JOC Article

Thermolyses of *O*-Phenyl Oxime Ethers. A New Source of Iminyl Radicals and a New Source of Aryloxyl Radicals

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Six *O*-phenyl ketoxime ethers, RR′C═NOPh **1**−**6**, with RR′ = diaryl, dialkyl, and arylalkyl, together with *N*-phenoxybenzimidic acid phenyl ether, PhO(Ph)C═NOPh, **7**, have been shown to thermolyze at moderate temperatures with "clean" N−O bond homolyses to yield iminyl and phenoxyl radicals, RR′C═N$^{\bullet}$ and PhO$^{\bullet}$. Since **1**−**6** can be synthesized at room temperature, these compounds provide a new and potentially useful source of iminyls for syntheses. The iminyl from **7** undergoes a competition between β-scission, to PhCN and PhO$^{\bullet}$, and cyclization to an oxazole. Rate constants, $10^6\ k/s^{-1}$, at 90 °C for **1**−**6** range from 4.2 (RR′ = 9-fluorenyl) to 180 (RR′ = 9-bicyclononanyl), and that for **7** is 0.61. The estimated activation enthalpies for N−O bond scission are in satisfactory agreement with the results of DFT calculations of N−O bond dissociation enthalpies, BDEs, and represent the first thermochemical data for any reaction yielding iminyl radicals. The small range in k (N−O homolyses) is consistent with the known σ structure of these radicals, and the variations in k and N−O BDEs with changes in RR′ are rationalized in terms of iminyl radical stabilization by hyperconjugation: RR′C═N$^{\bullet}$ ↔ R$^{\bullet}$R′C≡N. Calculated N−H BDEs in the corresponding RR′C═NH are also presented.

Kinetic studies on the thermal decomposition of a number of *O*-benzyl oxime ethers in hydrogen donor solvents, XH (such as tetralin and 9,10-dihydroanthracene), at 150 °C have shown that the dominant process is a reverse radical disproportionation (RRD) followed by β-scission of the N−O bond, reaction 1.[1]

$$\mathrm{XH} + \mathrm{RR'C{=}NOCH_2Ph} \rightarrow \mathrm{X^{\bullet}} + \mathrm{RR'C^{\bullet}NHOCH_2Ph} \rightarrow \mathrm{RR'C{=}NH} + {}^{\bullet}\mathrm{OCH_2Ph} \quad (1)$$

In non-hydrogen-donor solvents, e.g., *tert*-butylbenzene, and at higher temperatures (170 °C), these compounds undergo a relatively "clean" homolysis of their O−C bond, reaction 2.[2]

$$\mathrm{RR'C{=}NOCH_2Ph} \rightarrow \mathrm{RR'C{=}NO^{\bullet}} + {}^{\bullet}\mathrm{CH_2Ph} \quad (2)$$

During these studies, it occurred to us that it might be possible to achieve a clean homolysis of the N−O bond at much lower temperatures by using *O*-phenyl oxime ethers, reaction 3.

$$\mathrm{RR'C{=}NOPh} \rightarrow \mathrm{RR'C{=}N^{\bullet}} + {}^{\bullet}\mathrm{OPh} \quad (3)$$

Reaction 3 would then provide a new, convenient, and relatively low-temperature, nonazo and nonperoxide, class of free-radical initiators as well as a source of iminyl radicals which have become of considerable synthetic interest in recent years.[3] Herein, we report on the kinetics and products of the thermolyses of seven *O*-phenyl oxime ethers in *tert*-butylbenzene mainly at 90 °C but with some work done at temperatures ranging from 60 to 150 °C. RRD is demonstrated to be unimportant, and the activation enthalpies, E_a, for decomposition are compared with DFT-calculated N−O bond dissociation enthalpies, BDEs.

Results

The compounds synthesized and studied in the present work are shown in Chart 1. The synthesis of **1**−**6** involved only a simple condensation of the corresponding ketone with commercially available *O*-phenylhydroxylamine (hydrochloride) in anhydrous pyridine at room temperature, reaction 4.

$$\mathrm{RR'C{=}O} + \mathrm{H_2NOPh} \xrightarrow{-\mathrm{H_2O}} \mathrm{RR'C{=}NOPh} \quad (4)$$

Compound **7** was prepared from benzohydroxamic acid in a four-step process based on its original synthesis by

