Reduction of the Benzyl Ether Lactone 4 to 6. Following the procedure described for the preparation of **5**, the double bond in benzyl ether **4** was selectively reduced over 5% Pd/C to furnish the saturated benzyl ether **6** in 97% yield: bp 150–155 °C (0.5 mm); IR ($CHCl_3$) 1776 cm^{-1}; NMR ($CDCl_3$) δ 3.4 (2 H, d, J = 6 Hz, $-CH_2O-$), 4.54 (2 H, br, $-OCH_2Ph$), 4.9 (1 H, m, -CHOCO), and 7.3 (5 H, s, C_6H_5); TLC R_f 0.55 (1:1 C_6H_6/ether).

Preparation of Lactone Alcohol 7: (a) From the Methyl Ether 5. A solution of 0.17 g (1 mmol) of lactone methyl ether **5** in 5 mL of CH_2Cl_2 was stirred at −78 °C under a nitrogen atmosphere. To this solution was added 0.5 mL (5.5 mmol) of BBr_3, and the resulting white slurry was brought rapidly to 0 °C. After completion of the reaction (5.5 h), 2 mL of ether was added dropwise and the mixture was stirred for 5 min and then added to a stirred slurry of 2.3 g of $NaHCO_3$ in 12 mL of saturated sodium potassium tartrate solution. The organic layer was separated and the water layer extracted with CH_2Cl_2. The combined organic extracts were washed with saturated sodium potassium tartrate and dried (Na_2SO_4). The crude product, weighing 154 mg, was purified by chromatography on silica gel (Baker) eluting with CH_2Cl_2 followed by CH_2Cl_2/EtOAc (9:1). Evaporation of the combined fractions gave pure **7** (121 mg, 77% yield): bp 135–138 °C (0.1 mm); IR ($CHCl_3$) 1770 cm^{-1} (C=O); NMR ($CDCl_3$) δ 1.3–2.9 (8 H, m), 3.05 (1 H, s, OH), 3.60 (2 H, d, J = 6 Hz, $-CH_2O-$), and 5.00 (1 H, br, -CHOCO); TLC R_f 0.3 (EtOAc). Optically active material had $[\alpha]^{27}_D$ −26.1° (c 1, $CHCl_3$).

(b) From the Benzyl Ether 6. A 52-g amount of the benzyl ether **6**, dissolved in 400 mL of EtOAc containing 0.5 mL of concentrated HCl, was hydrogenated over 10% Pd/C (4 g) at room temperature and pressure. After hydrogen absorption had ceased (1 h), workup followed by distillation gave 33 g of **7** (98% yield), identical in all respects with the material prepared above.

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Registry No.—**1**, 52578-42-4; **2**, 50889-56-0; **3**, 39673-26-2; **4**, 35761-79-6; **5**, 66748-93-4; **6**, 54382-69-3; **7**, 43119-34-2; (+)-**9**, 41787-51-3.

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(7) Melting points (uncorrected) were taken with a Thomas-Hoover capillary apparatus. NMR spectra were recorded on Varian A-60 and T-60 spectrometers with Me_4Si as an internal standard. IR spectra were determined with a Perkin-Elmer Model 21 spectrometer.

The *E* Isomer of Acetophenone Iminoxy, an Overlooked Radical

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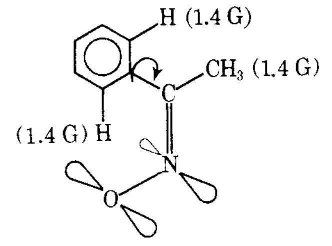
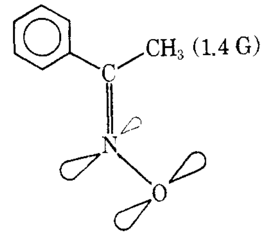
The acetophenone iminoxy radical has been observed by ESR spectroscopy during oxidation of acetophenone oxime in a number of studies: in a flow system[1] with ceric salts, in static systems with lead tetraacetate in benzene[2,3] or methylene chloride,[4,5a] and by other methods.[5b]

It is a transient radical which rapidly disappears after its generation at ambient temperatures, giving rise to diamagnetic products[3] and secondary radicals of the nitroxide type as noted by several authors. The latter radicals are readily distinguished from the iminoxy radical by their lower nitrogen hyperfine splitting constants (hfsc): a_N(iminoxy) $\simeq$ 31 G; a_N(nitroxide) $\leq$ 16 G.

