The Geometric Isomers of *O*-Alkylbenzohydroximoyl Chlorides. Synthesis, Identification, and Acid-Catalyzed Isomerization[1]

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Preparation of the *E* and *Z* isomers of nine *O*-alkylbenzohydroximoyl chlorides is described. The configurations of several of these geometric isomers were determined from dipole moment measurements. A correlation between configuration and the NMR chemical shift of the *O*-alkyl group hydrogens in these isomers was established. The acid-catalyzed (benzene–HCl, 40°) isomerization of a (*Z*)-hydroximoyl chloride went completely (within the detection limits of NMR spectroscopy) to the corresponding *E* isomer. In contrast, the acid-catalyzed (glacial acetic acid, 80°) isomerization of alkyl *O*-alkylbenzohydroximates gives significant amounts of the *Z* isomers (12–39%) at equilibrium. It is suggested that dipole moment effects may determine the relative stabilities of isomeric hydroximoyl chlorides and related compounds.

In connection with a study on the stereochemistry of nucleophilic substitution reactions in systems containing a carbon–nitrogen double bond, we undertook an investigation into the synthesis and identification of the geometric isomers of certain imidoyl halides.[3] The literature contains only a few examples of geometrical isomerism of imidoyl halides.[4–7] In fact, most of the well-documented reports concern preparation of isomeric imidoyl fluorides.[4,5] In other instances, attempts to isolate the geometric isomers of imidoyl halides have failed.[8,9] In these cases the preparation of both isomers may not be possible because of rapid isomerization of one of the isomers to the thermodynamically stable isomer. On the other hand, the stabilities of many types of imidoyl halides have not been investigated.

Geometrical isomerism due to restricted rotation around a carbon–nitrogen double bond is commonly observed in systems where an electronegative atom such as oxygen, nitrogen, or halogen is bonded to the imino nitrogen.[10,11] Consequently, we chose to investigate the stability of the geometric isomers of *O*-alkylbenzohydroximoyl halides. Numerous *O*-alkylbenzohydroximoyl chlorides have been reported in the early literature,[12–14] but it appears that no attempt has been made to prepare and identify the geometric isomers of these compounds.

The method of synthesis of the *E* and *Z* isomers of *O*-methylbenzohydroximoyl chloride (**3a** and **4a**) is outlined in Scheme I. Monomethylation of potassium benzohydroxamate (**1a**) resulted in the formation of methyl benzohydroxamate (**2a**). Reaction of **2a** with phosphorus pentachloride furnished *O*-methylbenzohydroximoyl chloride (**3a**). The NMR spectrum and gas chromatographic analysis of **3a** indicated that it was primarily a single stereoisomer (<1% contamination by the other geometric isomer). Ultraviolet irradiation of a hexane solution of **3a** gave a photostationary state mixture of **3a** and **4a** from which **4a** was separated by preparative gas chromatography. The ultraviolet irradiation produced along with **4a** a small amount of decomposition product which was identified as benzonitrile. Although pure samples of **4a** appear to be stable at room temperature, it is rather unstable in the crude photoreaction mixture. If this mixture is kept at room temperature without purification, the hydroximoyl chloride **4a** will isomerize to **3a** almost completely in about 1 week. This isomerization is probably catalyzed by hydrogen chloride which could be produced when the by-product benzonitrile is formed during the photoreaction. An attempt at deliberate thermal isomerization of **4a** in benzene at 50° failed to give any significant isomerization within a period of 1 week.

Using the methods outlined in Scheme I, eight other pairs of *O*-alkylbenzohydroximoyl chlorides (**3b–i** and **4b–i**) were synthesized. In addition, (*E*)-*O*-methylbenzohydroximoyl bromide (**3j**) was prepared in low yield by the reaction of **2a** with phosphorus tribromide. Ultraviolet irradiation of a hexane solution of **3j** failed to produce a detectable amount of the *Z* isomer.

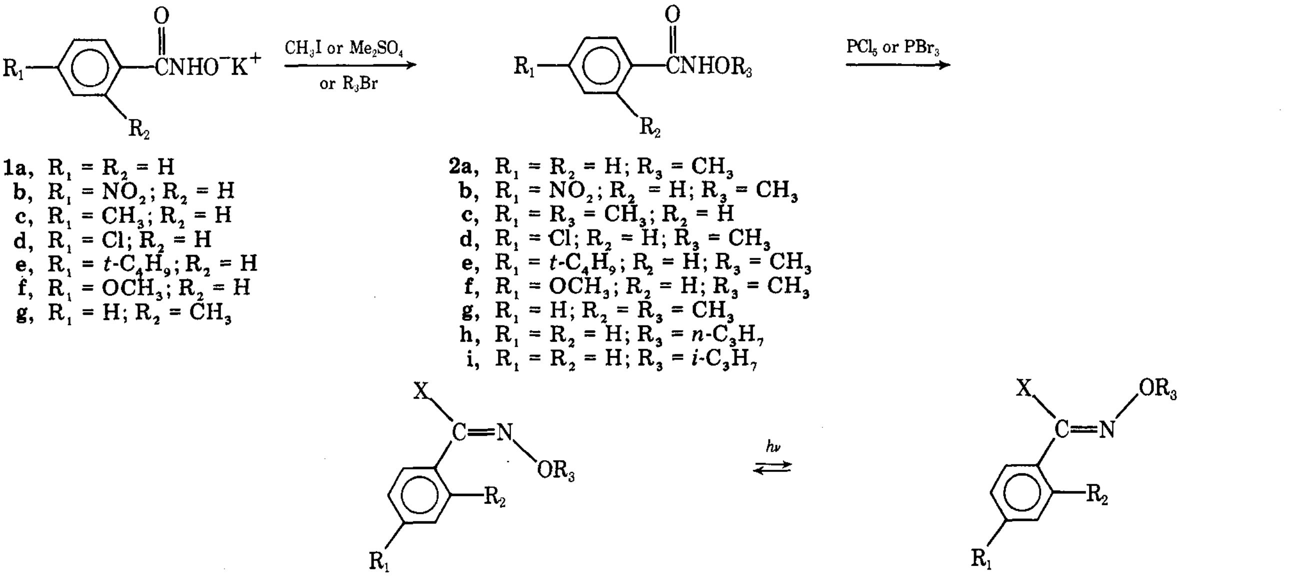
Configurational assignments for some of the hydroxi-