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(1) Blake, J. A.; Ingold, K. U.; Lin, S.; Mulder, P.; Pratt, D. A.; Sheeler, B.; Walton, J. C. *Org. Biomol. Chem.* **2004**, *2*, 415−420.
(2) Pratt, D. A.; Blake, J. A.; Mulder, P.; Walton, J. C.; Korth, H.-G.; Ingold, K. U. Manuscript in preparation.
(3) See, e.g.: Boivin, J.; Schiano, A.-M.; Zard, S. Z. *Tetrahedron Lett.* **1994**, *35*, 249−252. Boivin, J.; Fouquet, E.; Zard, S. Z. *Tetrahedron* **1994**, *50*, 1745−1746. Zard, S. Z. *Synlett* **1996**, 1148−1154. Uchiyama, K.; Hayashi, Y.; Narasaka, K. *Chem. Lett.* **1998**, 1261−1262. Calestani, G.; Leardini, R.; McNab, H.; Nanni, D.; Zanardi, G. *J. Chem. Soc., Perkin Trans. 1* **1998**, 1813−1824. Gagosz, F.; Zard, S. Z. *Synlett* **1999**, 1978−1980. Guidon, Y.; Guérin, B.; Landry, S. R. *Org. Lett.* **2001**, *3*, 2293−2296. Mikami, T.; Narasaka, K. *C. R. Acad. Sci. Paris, Chim./Chem.* **2001**, *4*, 477−486. Leardini, R.; McNab, H.; Minozzi, M.; Nanni, D. *J. Chem. Soc., Perkin Trans. 1* **2001**, 1072−1078. Gennet, D.; Zard, S. Z.; Zhang, H. *Chem. Commun.* **2003**, 1870−1871.

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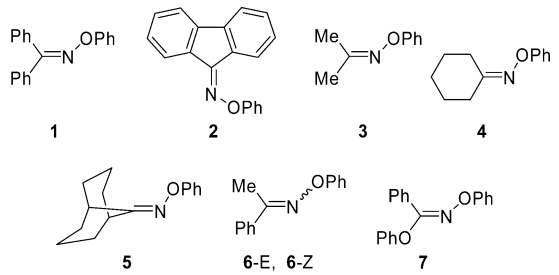
CHART 1



Taylor and Kienzle[4] but modified to avoid the use of a (highly toxic) thallium salt; see the Experimental Section.

Thermolyses of *O*-Phenyl Oxime Ethers. The oxime ethers (8−13 mg) were dissolved in 0.5 mL of *tert*-butylbenzene (*t*BB) in small Pyrex tubes. The solutions were degassed via three or more freeze−pump−thaw cycles on a vacuum line, and the tubes were flame-sealed under vacuum. The tubes were then heated in a constant temperature (±1 °C) oven at chosen temperatures for various lengths of time. Following thermolyses, the tubes were cooled to room temperature and opened, and the contents were added to 3 mL of acetonitrile. The solutions were subsequently filtered, when necessary, and analyzed by HPLC (see the Supporting Information).

Diaryl Ethers 1 and 2. The products of the thermolyses of these two $Ar_2C{=}NOPh$ compounds in *t*BB were the corresponding imines, $Ar_2C{=}NH$, the corresponding ketones, $Ar_2C{=}O$ (formed presumably by hydrolysis of the imines by trace water in the acetonitrile), and phenol. The identities of the imines and ketones were determined by comparison of their HPLC retention times and UV spectra with authentic materials, and their identities were further confirmed by GC/MS on samples where all the starting material had decomposed. Quantification of the loss of the starting oxime ether and formation of products was based on calibration of the HPLC's detector with the authentic compounds.

Product yields from the thermolyses of **1** and **2** in *t*BB at 90 °C as a percentage of the quantity of oxime ether decomposed after six and five, respectively, different time intervals are given in Table 1 (for additional details, see Table S1 in the Supporting Information). The major product is always the diarylimine, and the yields of imine plus ketone are fairly good ranging from 71% to 89% (Table 1). The yields of phenol are always poor, ranging from 17% to 35%.

Since *t*BB is not a hydrogen atom donor solvent, the obvious question is: What is the H-atom donor that converts iminyl and phenoxyl radicals to imine and phenol? We suggest that this hydrogen donor is formed in situ during the reaction via the dimerization and subsequent oligomerization of the phenoxyl radicals. The initial dimerization is known to involve both C−C and C−O coupling at the *ortho* and *para* positions and to yield much better H-atom donors than phenol itself.[5] The expected initial dimers arising from a C−C *ortho* and a C−O *ortho* coupling are shown in Scheme 1. Initial dimerization will be followed by oligomerization and the consequent formation of compounds containing additional labile hydrogens. Oligomerization is implied by the fact that a precipitate was formed when these product solutions in *t*BB were mixed with acetonitrile. This solid, which had to be removed by filtration prior to analysis, was dissolved in deuterated chloroform, and the ^{1}H NMR spectrum showed only the presence of aromatic residues. No precipitate was formed when the thermolyses of **1** and **2** were run in *t*BB containing a deliberately added good hydrogen donor, vide infra.

(4) Taylor, E. C.; Kienzle, F. *J. Org. Chem.* **1971**, *36*, 233−235.
(5) See, e.g.: Ingold, K. U. In *Essays on Free Radical Chemistry*; Special Publication 24, 1970; Chapter 11, Royal Chemistry Society, London, U.K., ISBN 0-85186-009-5.