In these studies only one iminoxy radical was detected, and it was established by Gilbert and Norman[5a] to be the Z isomer [(Z)-**1**] in which a characteristic 1.4 G coupling with both ortho hydrogens is present due to interaction of the rapidly rotating phenyl group with the unpaired electron which is contained in a σ-type orbital.[6a] This orbital is derived from an oxygen p orbital and the nitrogen nonbonding sp^2 orbital which are in the C=N–O plane. The spin density in iminoxy radicals is almost evenly distributed over nitrogen and oxygen. The C=N–O angle has been calculated to be 139°, and thus it is larger than in the parent oxime.[6b] It is rather surprising that for the iminoxy radical only the Z form has been found so far, while for the oxime the E form strongly predominates ($\simeq$95% in the equilibrium mixture; the isolation of the Z isomer has only recently been accomplished[7,8,9]). Apparently, in **1** the $E \rightarrow Z$ isomerization is a very rapid process and (Z)-**1** is the thermodynamically more stable isomer.



(Z)-1 (anti)



(E)-1 (syn)

Z/E isomerization in iminoxy radicals leading to an equilibrated mixture of two radicals with separate ESR signals has been observed frequently.[10] The same situation exists in a number of para- or meta-substituted acetophenone iminoxy radicals.[11,12] It therefore seemed desirable to confirm the previous assignment of the ESR signal of the acetophenone iminoxy radical to exclusively (Z)-**1** with the aid of the compounds perdeuterated either in the methyl or phenyl group.

Experimental Section

(E)-Acetophenone oxime was characterized by its melting point (58–59 °C) and NMR spectrum. In addition to a correct melting point, the α,α,α-trideuterated compound was found to contain a methyl group with >95% deuterium content by NMR spectroscopy and ≥98% by mass spectrometry; the pentadeuteriophenyl oxime had 97.5 (NMR) and 98% (MS) deuterium content. NMR spectra were taken on Varian A-60 and HA-100 spectrometers. Mass spectra were run on an AEI-MS-902 mass spectrometer.[13] ESR spectra were taken on a Varian E-4 spectrometer with a variable temperature accessory. The hfsc are uncorrected, but they can be compared with those obtained with the same instrument for the perylene radical cation[14] in 98% sulfuric acid at 20 °C (found: 4.10, 3.10, and 0.45 G). Values of g were measured with respect to solid DPPH (taken as g = 2.0036).

Results and Discussion

We have previously analyzed the ESR spectra of aromatic iminoxy radicals in more detail than was done before[15,16] using *tert*-butyl peroxalate[17] (TBPO) as a convenient thermal source of *tert*-butoxy radicals in apolar solvents at ambient temperature, which in turn generate iminoxy radicals from the oximes.

This method enabled us to maintain a steady state of acetophenone iminoxy radicals for periods up to hours and to study them at leisure under high resolution. In addition to the previously reported a_N = 1.4 G (5 H, CH_3 and ortho H's), the spectra of (Z)-**1** contain a small para H coupling ($a_H{}^p$ = 0.56 G), indicating the presence of some unpaired spin density in the aromatic π-electron system. The coupling is removed by para substituents like OCH_3 (Figure 1). To explain the unpaired π-spin density in (Z)-**1** and in other aromatic iminoxy radicals in which the oxygen atom and the phenyl group are in a Z position, the author has proposed a $\sigma \rightarrow \pi$ spin polarization mechanism at nitrogen and/or oxygen and a distri-

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Table I. ESR Spectral Parameters of Acetophenone Iminoxy Radicals[a]

		Z isomer				*E* isomer			
Radical	Temp, °C	a_N	a_H	Other $a_{H(D)}$	*g* value	a_N	a_H	Other $a_{H(D)}$	*g* value
1	25	31.44	1.39 (5 H)	0.56 (*p*-H)	2.0059	Obscured by *Z* isomer			
2[b]	−30	31.5	*c*	*c*	*c*	31.1	–	*c*	*c*
2	20	31.40	1.44 (2 H)	$a_D \sim 0.24$	2.0058	31.00	–	–	2.0064
2	38	31.3	*c*	*c*	*c*	30.9	–	*c*	*c*
2[d]	38	31.6	~1.5 (2 H)	*c*	*c*	31.1	–	*c*	*c*
2[e]	25	31.4	1.44 (2 H)	$a_D \sim 0.24$	2.0057	31.0	–	–	2.0065
3	20	31.40	1.37 (3 H)	–	2.0059	31.12	1.40 (3 H)	$a_D \sim 0.25$	2.0066

[a] Obtained by oxidation of the oxime with TBPO (in CS_2 unless stated otherwise). Hfsc are given in gauss. [b] With lead tetraacetate as an oxidant. [c] Not recorded. [d] In methylene chloride. [e] In benzene.