Table I
Dipole Moment Data for the *E* and *Z* Isomers of *O*-Methylbenzohydroximoyl Chlorides

Hydroximoyl chloride	Conformation	Theoretical dipole moment, D[a]	Experimental dipole moment, D[b]
3a	s-trans	1.25	1.38 ± 0.02 (1.40 ± 0.03)[c]
3a	s-cis	2.81	
4a	s-trans	1.78	
4a	s-cis	1.93	2.00 ± 0.04
3b	s-trans	3.52	3.58 ± 0.03
3b	s-cis	1.70	
4b	s-trans	3.18	
4b	s-cis	2.98	2.91 ± 0.04 (2.86 ± 0.08)[c]
3c	s-trans	1.57	1.73 ± 0.03
3c	s-cis	3.17	
4c	s-trans	2.10	
4c	s-cis	2.26	2.36 ± 0.04
3d	s-trans	1.03 (0.89)[d]	1.22 ± 0.03
3d	s-cis	1.02 (1.22)[d]	
4d	s-trans	1.03 (0.99)[d]	
4d	s-cis	0.98 (0.97)[d]	1.21 ± 0.05
3e	s-trans	1.72	1.87 ± 0.04
3e	s-cis	3.34	
4e	s-trans	2.30	
4e	s-cis	2.41	
3j	s-trans	1.16	1.40 ± 0.05
3j	s-cis	2.77	
4j	s-trans	1.69	
4j	s-cis	1.94	

[a] Calculated using the following bond (or group) moments and bond angles: CH_3–O, 1.04 D; N–O, 0.30 D; C=N, 1.80 D; C–Cl, 1.75 D; NO_2, 4.50 D; C–Br, 1.64 D; CH_3–C, 0.37; *t*-C_4H_9–C, 0.53; Ar–Cl, 1.60; 110° for N–O–CH_3(*E* and *Z* isomer); 114° for C=N–O (*E* and *Z* isomer); 115° for N=C–Cl (*E* isomer); 125° for N=C–Cl (*Z* isomer); 130° for N=C–C (*E* isomer); 120° for N=C–C (*Z* isomer). [b] The experimental dipole moments were determined in benzene at 25°; see the Experimental Section for details. [c] Duplicate determination. [d] The dipole moments in parentheses were calculated using the usual value of 1.60 D for Ar–Cl. The theoretical dipole moments based on an enhanced value for Ar–Cl of 1.80 D are outside the parentheses.

Scheme I



1a, $R_1 = R_2 = H$
b, $R_1 = NO_2$; $R_2 = H$
c, $R_1 = CH_3$; $R_2 = H$
d, $R_1 = Cl$; $R_2 = H$
e, $R_1 = t\text{-}C_4H_9$; $R_2 = H$
f, $R_1 = OCH_3$; $R_2 = H$
g, $R_1 = H$; $R_2 = CH_3$

2a, $R_1 = R_2 = H$; $R_3 = CH_3$
b, $R_1 = NO_2$; $R_2 = H$; $R_3 = CH_3$
c, $R_1 = R_3 = CH_3$; $R_2 = H$
d, $R_1 = Cl$; $R_2 = H$; $R_3 = CH_3$
e, $R_1 = t\text{-}C_4H_9$; $R_2 = H$; $R_3 = CH_3$
f, $R_1 = OCH_3$; $R_2 = H$; $R_3 = CH_3$
g, $R_1 = H$; $R_2 = R_3 = CH_3$
h, $R_1 = R_2 = H$; $R_3 = n\text{-}C_3H_7$
i, $R_1 = R_2 = H$; $R_3 = i\text{-}C_3H_7$

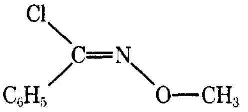
3 4

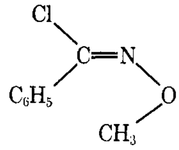
3 and 4f, $R_1 = OCH_3$; $R_2 = H$, $R_3 = CH_3$, $X = Cl$
g, $R_1 = H$; $R_2 = R_3 = CH_3$; $X = Cl$
h, $R_1 = R_2 = H$; $R_3 = n\text{-}C_3H_7$; $X = Cl$
i, $R_1 = R_2 = H$; $R_3 = i\text{-}C_3H_7$; $X = Cl$
3j, $R_1 = R_2 = H$; $R_3 = CH_3$; $X = Br$

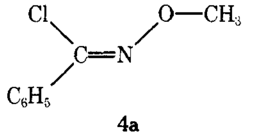
3 and 4a, $R_1 = R_2 = H$; $R_3 = CH_3$; $X = Cl$
b, $R_1 = NO_2$; $R_2 = H$; $R_3 = CH_3$; $X = Cl$
c, $R_1 = R_3 = CH_3$; $R_2 = H$; $X = Cl$
d, $R_1 = X = Cl$; $R_2 = H$, $R_3 = CH_3$
e, $R_1 = t\text{-}C_4H_9$; $R_2 = H$; $R_3 = CH_3$; $X = Cl$

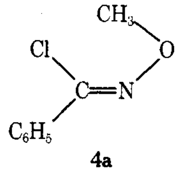
moyl chlorides 3 and 4 are based on dipole moment measurements (Table I). The theoretical dipole moments in Table I were calculated from bond moments[8a] and estimated bond angles. Various possible sets of bond angles were tried in these calculations. Although the resultant dipole moment is altered somewhat by small changes in bond angles, our configurational assignments are not affected. The bond angles chosen for Table I resulted in the best overall fit of the theoretical with the experimental dipole moments. These bond angles correspond to those used by Exner for his dipole moment calculations on (*E*)- and (*Z*)-benzohydroximoyl chloride.[8a,15]