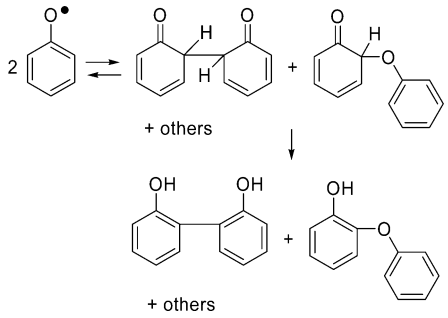
TABLE 1. Decomposition of $Ph_2C{=}NOPh$ (1) and $Fl{=}NOPh$ (2) in *tert*-Butylbenzene at 90 °C for Various Time Periods[a,b]

time (10^{-3} s)	**1**	Ph_2CNH	Ph_2CO	$Ph_2CNH + Ph_2CO$	PhOH
54.0	50.7	66.3	5.1	71.4	28.5
86.4	33.8	68.4	5.0	73.4	31.1
97.2	31.4	72.4	6.0	78.4	34.8
122.0	21.4	63.0	9.3	72.3	31.2
172.8	11.1	65.0	7.7	72.7	32.4
244.8	4.6	66.1	11.5	77.6	35.7

time (10^{-3} s)	2	FlNH	FlO	FlNH + FlO	PhOH
68.4	72.5	83.0	5.6	88.6	20.7
118.8	57.9	76.2	3.1	79.3	17.1
176.4	47.1	80.0	3.7	83.7	18.1
230.4	39.1	81.9	4.6	86.5	19.8
248.4	35.1	78.3	4.2	82.5	18.3

[a] Remaining $Ar_2C{=}NOPh$ is given as a percentage of the initial concentration and products as a percentage of decomposed $Ar_2C{=}NOPh$. [b] For additional data, see Table S1 (Supporting Information).

SCHEME 1



The induced decomposition of *O*-benzyl oxime ethers in hydrogen donor solvents by the RRD process, reaction 1, was most pronounced for $Ph_2C{=}NOCH_2Ph$ and $Fl{=}NOCH_2Ph$.[1] This is, presumably, a consequence of the more favorable thermodynamics arising from the resonance stabilization of the intermediate diarylalkoxyaminocarbinyl radical (see reaction 1). Although the solvent-induced RRD reaction appears not to occur in *t*BB,[2] there was no assurance that the radicals formed by homolysis of $RR'C{=}NOPh$ (reaction 3) might not also be capable of inducing decomposition. To asses this possibility with the two oxime ethers where it was expected to be most important, and to see if the product yields shown in Table 1 could be improved, we studied the decomposition of **1** and **2** in *t*BB to which was added either 2,2,5,7,8-pentamethyl-6-hydroxychroman, PMHC (a vitamin E analogue), or 1,2-diphenylhydrazine, DPHA, both of which are known to be excellent H-atom donors to

TABLE 2. Decomposition of Ph_2C=NOPh (1) and Fl=NOPh (2) in *tert*-Butylbenzene Containing a Hydrogen Donor, XH, at 90 °C for Various Time Periods[a,b]

XH	time (10^{-3} s)	**1**	Ph_2CNH	Ph_2CO	Ph_2NH + Ph_2CO	PhOH
PMHC	57.6	40.9	91.1	3.8	94.9	78.5
	108.0	22.0	91.7	4.3	96.0	78.1
	172.2	6.3	86.7	6.2	92.9	74.8
	248.4	2.7	86.9	7.1	94.0	74.3
DPHA	61.2	42.4	*c*	3.2	*c*	75.7
	108.0	21.1	*c*	3.8	*c*	69.7
	172.8	8.1	*c*	4.6	*c*	71.5
	249.0	2.5	*c*	5.9	*c*	71.0

XH	time (10^{-3} s)	**2**	FlNH	FlO	FlNH + FlO	PhOH
PMHC	72.0	63.6	45.9	7.0	52.9[d]	56.4
	100.8	57.7	51.0	8.8	59.8[d]	68.5
	172.8	44.4	56.0	10.4	66.4[d]	76.9
	244.8	32.5	53.7	11.3	65.0[d]	78.0
DPHA	64.8	71.7	85.4	8.7	94.1	82.9
	108.0	63.8	92.9	10.4	103.3	97.4
	172.8	48.5	90.6	11.2	101.8	97.7
	249.0	32.5	86.1	11.4	97.5	106.5

[a] Remaining Ar_2C=NOPh is given as a percentage of the initial concentration and products as a percentage of decomposed Ar_2C=NOPh [b] For additional data, see Table S2 (Supporting Information). [c] Could not be determined because this imine elutes at the same time as DPHA. [d] Three unidentified products are formed as well, which are attributed to trapping of the Fl=N• radical by the relatively persistent phenoxyl radical from PMHC. Assuming the same UV response factors as the imine and starting Fl=NOPh, the yields of fluorenyl-containing products rise to 59.2, 68.4, 79.6, and 79.7% with increasing time.

radicals.[6] The initial concentrations of **1** and **2** were generally 86 mM, and 2.2 molar equiv of these two H-donors were used, i.e., 189 mM. The results of these experiments at 90 °C are given in Table 2. Additional data, including data at 60 °C and 110 °C, are available as Supporting Information (Table S2).