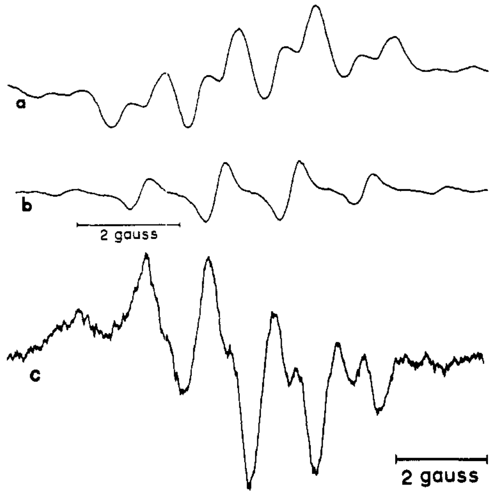
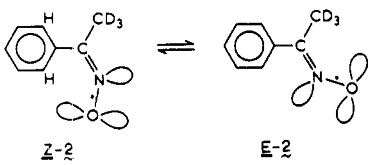


Figure 1. ESR spectra of the low-field nitrogen groups of (a) acetophenone iminoxy (**1**) and (b) *p*-methoxyacetophenone iminoxy radicals (in CS_2 at 40 °C) and (c) the high-field nitrogen group of acetophenone iminoxy (**1**) (in CS_2 at 10 °C).



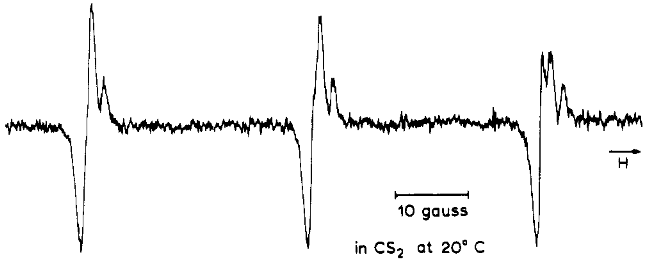


Figure 2. ESR spectrum of compound **2**.

bution of the unpaired π-electron density over the entire π-electron system, as expected for a π radical.[15,16]

At first sight, the spectrum of **1** in the temperature range from 20–40 °C does not show evidence for the presence of the *E* isomer. However, this evidence was obtained from a study of the α,α,α-trideuterated compound $C_6H_5C(CD_3)=NO\cdot$ (**2**). The ESR spectrum reproducibly showed the presence of two iminoxy radicals **2** in comparable amounts with different a_N and *g* values and line widths (Figure 2). Only one of these radicals shows the expected hfsc of ~1.4 G with presumably the two ortho hydrogens, and therefore it is assigned structure (*Z*)-**2** (cf. Table I). The other radical which slightly predominates in the spectrum gives a single broad line in each nitrogen group of lines (Figures 2 and 3). The same results were obtained when TBPO as a hydrogen abstracting agent was replaced by lead tetraacetate; at −30 °C a mixture was observed in which the second radical predominates more strongly. Replacing CS_2 as a solvent by methylene chloride or benzene had no effect on the appearance of the second radical.

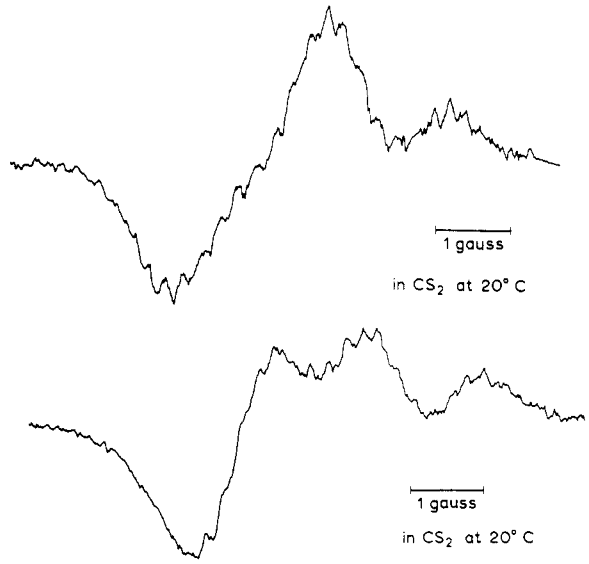
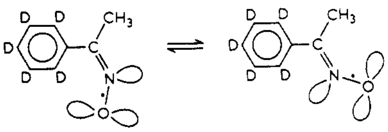


Figure 3. Enlarged ESR spectra of the low-field (top) and high-field (bottom) nitrogen groups of radical **2**.