Because of possible free rotation about the N–O bond axis in these compounds, calculations were made for the planar s-cis and s-trans conformations (as illustrated for 3a and 4a) of each compound. It is apparent from comparison of the experimental dipole moments with the theoretical values that the phosphorus pentachloride reaction with a methyl benzohydroxamate (2) produces the *E* hydroximoyl chloride. Furthermore, it appears that the *E* hydroximoyl chlorides (3) exist in a planar s-trans conformation. The dipole moments of the *Z* hydroximoyl chlorides are in close agreement with the theoretical values for the s-cis conformation.[16] The assignment of a s-cis conformation to the *Z* isomers is somewhat uncertain since the theoretical dipole moments for *Z* (s-trans) and *Z* (s-cis) conformations differ at the most by only 0.2 D. To illustrate our conclusions, Exner's[17] method of graphical comparison of dipole moments is useful (Figure 1). In this graph the theoretical dipole moments for s-cis and s-trans conformations of the *E* and *Z* isomers of the unsubstituted compounds 3a and 4a (μ^2_{H}, plotted along the *x* axis) are compared to the dipole moments for the same conformations of the *E* and *Z* isomers of the *p*-nitro derivatives ($\mu^2_{NO_2}$, *y* axis). The tie lines between s-cis and s-trans conformations of the same geometric isomer represent the dipole moments for nonplanar conformations formed by rotation around the N–O bond axis.[18] An experimental point corresponds to the dipole moments of an unsubstituted and *p*-nitro hydroximoyl


3a
E (s-trans)


3a
E (s-cis)


4a
Z (s-trans)


4a
Z (s-cis)

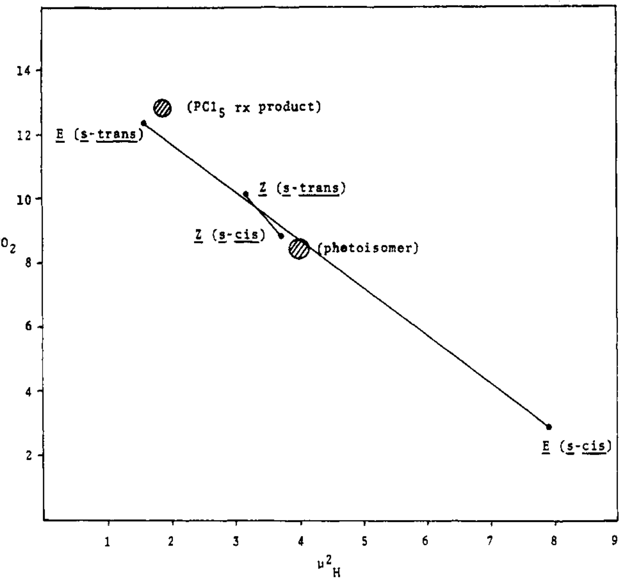


Figure 1. Comparison of theoretical and experimental dipole moments for the *E* and *Z* isomers of *O*-methylbenzohydroximoyl chloride (*x* axis, μ^2_{H}) and *O*-methyl-*p*-nitrobenzohydroximoyl chloride (*y* axis, $\mu^2_{NO_2}$); • represent theoretical values, ▨ represent experimental values.

Table II
Properties of Alkyl Benzohydroxamates, *O*-Alkylbenzohydroximoyl Chlorides, and Alkyl *O*-Alkylbenzohydroximates[a]

Compd	Method of preparation[b]	Yield, %	Mp or bp, °C	NMR, δ, ppm[c]	Ir, principal absorptions,[d] cm^{-1}	Uv max, nm (log ε)[e]
2a	A	47	mp 61–62[f] from ether–hexane	3.80 (s, 3 H), 7.4 (m, 3 H), 7.8 (m, 2 H)	3210, 1640, 1590, 1567 (Nujol)	
2b	B	42	mp 176–178[g] from ethanol–water	3.77 (s, 3 H), 8.0 (m, 2 H), 8.4 (m, 2 H), Me$_2$SO-d_6	3150, 1650, 1590 (Nujol)	
2c	B	70	mp 70–71 from ether–hexane	2.33 (s, 3 H), 3.80 (s, 3 H), 7.15 (d, J = 8 Hz, 2 H), 7.72 (d, J = 8 Hz, 2 H)		
2d	B	51	mp 106–109 from ethanol	3.74 (s, 3 H), 7.53 (ca. d, J = 8 Hz, 2 H), 7.80 (ca. d, J = 8 Hz, 2 H), Me$_2$SO-d_6		
2e	B[h]	74	Viscous oil[i]	1.31 (s, 9 H), 3.84 (s, 3 H), 7.41 (ca. d, J = 8 Hz, 2 H), 7.74 (ca. d, J = 8 Hz, 2 H)		
2f	B	77	mp 102–103 from water	3.79 (s, 6 H), 6.85 (d, J = 8.5 Hz, 2 H), 7.28 (d, J = 8.5 Hz, 2 H)	3160, 1640, 1600, 1565 (Nujol)	
2g	B	59	mp 105–106 from ether–hexane	2.38 (s, 3 H), 3.80 (s, 3 H), 7.25 (ca. s, 4 H)	3130, 1630, 1591 (Nujol)	
2i	C	29	mp 88–90 from ether–hexane	1.30 (d, J = 6 Hz, 6 H), 4.28 (septet, 1 H), 7.4 (m, 3 H), 7.8 (m, 2 H)	3140, 1623, 1564 (Nujol)	
3a	D (55°, 24 hr)	82	bp 53–54 (0.1 Torr)[j]	4.06 (s, 3 H), 7.4 (m, 3 H), 7.9 (m, 2 H)	1580, 1560	290 sh (2.88), 257 (4.11), 217 sh (3.96); 290 sh (2.76), 257 (4.08), 218 sh (3.94), 212 sh (4.03) in cyclohexane
4a	E		bp 43–44 (0.1 Torr)	3.92 (s, 3 H), 7.4 (m, 3 H), 7.7 (m, 2 H)	1595, 1580, 1565, 1553	254 (3.92), 217 sh (3.85), 256 (3.88), 218 sh (3.91) in cyclohexane
3b	D[k] (61°, 68 hr)	49	mp 121–122 from methanol	4.16 (s, 3 H), 8.10 (d, J = 8 Hz, 2 H), 8.30 (d, J = 8 Hz, 2 H)	1598 (w), 1590 (w), 1554, 1506 (Nujol)	296, (4.15), 227 (4.00)
4b	E[l]		mp 110–112 from methanol	4.04 (s, 3 H), 8.00 (d, J = 8 Hz, 2 H), 8.36 (d, J = 8 Hz, 2 H)	1595 (w), 1572 (w), 1510 (Nujol)	293 (3.98), 220 (3.94)