In *t*BB, even in the absence of an added H-donor, the combined yields of imine plus ketone are fairly good (71−89% of the *O*-phenyl ether decomposed) but there is a large deficit in the yields of phenol (17−36%), see Table 1, due presumably to phenoxyl radical dimerization and oligomerization, vide supra. In the presence of a hydrogen donor (PMHC for **1** and DPHA for **2**), the combined yields of imine plus ketone become essentially quantitative and phenol yields increase dramatically (to 70−100%); see Table 2.

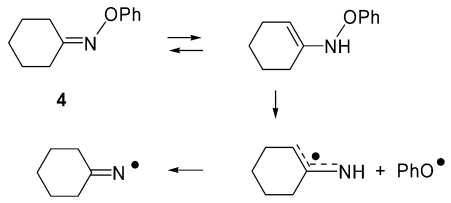
The same data that were used to formulate Tables 1 and 2 can be converted into rate constants for the thermolyses of **1** and **2**. These rate constants can be derived both from the loss of the *O*-phenyl ether reactant and from both the formation of imine plus ketone and the formation of phenol. For each set of conditions, reactant and product derived rate constants are in excellent agreement (see Table S3, Supporting Information). More significantly, the rate constants in the absence of a hydrogen donor are essentially identical to those in the presence of a H-donor. This proves that there is little or no RRD-induced decomposition of either **1** or **2** even with these strong H-donors.[6] Rate constants for the thermolyses of **1** and **2** determined from the rates of loss of these compounds at 60, 90, and 110 °C are presented in Table 3. These rate constants at 60 and 110 °C are, like those at 90 °C, also in good agreement with those determined from the formation of imine plus ketone or phenol (see also Table S6, Supporting Information).

TABLE 3. First-Order Rate Constants for Homolyses of the N−O Bond in *O*-Phenyl Oxime Ethers, RR′C=NOPh, 1−7 from Loss of Ether in *tert*-Butylbenzene without and in Parenthesis with 2.2 Molar Equiv of a Hydrogen Donor, XH, at Various Temperatures[a]

	R	R′	$10^6k/s^{-1}$ 60 °C	90 °C	110 °C
1	Ph	Ph	0.25 (0.31, −)	12 (15, 15)	110 (160, −)
2	9-fluorenyl		0.12 (−, 0.14)	4.2 (4.8, 4.4)	46 (−, 42)
3	Me	Me		12 (15, 16)	
4	cyclohexyl		1.4 (1.7, −)	56 (64, −)	
5	bicyclononanyl		4.9 (6.1, −)	180 (200, −)	
6-*E*	Ph	Me		7.7 (7.9, −)	
7	PhO	Ph		0.61	21[b] (25[b,c])

[a] In parentheses, *k* values as determined in the presence of a hydrogen donor, XH = PMHC (first entry), or XH = DPHA. Rate constants calculated from product formation are generally in excellent agreement with those given in this table. They are presented in Table S6 (Supporting Information). [b] At 120 °C, see Table 4. [c] No PMHC but with XH = tetralin as the solvent.

SCHEME 2



Since **1** and **2** have the iminyl moieties most susceptible to RRD-induced decomposition of RR′C=$NOCH_2$Ph compounds[1] it would appear to be highly unlikely that the kinetics for the decomposition of **3**−**7** in *t*BB will be contaminated by such a process. Nevertheless, we did carry out experiments that confirm the absence of significant RRD for all of these compounds, vide infra.

Dialkyl Ethers 3−5. The product imines from the three *O*-phenyl dialkyl oxime ethers are not expected to absorb strongly at 254 nm, the applied wavelength for the HPLC analysis. Therefore, rate constants could only be determined from the rate of loss of the reactant (see Table 3) and from the rate of formation of phenol. Rate constants derived by these two procedures were again in excellent agreement (see Table S6, Supporting Information). Compounds **4** and **5** were chosen to explore the possibility that the observed N−O bond scission in *O*-phenyl dialkyl (and alkyl aryl) oxime ethers was not the straightforward reaction, 3, but instead involved an initial tautomerism to the enamine followed by N−O cleavage at an sp^3 nitrogen atom, e.g., Scheme 2.

This potential alternative decomposition pathway is not possible for **5** because the enamine intermediate would have a double bond at its bridgehead, reaction 5, which is prohibited by Bredt's rule. Since **5** decomposes more rapidly than **4** we can discount decomposition via

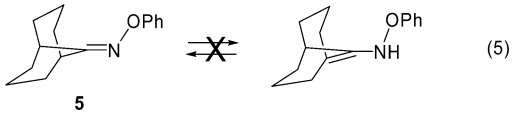
(6) For PMHC, see, e.g.: Burton, G. W.; Doba, T.; Gabe, E. J.; Hughes, L.; Lee, F. L.; Prasad, L.; Ingold, K. U. *J. Am. Chem. Soc.* **1985**, *107*, 7053−7065. For DPHA, see, e.g.; Mahoney, L. R.; Ferris, F. C.; DaRooge, M. A. *J. Am. Chem. Soc.* **1969**, *91*, 3883−3889. Mahoney, L. R.; Menderhall, G. D.; Ingold, K. U. *J. Am. Chem. Soc.* **1973**, *95*, 8610−8614.