Z-3 E-3

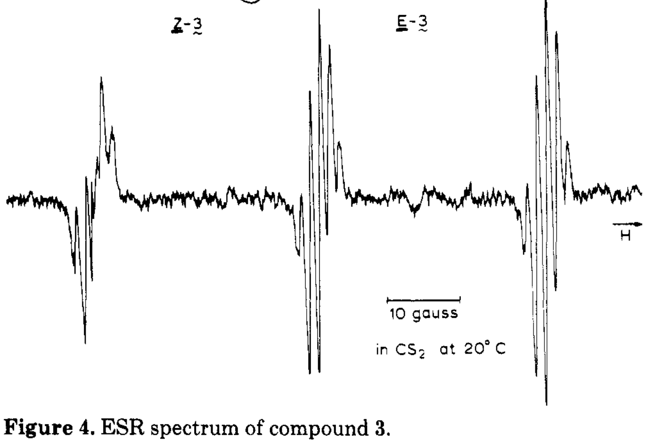


Figure 4. ESR spectrum of compound **3**.

It is therefore concluded not only that a *Z*/*E* equilibrium mixture of **2** is formed upon oxidation of the oxime but that the so far unknown *E* isomer is even slightly predominating, at least in acetophenone iminoxy with a trideuterated methyl group under our conditions.

The spectrum of the pentadeuteriophenyl compound $C_6D_5C(CH_3)=N–O\cdot$ (**3**) supports this conclusion (Figure 4).

Figure 5. ESR spectrum of the low-field nitrogen group of **3**.

Although the asymmetry of the three nitrogen groups of lines is less obvious than in **2**, the shape, number of hf lines, and overall width of each group are sufficiently different to allow an unambiguous interpretation. Again the mixture contains at least 50% of the *E* isomer of **3.** In the low-field nitrogen group all 8 lines of the two overlapping 1:3:3:1 quartet splittings of the methyl group can be recognized (Figure 5). The results for **1**, **2**, and **3** are presented in Table I.

Conclusions

From these consistent results with deuteration either in the side chain or in the aromatic nucleus, we are forced to conclude that 1 also exists, at least 50%, as its *E* isomer. Formerly, this isomer was not recognized due to the fact that its spectrum strongly coincides with and is obscured by that of (*Z*)-1. Both radicals possess a methyl group hfsc of ~1.4 G, as is found in acetone iminoxy;[5] in (*Z*)-1 the aromatic ortho hydrogens have only a slightly different hfsc. The *E* isomer of 1 will give rise to a 1:3:3:1 quartet in each nitrogen line, possibly broadened by unresolved hfsc from aromatic hydrogen atoms and appearing on the low-field side of each nitrogen line of (*Z*)-**1.** Since in **2** and **3** the spectra of *E* and *Z* isomers are best separated in the high-field nitrogen group, the *E* isomer of 1 is also expected to show up most clearly in this part of the spectrum. Indeed, the high-field nitrogen group of **1** is asymmetric and it contains broadened and intensified lines on its low-field side, supporting the correctness of the foregoing conclusions (Figure 1c). Moreover, it appears that the *E* radical is slightly favored over the *Z* form, especially at low temperatures. An increase in the *Z*/*E* ratio from parent oxime to radical is consistent with the larger C=N–O angle in the radical. However, this increase is less dramatic than believed formerly. The widespread acceptance in the literature of the strong preference of acetophenone iminoxy radical for the *Z* configuration and further conclusions, which are based on this incorrect assumption, will have to be reconsidered accordingly. These results stress again that great care has to be exercised when interpreting partially resolved ESR spectra of iminoxy radicals.[18]

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Registry No.—(*Z*)-**1**, 66538-90-7; (*Z*)-**2**, 66538-91-8; (*Z*)-**3**, 66538-92-9; (*E*)-**1**, 66538-95-2; (*E*)-**2**, 66538-93-0; (*E*)-**3**, 66538-94-1.

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