Table II
(*Continued*)

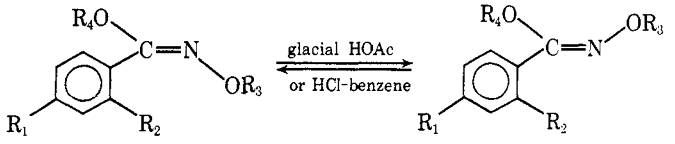
Compd	Method of preparation[b]	Yield, %	Mp or bp, °C	NMR, δ, ppm[c]	Ir, principal absorptions,[d] cm^{-1}	Uv max, nm (log ε)[e]
3c	D (60°, 2 hr)	66	bp 56–57 (0.06 Torr)	2.28 (s, 3 H), 4.02 (s, 3 H), 7.08 (d, *J* = 8.5 Hz, 2 H), 7.70 (d, *J* = 8.5 Hz, 2 H)	1603, 1580, 1575, 1552	293 sh (3.06), 262 (4.18), 219 sh (3.95), 212 (4.15)
4c	E			2.32 (s, 3 H), 3.91 (s, 3 H), 7.15 (d, *J* = 8 Hz, 2 H), 7.68 (d, *J* = 8 Hz, 2 H)	1601, 1582, 1579, 1555	261 (4.08), 220 sh (3.88)
3d	D (60°, 4 hr)	28	mp 28–29 from methanol	4.06 (s, 3 H), 7.29 (ca. d, *J* = 9 Hz, 2 H), 7.74 (ca. d, *J* = 9 Hz, 2 H)	1577, 1545 (w)	295 sh (3.19), 263 (4.24), 220 sh (3.98), 214 sh (4.14)
4d	E		mp <25	3.95 (s, 3 H), 7.35 (ca. d, *J* = 9 Hz, 2 H), 7.75 (ca. d, *J* = 9 Hz, 2 H)	1585	260 (4.04), 220 sh (3.88)
3e	D[m] (52°, 22 hr)	54	bp 82 (0.25 Torr)	1.30 (s, 9 H), 4.08 (s, 3 H), 7.41 (ca. d, *J* = 8.5 Hz, 2 H) 7.80 (ca. d, *J* = 8.5 Hz, 2 H)	1600, 1578	
4e	E			1.32 (s, 9 H), 3.98 (s, 3 H), 7.43 (ca. d, 2 H), 7.78 (ca. d, 2 H)		
3f	D (55°, 24 hr)	53	mp 51–53 from methanol	3.82 (s, 3 H), 4.06 (s, 3 H), 6.89 (d, *J* = 8.5 Hz 2 H), 7.80 (d, *J* = 8.5 Hz, 2 H)	1590, 1575	300 sh (3.54), 271 (4.29)
4f	E		mp 40–41	3.82 (s, 3 H), 3.95 (s, 3 H), 6.91 (d, *J* = 9 Hz, 2 H), 7.82 (d, *J* = 9 Hz, 2 H)	1596	271 (4.20), 215 sh (4.05)
3g	D (115°, 4 hr)	80	bp 55 (0.05 Torr)	2.42 (s, 3 H), 4.06 (s, 3 H), 7.3 (m, 4 H)	1585	242 (3.86)
4g	E			2.30 (s, 3 H), 3.88 (s, 3 H), 7.24 (s, 4 H)	1601, 1587	273 sh (2.98), 232 sh (3.81)
3h	D	Ref 20		0.99 (t, 3, *J* = 7 Hz, 2 H), 1.8 (m, 2 H), 4.24 (t, *J* = 6.5 Hz, 3 H), 7.4 (m, 3 H), 7.8 (m, 2 H)[n]	Ref 20	
4h	E			0.90 (t, *J* = 7 Hz, 2 H), 1.7 (m, 2 H), 4.10 (t, *J* = 6.5 Hz, 3 H), 7.4 (m, 3 H), 7.8 (m, 2 H)	1597, 1582, 1565, 1559	
3i	D (98°, 3 hr)	85	bp 48 (0.1 Torr)	1.35 (d, *J* = 6 Hz, 6 H), 4.56 (septet, *J* = 6 Hz, 1 H), 7.4 (m, 3 H), 7.9 (m, 2 H)	1580, 1557	

Table II
(*Continued*)