TABLE 4. Decomposition of PhO(Ph)C=NOPh (7) in *tert*-Butylbenzene and Tetralin at 120 °C for Various Time Periods[a,b]

*t*BB	time (10^{-3} s)	**7**	**8** imine	**9** PhCN	**10** oxazole	Σ(**8** + **9** + **10**)[c]	PhOH	**9**/**10**[d]
	7.2	83.3	8	0	8	86	78	8.8
	16.2	67.2	14	59	8	81	74	7.4
	57.6	35.5	4	58	11	73	79	5.3
	73.8	20.2	22	55	9	86	76	6.1
	95.4	12.1	15	71	8	94	83	8.9
	10^6 k/s^{-1}	21	*e*	*e*	21		21	
	R^2	0.982			0.947		0.984	
tetralin	time (10^{-3} s)	**7**	**8** imine	**9** PhCN	**10** oxazole	Σ(**8** + **9** + **10**)[c]	PhOH	**9**/**10**[d]
	3.6	84.9	14	26	5	45	62	5.2
	8.1	70.8	15	25	5	45	72	5.0
	18.0	62.2	29	36	8	73	118	4.5
	64.8	21.6	*f*	*f*	*f*		*f*	
	79.2	12.3	24	49	9	82	137	5.4
	10^6 k/s^{-1}	25	*e*	*e*	21		*e*	
	R^2	0.984			0.886			

[a] Remaining **7** is given as a percentage of the initial concentration, and products are given as a percentage of decomposed **7**. Rate constants (and R^2) calculated from loss of **7** and from formation of some products are included in italics. [a] For additional data, see Table S7 (Supporting Information). [b] Nitrogen balance for product formation. [c] Ratio of the rates of β-scission to cyclization, see Scheme 3. [d] Not calculated because the large changes in the ratio [product]$_t$/([**7**]$_0$ − [**7**]$_t$) suggest that additional chemistry is occurring. [e] Not measured.

the enamine tantomers of **3**−**6** and other *O*-phenyl alkyl oxime ethers.



5 (5)

Alkyl Aryl Ether 6. This compound is formed as a mixture of **6**-*E* (83%, Me and PhO *cis* to one another) and **6**-*Z* (17%) isomers. After heating at 90 °C for 24 h, 94% of the *Z*-isomer but only 46% of the *E*-isomer had decayed. The rate constant for decay of the *Z*-isomer at 90 °C is 33.2×10^{-6} s^{-1}, but this rate constant probably contains contributions from N−O bond homolysis *and* from isomerization of the less to the more stable isomer.[7] For this reason, Table 3 contains only rate constants measured for decay of the *E*-isomer (which can, of course, be determined reliably after most of the *Z*-isomer has been destroyed). Full kinetic details are given in Tables S4−S6 (Supporting Information).

***N*-Phenoxybenzimidic Acid Phenyl Ether, 7.** We have previously invented a clean, novel, aryloxyl radical thermal source, ARTS-1 (reaction 6), and synthesized two examples

$$(\mathrm{ArOCH_2ON{=}})_2 \xrightarrow{k_6} 2\ \mathrm{ArO^\bullet} + 2\ \mathrm{CH_2O} + \mathrm{N_2} \quad (6)$$

(ArO$^\bullet$ = PhO$^\bullet$ and α-tocopheroxyl).[8] These compounds decayed rather too rapidly at 37 °C (k_6 = 10^{-3} s^{-1}) to be useful for long-term studies of aryloxyl radical-induced oxidative stress in biological systems. The search for a thermally more stable ARTS-2 family led to **7** with the expectation finding reactions 7 and 8:

$$\underset{\mathbf{7}}{\mathrm{PhO(Ph)C{=}NOPh}} \xrightarrow{slow} \mathrm{PhO(Ph)C{=}N^\bullet} + \mathrm{PhO^\bullet} \quad (7)$$

$$\mathrm{PhO(Ph)C{=}N^\bullet} \xrightarrow{\beta\text{-scission}} \underset{\mathbf{9}}{\mathrm{PhCN}} + \mathrm{PhO^\bullet} \quad (8)$$

Reaction 8 was expected to be fairly rapid because the β-scission of ketiminyl radicals, or rather of sterically crowded ketiminyls, is known to be a fairly facile process, e.g.,[9] the β-scission: $(Me_3C)_2C{=}N^\bullet \rightarrow Me_3CCN + Me_3C^\bullet$, occurs at a rate comparable to that for the well-known β-scission: $Me_3CO^\bullet \rightarrow Me_2CO + Me^\bullet$.

