NO ₂	135.9	142.7	8.5	138.4	134.2	12.5	139.6	146.7
Mesityl		145.8	14.8		131.0	16.1		147.1

X	(E)-(IV)			(Z)-(IV)	
	C(1)	C-OC ₂ H ₅	$\Delta\delta(\text{COC}_2\text{H}_5 - \text{CCl})$	C(1)	C-OC ₂ H ₅
	129.8	157.0	21.8	132.4	153.2

the study of the parent compounds (I) (Table 1). The *ortho*-hydrogens of benzohydroxamoyl chlorides (I) show a shift of 0.2 p.p.m. with respect to (*E*)-benzaldoximes. Since an identical shift has been observed for *O*-benzohydroxamoyl chlorides¹ (II), whereas the difference between *E*- and *Z*-aldoximes is twice as large, this supports the *Z*-configuration for compounds (I). On the other hand, a very small difference has been found for stereoisomeric *O*-methylbenzohydroxamoyl chlorides,²⁸ but in view of the discrepancy between the configurational assignment in solution from dipole moment data²⁸ and in the solid state from *X*-ray crystallography,³⁰ these compounds cannot be used as a stereochemical probe for other systems.

¹³C N.m.r. Spectra.—The most significant resonances from the ¹³C n.m.r. spectra of compounds (I) and corresponding *E*- and *Z*-benzaldoximes (III) as well as the pair of hydroximates (IV) are collected in Table 2. The chemical shifts of the C(1) of the phenyl ring in *E*- and *Z*-benzaldoximes (III) and benzohydroxamoyl chlorides (I) are affected in the same way by the aryl substituents. Specifically, with respect to the unsubstituted compound (Ia) and (IIa) downfield resonances occur when there is an electron-withdrawing group (Cl and NO₂) whereas upfield shifts result when there is an electron-releasing substituent OMe. However, the C(1) resonances are only slightly and irregularly affected by the configuration and by the substituent (H, Cl, OC₂H₅) on the C=N bond; therefore, they are useless for configurational assignments. The opposite is found for the C=N carbon. (*Z*)-Benzaldoximes (OH *cis* to phenyl) show the C=N carbon resonances upfield with respect to the *E*-isomers,³¹ whereas in both series of isomers there is practically no substituent effect. In the case of ethyl benzohydroximates, the configuration has just the opposite effect on the chemical shifts: *Z* (OH *trans* to phenyl) δ 153.2 p.p.m., *E* (OH *cis* to phenyl) δ 157.0 p.p.m.

Hydroxamoyl chlorides (Ia–e) have the azomethine

with respect to the *Z*-isomers ($\Delta\delta$ 7.7–9.1 p.p.m.); an identical situation occurs for the mesityl derivative (Ie) although the $\Delta\delta$ values are both larger, *i.e.* 16.1 and 14.8 p.p.m. From these regular trends one can deduce that all benzohydroxamoyl chlorides (Ia–d) have the same configuration on the C=N bond.

U.v. Spectra.—The u.v. spectroscopy proved to be of some utility for the configurational assignment of aromatic hydroxyimino-compounds.^{1,32,33} In the present case, however, it appears to fail since the u.v. spectrum of 4-chlorobenzohydroxamoyl chloride (Ic) matches that of (*E*)-4-chlorobenzaldoxime in the proximity of the main maximum but approaches that of the *Z*-isomer at lower absorptions (Figure 1). Identical behaviour emerged from a comparison of (Ia) and (Ib), with the corresponding pairs of oximes.

E.s.r. Spectra.—A previous e.s.r. study of iminoxyl radicals derived from hydroxamoyl chlorides (I) pointed to the *E*-configuration.³⁴ However, a more detailed analysis led the configuration of these radicals³⁵ to be reassigned in favour of the *Z*-form, this being in agreement with the *Z*-configuration of their precursors.

Dipole Moments.—The only dependable evidence so far for the configurational assignment of compounds (I) in solution comes from the i.r. data combined with the results from *X*-ray crystallography. Another approach which in principle could solve the problem without resorting to empirical correlations, is the analysis of dipole moments. Previous applications of this method, however, gave ambiguous results^{4–8} which led to an incorrect configurational assignment.^{4,5} The failure of this method warrants an explanation (Figure 2).

The direction of the experimental dipole moment of benzohydroxamoyl chloride (Ia) in benzene (point B) as deduced⁵ from a comparison with *para*-substituted derivatives, is in fair agreement with that determined in dioxan^{6,7} (point D). Its resolution into components is shown for the *E*- and *Z*-configurations in connection with

the *ap* conformation^{4,5,8,9} about the N-O bond. The predicted vectors, *E* and *Z*, differ slightly from our previous calculations⁵ because of the new values for the bond angles.² Nevertheless, none of the calculated vectors corresponds to the experimental point B nor is a substantial improvement obtained by further calculations⁷ based on the dipole moment of benzaldoxime (point *Z'*). The difference between the *E*- and *Z*-possibilities is not so marked to allow a choice with a good degree of certainty. It is because the conformation on the N-O bond is more significant for the dipole moment than the configuration at C=N; the latter is manifested mainly by the small N-O moment.^{1,36} We attempted previously to solve this ambiguity by using as model compound 4-chloro-1*H*-2,3-benzoxazine³⁶ (Va)