Compd	Method of preparation[b]	Yield, %	Mp or bp, °C	NMR, δ, ppm[c]	Ir, principal absorptions,[d] cm^{-1}	Uv max, nm (log ε)[e]
4i	E[o]			1.28 (d, *J* = 6 Hz, 6 H), 4.48 (septet, *J* = 6 Hz, 1 H), 7.4 (m, 3 H), 7.9 (m, 2 H)	1595, 1580, 1586	
3j	F	19	bp 66 (0.7 Torr)	4.13 (s, 3 H), 7.4 (m, 3 H), 7.8 (m, 2 H)	1581, 1560	
5a	H			3.80 and 3.84 (singlets, 6 H), 7.4 (m, 3 H), 7.7 (m, 2 H)	1618, 1595, 1571	
6a	G	68	bp 70 (0.3 Torr)	3.88 and 3.90 (singlets, 6 H), 7.4 (m, 3 H), 7.6 (m, 2 H)	1602, 1564	
5b	H			2.34 (s, 3 H), 3.80 (s, 3 H), 7.18 (d, *J* = 8.5 Hz, 2 H), 7.32 (d, *J* = 8.5 Hz, 2 H)		
6b	G	56	bp 75 (0.4 Torr)	2.34 (s, 3 H), 3.89 (s, 3 H), 7.15 (d, *J* = 8.5 Hz, 2 H), 7.56 (d, *J* = 8.5 Hz, 2 H)		
5c	H			2.23 (s, 3 H), 3.66 (s, 3 H), 3.76 (s, 3 H), 7.15 (s, 4 H)	1636, 1626, 1599	
6c	G	60	bp 62 (0.1 Torr)	2.37 (s, 3 H), 3.54 (s, 3 H), 3.87 (s, 3 H), 7.25 (s, 4 H)	1625	
5e	H			1.25 (d, *J* = 6 Hz, 6 H), 3.82 (s, 3 H), 4.27 (septet, *J* = 6 Hz, 1 H), 7.4 (m, 3 H), 7.8 (m, 2 H)	1612, 1592, 1558	
6e	G	76	bp 61–63 (0.1 Torr)	1.33 (d, *J* = 6 Hz, 6 H), 3.97 (s, 3 H), 4.36 (septet, *J* = 6 Hz, 1 H), 7.4 (m, 3 H), 7.7 (m, 2 H)	1604, 1565	

[a] Satisfactory elemental analyses (C, H, and N or C, H, N, and Cl) were reported for all new compounds listed in this table. Ed. [b] Obtained from reactions of the following types: A, a potassium benzohydroxamate with methyl iodide; B, a potassium benzohydroxamate with dimethyl sulfate; C, potassium benzohydroxamate with isopropyl bromide; D, alkyl benzohydroxamate with phosphorus pentachloride, reaction temperatures and times in parentheses; E, photoisomerization of the *E* isomer followed by preparative glc; F, methyl benzohydroxamate with phosphorus tribromide and purified by preparative GLC; G, (*E*)-*O*-alkylbenzohydroximoyl chloride with sodium alkoxide in alcohol (10%) and Me$_2$SO (90%); H, isomerization of the *Z* isomer in glacial acetic acid followed by preparative GLC. [c] Unless otherwise noted all NMR spectra were determined on CDCl$_3$ solutions. [d] Unless otherwise noted the ir spectra were determined on thin films of the neat liquids. The principal absorptions include NH, C=O, C=N, and aromatic absorptions. [e] Unless otherwise noted the uv spectra were determined on 95% ethanol solutions. [f] Reported mp 63.5–64.5° [J. H. Cooley, W. D. Bills, and T. R. Throckmorton, *J. Org. Chem.*, **25**, 1734 (1960)]; 62° [O. Exner and B. Kákăc, *Collect. Czech. Chem. Commun.*, **28**, 1656 (1963)]. [g] Reported mp 180° [O. Exner and J. Holubek, *Collect. Czech. Chem. Commun.*, **30**, 940 (1965)]. [h] Analytical sample prepared from reaction of thallium(I) *p-tert*-butylbenzohydroxamate with methyl iodide. See E. C. Taylor and F. Kienzle, *J. Org. Chem.*, **36**, 233 (1971), for a similar procedure. [i] Distilled with a Kontes micromolecular distillation apparatus. [j] A compound with this structural formula (configuration not determined) has been prepared previously by the reaction of *O*-methylbenzamide oxime with sodium nitrite and hydrochloric acid, bp 225°: F. Tiemann and P. Kruger, *Ber.*, **17**, 1665 (1884); **18**, 727 (1885); P. Kruger, *ibid.*, **18**, 1053 (1885). [k] Reaction carried out in chloroform solvent. [l] Separated from the *E*-isomer by preparative TLC (silica gel with 25:75 benzene–hexane eluent). [m] Reaction carried out in carbon tetrachloride solvent. [n] Correction of chemical shifts reported previously in ref 20. [o] Purified by preparative HPLC (Corasil column with hexane solvent).

Table III
Equilibrium Distributions of (*E*)- and (*Z*)-*O*-Alkylbenzohydroximates

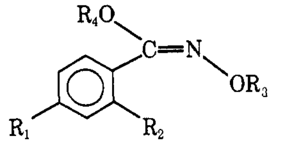


5 **6**

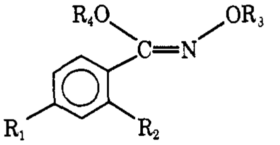
Isomers	R_1	R_2	R_3	R_4	Temp, °C	Solvent	% *Z* isomer (6)
5a and 6a	H	H	CH_3	CH_3	80	HOAc	32
5b and 6b	CH_3	H	CH_3	CH_3	80	HOAc	23
5c and 6c	H	CH_3	CH_3	CH_3	80	HOAc	12
5d and 6d	H	H	n-C_3H_7	CH_3	80	HOAc	30
5e and 6e	H	H	i-C_3H_7	CH_3	80	HOAc	32
5f and 6f	H	H	n-C_3H_7	C_2H_5	80	HOAc	39
5g and 6g	H	H	n-C_3H_7	n-C_3H_7	80	HOAc	39
5a and 6a	H	H	CH_3	CH_3	40	HOAc	27
5a and 6a	H	H	CH_3	CH_3	60	HOAc	29
5a and 6a	H	H	CH_3	CH_3	30	HCl–benzene	20
5a and 6a	H	H	CH_3	CH_3	40	HCl–benzene	23
5a and 6a	H	H	CH_3	CH_3	50	HCl–benzene	25

chloride that were obtained from the same kind of reactions, i.e., the phosphorus pentachloride reactions were assumed to give the same geometric isomer in both the unsubstituted and *p*-nitro cases. The position of the experimental values in relation to the theoretical points allows one to determine configuration and conformation along with the accuracy of the decisions. This graphical representation reinforces our configurational and onformational assignments for these compounds.