In the event, the thermolyses of **7** in *t*BB at temperatures from 90 to 150 °C showed that reactions 7 and 8 represent **7**'s major decomposition pathways, and therefore, **7** represents the first member of the new ARTS-2 family. Next to benzonitrile, **9**, and phenol, two additional products emerged, which were identified (with EIMS or GCMS) as phenoxy phenyl ketimine, **8**, and 2-phenylbenzoxazole, **10**. Quantitative HPLC analyses were based on authentic **7**, **9**, **10**, and phenol, but for **8** we had to use the nearest carbonyl analogue, phenyl benzoate. The product yields from a thermolysis at 120 °C in *t*BB are given in Table 4 where it can be seen that Σ([**8**] + [**9**] + [**10**]), i.e., the "nitrogen balance" for product formation, is fairly good (73−94%), a result which justifies our use of the phenyl benzoate response to quantify **8**.

As with **1** and **2**, a precipitate formed when the *t*BB solutions of thermolyzed **7** were diluted with acetonitrile, and again the ^{1}H NMR spectrum of this solid dissolved in $CDCl_3$ showed only a complex pattern in the aromatic region. Since the nitrogen balance is good, this precipitate must be phenoxyl radical dimers and oligomers, the formation of which is consistent with yields of phenol in

(7) Isomerization routes potentially include (i) N−O bond homolysis followed by an in-cage collapse of the geminate iminyl/phenoxyl radical pair to the more stable oxime ether isomer, (ii) inversion at nitrogen, and (iii) rotation about the C=N double bond. Theoretical calculations on the isomerizations of aldoximes suggest that the barriers for (ii) and (iii) will be very high in energy (they are both ca. 61 kcal/mol for the isomerization of vinylaldoxime), favoring (i). See: Alberti, A.; Barbaro, G.; Battaglia, A.; Guerra, M.; Bernardi, F.; Dondoni, A.; Pedulli, G. F. *J. Org. Chem.* **1981**, *46*, 742−750.

(8) Paul, T.; Ingold, K. U. *Angew. Chem., Int. Ed.* **2003**, *41*, 804−806.

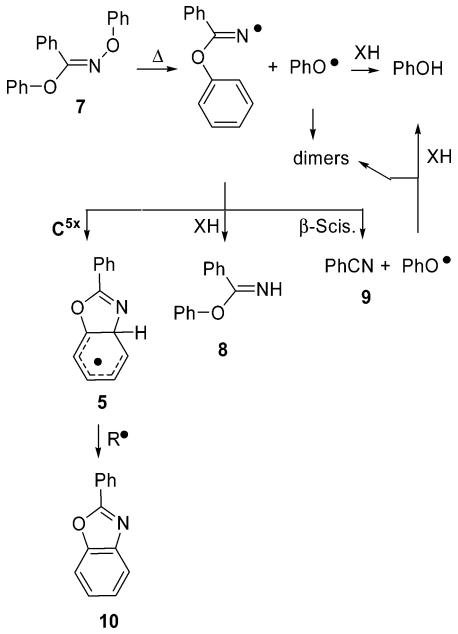
(9) Griller, D.; Mendenhall, G. D.; Van Hoof, W.; Ingold, K. U. *J. Am. Chem. Soc.* **1974**, *96*, 6068−6070.

TABLE 5. Decomposition of PhO(Ph)C=NOPh (7) at 90 °C in *tert*-Butylbenzene in the Absence or Presence of XH and PMHC for Various Periods of Time[a,b]

XH	time (10^{-3} s)	**7**	**8** imine	**9** PhCN	**10** oxazole	Σ(**8** + **9** + **10**)[c]	PhOH	**9**/**10**[d]
none	82.8	93.9	11	64	9	84	69	7.1
	169.2	88.3	15	53	9	77	65	5.9
	354.6	79.1	20	45	8	73	62	5.6
	435.6	76.8	23	46	9	78	66	5.1
	1040.4	53.1	25	42	9	76	70	4.7
$10^6k/s^{-1}$		0.61	*e*	*e*	0.55[f]		0.56[f]	
R^2		0.998			0.934		0.945	
PMHC	504.0	72.2	21	20	8	49	120	(2.5)[g]
	595.5	66.8	20	15	8	43	117	(1.9)[g]
	761.5	59.7	21	15	8	44	128	(1.9)[g]
	1277.0	42.0	21	16	9	46	145	(1.8)[g]
$10^6k/s^{-1}$		0.67	0.68	0.74	0.60		0.57	
R^2		0.998	0.988	0.876	0.971		0.945	

[a] Remaining **7** is given as a percentage of the initial concentration, and products are given as a percentage of decomposed **7**. Rate constants (and R^2) calculated from loss of **7** and from formation of some products are included in italics. [b] For additional data, see Tables S7 and S8 (Supporting Information). [c] Nitrogen balance for product formation. [d] Ratio of the rates of β-scission to cyclization, see Scheme 3. [e] Not calculated because the large monotonic change with time of the ratio $[product]_t/([\mathbf{7}]_0 - [\mathbf{7}]_t)$ indicates that this product suffers from time-dependent chemistry as the reaction progresses from $t = 0$ to t. [f] Since the ratio $[product]_t/([\mathbf{7}]_0 - [\mathbf{7}]_t)$ is reasonably constant, this rate constant was calculated by plotting $\ln(\{[product]_t/[\mathbf{7}]_0 - [\mathbf{7}]_t\}_{average} \times [\mathbf{7}]_0 - [product]_t)$ vs t. [g] These ratios reflect the loss of a substantial fraction of the PhCN presumably formed in the reaction, see text.