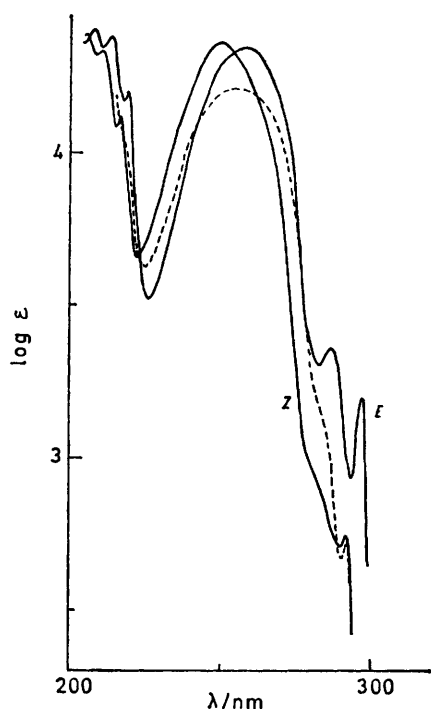


FIGURE 1 U.V. spectra of 4-chlorobenzhydroxamoyl chloride (Ic) (broken line) and of (*E*)- and (*Z*)-4-chlorobenzaldoximes (solid lines)

which has a fixed *E sp* conformation. Recent studies⁸ on the 6-chloro-derivative (Vb) allow the direction of the dipole moment to be evaluated (point BOx). This point does not correspond to the calculated value (*E sp*) and the deviation can be hardly explained by the distortion of angles.

More effective model compounds are the *O*-benzoyl derivatives (II), whose *Z*-configuration has been unambiguously established owing to substitution in both phenyl rings.¹ However, it remained uncertain whether the parent compounds (I) had the same configuration as (II). A detailed analysis of (II) has shown that the bond moment of C-Cl is somewhat lower than in alkyl chlorides, *viz.* *ca.* 1.4 D. If this correction is introduced into Figure 2 (shorter arrows at *Z* and *E*), a choice in favour of the *Z* configuration becomes evident. This

correction appears unnecessary for aliphatic compounds, since the dipole moment of 2,2-dimethylpropionhydroxamoyl chloride (If), whose direction is unknown, agrees only with the *Z*-configuration (Al in Figure 2). The successful assignment thus depends on properly chosen model compounds. The especial difficulty with this class of compounds lies in the fortuitous coincidence

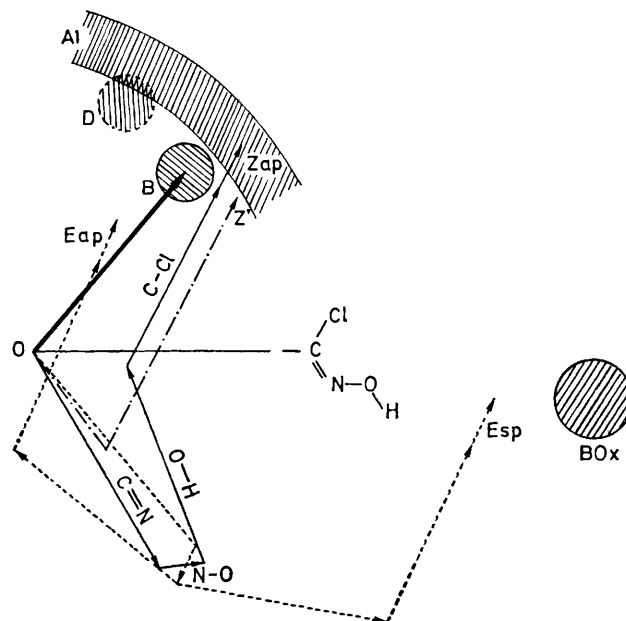
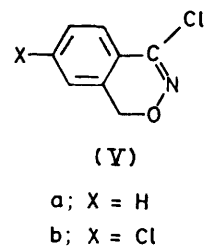


FIGURE 2 Analysis of dipole moments of hydroxamoyl chlorides [experimental values: B, aromatic derivatives in benzene; D, in dioxan, Al, aliphatic derivative (If) in benzene, BOx, benzoxazine derivatives (V); calculated values are shown for configurations *E ap*, *Z ap*, and *E sp*; *Z'* calculated according to ref. 6]

of several bond moments and no special phenomenon is involved.

We conclude therefore that the single stereoisomeric form of hydroxamoyl chlorides which has been so far isolated, possesses the *Z*-configuration in the solid state as well as in solution; the only probable exception might be '*amphi*'-2-hydroxyiminoacetohydroxamoyl



chloride.²⁶ A recent theoretical treatment³⁷ of the model molecule CHF=NF indicates the preference for the *Z*-form, the controlling factor being an attractive non-bonded orbital interaction between the two fluorine atoms. This factor might be of importance in the stereochemistry of most hydroxyimino-compounds, such as hydroxamoyl chlorides,^{38,39} *S*-alkyl thiohydroximates,⁴⁰ and *O*-alkyl hydroximates.¹⁶

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