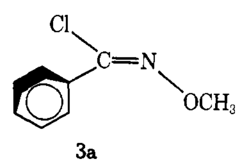
Having determined the configuration of several pairs of hydroximoyl chlorides (**3a–c** and **4a–c**) from dipole moment measurements, it was possible to establish a correlation of the configurations these compounds with their NMR spectra. In all of the compounds examined, the chemical shift of the *O*-methyl singlet (or *O*-alkyl multiplet) was further downfield in the case of the *E* isomer than in the corresponding *Z* isomer (Table II).[19] This correlation enabled us to make configurational assignments for compounds **3d–i** and **4d–i.** It is interesting to note that this correlation is the reverse of the NMR correlation established by us[20] for the *E* and *Z* isomers of alkyl *O*-alkylbenzohydroximates (**5** and **6**). In the isomeric pairs **5** and **6**, the *O*-alkyl absorptions are further downfield in the *Z* isomer than in the *E* isomer. The downfield shift of the *O*-alkyl group hydrogens in a *E* hydroximoyl chloride is probably due to the shielding effect of the phenyl ring that is twisted out of the plane of the carbon–nitrogen double bond (as shown for **3a**).



5



6



3a

In order to determine the relative stabilities of the hydroximoyl chlorides, the isomers **3a–g** and **4a–g** were equilibrated in hydrogen chloride–benzene (40°) solution. Within the detection limits of NMR spectroscopy it was found that in every case examined the *Z* isomer completely isomerized to the *E* isomer.

For purposes of comparison the *E* and *Z* isomers of several alkyl *O*-alkylbenzohydroximates[20] (**5** and **6**) were equilibrated (Table III). Unlike the hydroximoyl chlorides, equilibrium mixtures of benzohydroximates contain significant amounts of both isomers with the *E* isomer predominating. There seems to be little if any solvent affect on these equilibria since the equilibrium distribution (at 40°) of **5a** and **6a** is essentially the same in HCl–benzene and glacial acetic acid (Table II).

Various factors have been used to explain the equilibrium distributions of imino compounds including steric effects,[21,22] interorbital electron repulsions,[23,11b] and dipole moment effects.[22] In a recent report by Walter et al.,[22] it was proposed that the two factors determining the relative stability of imidates **7** and **8** are dipole interactions and steric effects. It was pointed out that in the absence of large steric effects (**7a** ⇌ **8a**), the isomer with the lowest dipole moment (**8a**) is found in the highest concentration. When the size of R_1 was increased by substitution with a *tert*-butyl group (**7b** ⇌ **8b**) a steric effect resulted in an increase in the equilibrium concentration of the *Z* isomer (**8b**).

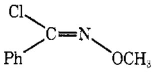
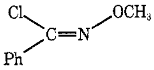
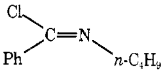
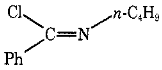
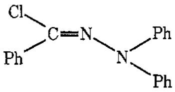
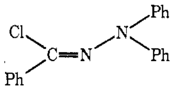
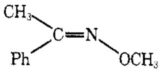
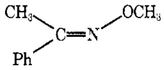
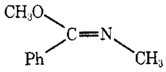
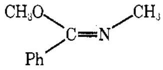
7 **8**

a, $R_1 = R_2 = R_3 = CH_3$ (E:Z 95:5)
b, $R_1 = t$-C_4H_9; $R_2 = R_3 = CH_3$ (E:Z 71:29)

Of the many factors that could contribute to the relative stabilities of the *E* and *Z* isomers of hydroximoyl chlorides, dipole interactions may be the most important. Considering only the isomeric pairs (**3a** and **4a**; **3c** and **4c**) that do not contain a para substituent with a large group moment (which masks the moment of the hydroximoyl chloride functional group) the stable *E* isomers have lower dipole moments than the *Z* isomers.

In contrast to hydroximoyl chlorides, where the stable isomer has the *E* configuration, dipole moment studies have shown that the only isolable isomer of a simple imidoyl chloride has the *Z* configuration (**10** in Table IV). In the case of imidoyl chlorides, the theoretical dipole moment for the *E* isomer (**9**) is higher than the experimentally

Table IV
Equilibrium Geometric Isomer Distributions for Compounds Containing a Carbon–Nitrogen Double Bond

Geometric isomers			Ref
 **3a** (*E*) μ = 1.38 D (exp) 100% *E*	⇌	 **4a** (*Z*) μ = 2.00 D (exp) 0% *Z*	This work
 **9** (*E*) μ = 2.18 D (theory) 0% *E*	⇌	 **10** (*Z*) μ = 0.54 D (exp) 100% *Z*	8d
 **11** (*E*) μ = 2.78 D (theory)[a] 0% *E*	⇌	 **12** (*Z*) μ = 0.91 D (exp) 100% *Z*	9
 **13** (*Z*) μ = 1.25 D (s-trans, theory)[b] 2% *Z*	⇌	 **14** (*E*) μ = 1.10 D (s-trans, theory)[b] 98% *E*	24
 **15** (*E*) μ = 1.29 D (exp) 100% *E*	⇌	 **16** (*Z*) μ = 2.32 D (s-trans, theory) 0% *Z*	25

[a] Calculation based on a planar diphenylamino group.
[b] Calculated by us using the bond moments and bond angles in Table I.

determined dipole moment of the *Z* isomer (**10**). Dipole moment effects could also be responsible for the differences in the stabilities (Table IV) of isomeric *N*,*N*-diphenylbenzhydrazidoyl chlorides (**11** and **12**), *O*-methylacetophenone oximes (**13** and **14**), and methyl *N*-methylbenzimidates (**15** and **16**).