SCHEME 3. Thermal Decomposition Pathways for PhO(Ph)C=NOPh[a]



[a] XH is a hydrogen atom donor which may be the solvent, a deliberately added XH (e.g., PMHC), and the phenoxyl radical dimers.

the 74−83% range (Table 4). That is, in the presence of a good hydrogen donor the yield of phenol should be (100% + **9** (%)), see Scheme 3, i.e., 155−171%, but the actual yields are only half as large (Table 4).

There are three potential sources of **10**. The first is a direct reaction between two of the products, phenol and benzonitrile, followed by oxidative aromatization. This possibility was eliminated by heating 81 mM phenol plus 81 mM benzonitrile in degassed *t*BB at 150 °C for ca. 24 h. No **10** was produced. The second is a direct reaction between a phenoxyl radical and benzonitrile, followed by oxidation. This possibility was eliminated by heating 86 mM **7**, plus 88 mM 4-*tert*-butylphenol, plus 100 mM benzonitrile in degassed *t*BB at 120 °C for 5 days. Compound **10** was produced, but there was no trace of 2-(4-*tert*-butylphenyl)benzoxazole. Since the phenoxyl/phenol → phenol/phenoxyl reaction is fast,[10,11] the absence of the *tert*-butyl-substituted **10** proves that the formation of **10** itself does not involve the phenoxyl radical. The mechanism of formation of compound **10** is, therefore, most probably a 5-*exo* intramolecular cyclization of the first formed phenoxy phenyl ketiminyl radical followed by oxidative aromatization of the resulting cyclohexadienyl radical (Scheme 3).

The partitioning of the phenoxy phenyl ketiminyl's unimolecular decay routes between β-scission and cyclization is given by the product ratio [**9**]/[**10**]. The mean value of this ratio in *t*BB at 120 °C is 7.3. That is, β-scission, reaction 8, which yields phenoxyl radicals, is favored over cyclization. The β-scission/cyclization ratio appears to have only a slight temperature dependence with a mean value of 5.7 at 90 °C (Table 5) which rises to ca. 9−10 at 150 °C (see also Table S9, Supporting Information).

The hydrogen donor solvent, tetralin, accelerated the decomposition of *O*-benzyl oxime ethers by RRD, reaction 1.[1] Tetralin was therefore employed in a preliminary exploration of RRD for **7** since extensive RRD would certainly limit the utility of this compound as a kinetically "steady", thermal source of phenoxyl radicals.

Comparison of the products of thermolysis of **7** at 120 °C in tetralin reveals that there is less benzonitrile and more phenol in this solvent than in *t*BB, as might be expected (Table 4). However, the rate constants calculated from the decay of **7** and from product formation show no significant differences in these two solvents (Table 4). That RRD-induced decomposition of **7** is unimportant was further confirmed by the thermolysis

(10) Foti, M.; Ingold, K. U.; Lusztyk, J. *J. Am. Chem. Soc.* **1994**, *116*, 9440−9447.
(11) (a) Lucarini, M.; Pedulli, G. F.; Cipollone, M. *J. Org. Chem.* **1994**, *59*, 5063−5070. (b) Lucarini, M.; Pedrielli, P.; Pedulli, G. F.; Ciabiddu, S.; Fattuoni, C. *J. Org. Chem.* **1996**, *61*, 9259−9263.

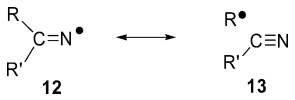
of **7** at 90 °C in *t*BB and in *t*BB containing 2.2 molar equiv of the hydrogen atom donor, PMHC. There was again a decrease in the yield of benzonitrile, a definite increase in the yield of phenol, but with no significant changes in the yields of imine and oxazole (Table 5). However, the rate constants derived from loss of **7** and from formation of the products were the same, within our experimental accuracy, in the absence or presence of PMHC (Table 5), indicating that there is no significant RRD-induced thermal decomposition of **7** even in the presence of a good H-atom donor. There is obviously some subsequent chemistry among the products which, although it does not appreciably change the rate of decomposition of **7**, does cause a loss of benzonitrile and, hence, a large change in the benzonitrile/oxazole (**9**/**10**) ratio. This secondary chemistry was not explored.