Experimental Section

Preparation of Compounds. Melting points are corrected and were determined on a Thomas-Hoover capillary melting point apparatus. All boiling points are uncorrected. Magnesium sulfate was employed as a drying agent for ether and chloroform extracts. Infrared spectra were determined with a Perkin-Elmer spectrophotometer, Model 225. The NMR spectra were determined at 60 MHz with a Varian Model A-60A spectrometer. The ultraviolet spectra were determined with a Cary Model 15 spectrophotometer. Compounds **3h, 5d, 6d, 5f, 6f, 5g,** and **6g** have been described in an earlier report.[20] The ultraviolet, infrared, and nuclear magnetic resonance spectra along with melting points or boiling points for all the other compounds prepared in this work are in Table II. The GLC (analytical and preparative) was carried out with a column (30 ft × 0.375 in.) consisting of 20% silicone gum rubber (SE-30) on 45–60 mesh Chromosorb W. Microanalyses were carried out by Atlantic Microlab, Atlanta, Ga. The potassium benzohydroxamates (**1a–f**) were prepared according to an organic synthesis procedure.[26,27] One representative example of each type of synthetic procedure is described in this section.

Methyl *p*-Methylbenzohydroxamate (2c). Dimethyl sulfate (34 ml) was added to a water (1000 ml) solution of potassium *p*-methylbenzohydroxamate (60.0 g) and potassium hydroxide (53 g). The solution was heated (75°) and stirred for 7 days, after which time it did not give a purple color with alcoholic ferric chloride solution. The solution was cooled in an ice bath and carefully acidified with cold glacial acetic acid. The crystals (37.0 g, 70%) which formed were filtered and dried, mp 55–69°. Several recrystallizations from ether–hexane gave colorless plates, mp 70–71°.

Anal. Calcd for $C_9H_{11}NO_2$: C, 65.44; H, 6.71; N, 8.48. Found: C, 65.22; H, 6.82; N, 8.34.

(*E*)-*O*-Methyl-*p*-methylbenzohydroximoyl Chloride (3c). Phosphorus pentachloride (18.2 g) was slowly added with stirring to methyl *p*-methylbenzohydroxamate (14.4 g) in an 100-ml round-bottom flask cooled in an ice bath. The flask was allowed to warm to room temperature and it was then heated at 56–60° for 2 hr. The flask was cooled to room temperature and the liquid product was poured slowly with stirring into cold water. The resulting mixture was extracted several times with chloroform. The combined chloroform extracts were washed alternately with 10% sodium bicarbonate solution, water, 6 *N* sodium hydroxide solution, and water. The chloroform solution was dried and the chloroform was removed by evaporation at aspirator pressure. The residual oil was distilled to give a colorless oil (9.50 g, 59%), bp 56–57° (0.06 Torr).

Anal. Calcd for $C_9H_{10}NOCl$: C, 58.87; H, 5.49; N, 7.63; Cl, 19.31. Found: C, 58.92; H, 5.53; N, 7.48; Cl, 19.47.

The oil did not form a white precipitate of silver chloride when added to an alcoholic silver nitrate solution, indicating the absence of phosphorus oxychloride. In most preparations of the (*E*)-hydroximoyl chlorides additional washing with 10% sodium hydroxide solution and redistillation was necessary in order to completely remove the phosphorus oxychloride.

(*Z*)-*O*-Methyl-*p*-methylbenzohydroximoyl Chloride (4c). Photoisomerization of 3c. A hexane (80 ml) solution of **3c** (2.0 g) was irradiated in quartz tubes for 3 hr using a Rayonet photochemical reactor, Model RPR-100 (The Southern New England Ultraviolet Co.) equipped with 2537-Å lamps. In order to prevent acid-catalyzed isomerization of **4c**, the hexane solution was shaken with solid, anhydrous sodium carbonate immediately after irradiation. The hexane was then removed by evaporation at aspirator pressure. The residual oil was analyzed by GLC and found to contain a 60:40 mixture of **3c** and **4c** along with a small amount of *p*-methylbenzonitrile. Pure **4c** was obtained by preparative GLC.

Anal. Calcd for $C_9H_{10}NOCl$: C, 58.87; H, 5.49; N, 7.63; Cl, 19.31. Found: C, 59.10; H, 5.57; N, 7.70; Cl, 19.08.

Isomerization of 4c in Benzene–Hydrogen Chloride Solution. A saturated solution (ca. 0.4 mol kg^{-1}) of hydrogen chloride in benzene was prepared by bubbling dry hydrogen chloride gas through anhydrous benzene for about 15 min. The hydroximoyl chloride **4c** (0.73 g) was added to the benzene–hydrogen chloride solution (1.00 g) in a NMR spin tube fitted with a rubber septum. The isomerization of **4c** to **3c** was followed by NMR spectroscopy (40°) until **4c** could no longer be detected (about 4 days).

Methyl (*Z*)-*O*-Methyl-*p*-methylbenzohydroximate (6b). A sodium methoxide solution prepared from 0.86 g of sodium and methanol (15 ml) was added to **3c** (4.5 g) dissolved in dimethyl sulfoxide (135 ml). The solution was heated at 45° for 25 hr and then poured into ice water (135 ml). Enough sodium chloride was added to saturate the aqueous layer and the mixture was extracted several times with ether. The ether extracts were dried and evaporated to give 4.15 g (94%) of oil. GLC analysis of the oil showed that it contained 98% **5b** and 2% **6b**. Distillation gave pure **6b** (2.48 g, 56%), bp 75° (0.4 Torr).

Anal. Calcd for $C_{10}H_{13}NO_2$: C, 67.02; H, 7.31; N, 7.82. Found: C, 67.18; H, 7.34; N, 7.91.

Methyl (*E*)-*O*-Methyl-*p*-methylbenzohydroximate (5b). Glacial Acetic Acid Isomerization of 6b. A glacial acetic acid (15 ml) solution of **6b** (1.34 g) was heated at 80° in a constant-temperature bath for 3.5 hr. The reaction solution was quenched by mixing with an excess of 6 *N* sodium hydroxide (50 ml) solution. The resulting mixture was extracted with ether (two 20-ml portions) and the ether extracts were dried and evaporated, yielding a clear oil. GLC analysis of the oil showed only two peaks due to **5b** and **6b** in a ratio of 77:23. Isomer **5b** was separated by preparative GLC.

Anal. Calcd for $C_{10}H_{13}NO_2$: C, 67.02; H, 7.31; N, 7.82. Found: C, 67.21; H, 7.35; N, 7.91.

For the equilibrium studies, the glacial acetic acid solutions of the *Z* or *E* hydroximates (**5**) were heated for various periods of time to determine when equilibrium had been reached. In all the isomerization reactions examined equilibrium had been attained within 3 hr.

Dipole Moment Measurements. Dipole moments were determined by the method of Guggenheim.[28] The dielectric constants were measured with a Kahl Scientific Type DM-01 Dipolmeter fitted with a DFL-1 sample holding cell (20-ml volume) which has a dielectric constant range of 1.0–3.4. The DFL-1 cell was calibrated in the D2 position of the dipolmeter with the following spectrophotometric grade liquids: cyclohexane (Baker), carbon tetrachloride (Aldrich), benzene (Baker), and toluene (Aldrich). These solvents had been stored over Linde type 4A molecular sieves at least 1 week prior to the measurements. Dielectric constants for these liquids have been reported.[28d] A calibration equation for conversion of the dipolmeter reading into dielectric constant was calculated by the method of least squares. Dielectric constants were measured on four or five benzene (Baker spectrophotometric grade kept over Linde type 4A molecular sieves) solutions of concentrations ranging from 0.005 to 0.06 weight fraction. The solutions were made up by weighing (Mettler semimicro analytical balance to the nearest 0.01 mg) the solute directly into a 25-ml volumetric flask and diluting to the mark with solvent. The flask was reweighed and the weight fraction of each solution was calculated. After the DFL-1 cell was filled with the solution to be measured the cell contents were allowed to stand for at least 5 min to allow the solution to reach thermal equilibrium. Five meter readings on the Dipolmeter were taken for each solution and the average was corrected with a correction diagram furnished with the instrument. After each measurement, the cell was rinsed thoroughly with acetone or methanol and dried by flushing with dry nitrogen. The cell was also rinsed with a few milliliters of the solution to be measured before the cell was filled. Immediately after measuring the dielectric constant, the refractive index of each solution was measured using an Abbe high-precision refractometer (Bellingham and Stanley Limited Model 60/ED) fitted with a 2-ml flow-through cell. The procedure previously described for cleaning and filling the Dipolmeter cell was used for the refractometer cell. Both the Dipolmeter and refractometer cells were maintained at 25.0 ± 0.1° by means of a circulating constant-temperature bath. The dipole moments were calculated from the equation

$$\mu^2 = \frac{27KT}{4\pi N}\frac{M(a_\epsilon - a_n)}{d(\epsilon_1 + 2)^2}$$

where K = Boltzmann's constant, N = Avogadro's number, T = temperature (K), M = molecular weight of the solute, d = density of the solvent, ϵ_1 = dielectric constant of the solvent, a_ϵ = slope of a line obtained by plotting $(\epsilon_{12} - \epsilon_1)$ vs. ω where ϵ_{12} is the dielectric constant of a solution and ω is the weight fraction of that solution, and a_n = slope of a line obtained by plotting $(n_{12}{}^2 - n_1{}^2)$ vs. ω where n_{12} is the refractive index of a solution and n_1 is the refractive index of the solvent. The values for a_ϵ and a_n were determined by least-squares evaluation of the data. The error limits in a_ϵ and a_n were estimated at the 95% confidence level. These errors limits were used to calculate the errors in the dipole moments given in Table I.

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Registry No.—**1a,** 32685-16-8; **1b,** 57139-18-1; **1c,** 57139-19-2; **1d,** 57139-20-5; **1e,** 57139-21-6; **1f,** 57139-22-7; **1g,** 57139-23-8; **2a,** 2446-51-7; **2b,** 1613-79-2; **2c,** 25563-06-8; **2d,** 25563-14-8; **2e,** 57139-24-9; **2f,** 24056-08-4; **2g,** 57139-25-0; **2i,** 3532-27-2; **3a,** 41071-34-5; **3b,** 41071-36-7; **3c,** 57139-26-1; **3d,** 57139-27-2; **3e,** 57139-28-3; **3f,** 57139-29-4; **3g,** 57139-30-7; **3h,** 57139-31-8; **3i,** 57139-32-9; **3j,** 41071-43-6; **4a,** 41071-35-6; **4b,** 41071-37-8; **4c,** 57139-33-0; **4d,** 57139-34-1; **4e,** 57139-35-2; **4f,** 57139-36-3; **4g,** 57139-37-4; **4h,** 57139-38-5; **4i,** 57139-39-6; **4j,** 57139-40-9; **5a,** 41071-40-3; **5b,** 57139-41-0; **5c,** 57139-42-1; **5d,** 26889-19-0; **5e,** 57139-43-2; **5f,** 26889-20-3; **5g,** 26889-17-8; **6a,** 41071-39-0; **6b,** 57139-44-3; **6c,** 57139-45-4; **6d,** 26889-13-4; **6e,** 57139-46-5; **6f,** 26889-14-5; **6g,** 26889-11-2.

References and Notes

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