Discussion

Thermal Stabilities of RR′C═NOPh, 1−6. The thermal decomposition of *O*-phenyl ketoxime ethers has been shown to occur by a simple, unimolecular N−O bond homolysis unperturbed by any parallel RRD-induced decomposition even in the presence of very good H-atom donors. Thermal decomposition occurs at reasonable rates at relatively low temperatures. This opens the prospect of using *O*-phenyl ketoxime ethers as thermal initiators of radical chain reactions and as thermal sources of ketiminyl radicals for organic syntheses.

For many potential uses, these compounds have another advantage that we have not attempted to explore and exploit in the present, very preliminary survey of their properties. This advantage arises from their facile synthesis *at room temperature* (see the Experimental Section). The structure of the ketone from which the *O*-phenyl ketoxime ethers are synthesized has only a rather small effect on the rate of N−O bond homolysis; i.e., the maximum difference in decomposition rates at 90 °C is the 43-fold faster decomposition of the bicyclononan-9-one derivative, **5**, than the fluorenone derivative, **2**, see Table 3. *However*, it is well established, both by experiment[11,12] and theory,[13] that *the O−X bond dissociation enthalpies (BDEs) in 4-YC$_6$H$_4$O−X (X = H, CH$_3$, CH$_2$Ph) can be increased and decreased dramatically by using Y groups which are electron-withdrawing (EW) or electron-donating (ED), respectively.* For example, the O−X BDEs in these three classes of compounds are ca. 6 kcal/mol lower when Y = MeO than when Y = H.[11−13] Our DFT calculations suggest that this difference also holds for *O*-aryl oxime ethers. That is, the calculated N−O BDE for *O*-4-methoxyphenyl acetoxime ether is 29.9 kcal/mol, which is 5.9 kcal/mol lower than the one for *O*-phenyl acetoxime ether (vide infra). For the *O*-phenyl ketoxime ethers **1**−**6**, the activation enthalpies for N−O bond homolysis decrease from ca. 34.2 kcal/mol for **2** to ca. 31.2 kcal/mol for **5**, vide infra. The corresponding *O*-4-methoxyphenyl ketoxime ethers would therefore be expected to have activation energies for decomposition lower by ca. 6 kcal/mol, i.e., 28.2 and 25.2 kcal/mol, respectively, from which the respective rate constants can be estimated, vide infra, to be ca. 1.6×10^{-2} and 1 s^{-1} at 90 °C and ca. 3×10^{-6} and 5×10^{-4} s^{-1} at 25 °C. This implies that at room temperature the *O*-4-methoxyphenyl analogue of **2** could probably be synthesized but the analogue of **5** would be too unstable. These calculated rate constants are certainly not precise. They are intended solely to indicate that the thermal stability of *O*-aryl ketoxime ethers derived from a specific ketone can be "tuned" to provide the corresponding ketiminyl radical at a temperature desired for some planned synthesis or other experiment.

The relatively similar thermal stabilities of **1**−**6** are fully consistent with the known σ radical nature of iminyls. In these radicals, the unpaired electron resides mainly in the nitrogen's 2p$_y$ atomic orbital and therefore lies in the plane of the local molecular framework **12**:[9,14]



The unpaired electron does not delocalize to the sp^2 carbon atom, and hence, iminyl radicals are not stabilized when R and/or R′ are aromatic groups. However, there is a powerful hyperconjugative interaction, the presence of which can be deduced from the large hydrogen hyperfine splitting (hfs) in $H_2C{=}N^\bullet$ (cf. **12** ↔ **13**, R, R′ = H, H) of about 87 G.[14] Since a "free" hydrogen atom (which necessarily has 100% of the unpaired electron in its 1s orbital) has a hfs ≈ 507 G,[15] the unpaired spin density on each hydrogen in $H_2C{=}N^\bullet$ is about 17%. Such hyperconjugation will obviously stabilize ketiminyl radicals and will be favored by R groups that are inductively electron donating (ED) and, hence, increase the electron density in the R−C bond. Similarly, hyperconjugation will be disfavored for R groups that are electron withdrawing (EW) and decrease the electron density in the R−C bond. Alkyl groups are ED and are therefore expected to stabilize ketiminyl radicals and hence weaken the N−O bond in RR′C═NOPh compounds, whereas aryl groups are EW and are expected to destabilize ketiminyls and strengthen the N−O bonds. These concepts are congruent with our experimental observations that the rate constants for decomposition of *O*-phenyl ketoxime ethers at 90 °C are smallest for the compounds derived from benzophenone (**1**), fluorenone (**2**), and acetophenone (**6**-*E*) and have magnitudes that span only a factor of 3;

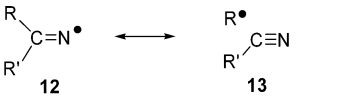
(12) (a) Mulder, P.; Saastad, O. W.; Griller, D. *J. Am. Chem. Soc.* **1988**, *110*, 4090−4092. (b) Lind, J.; Shen, X.; Eriksen, T. E.; Merényi, G. *J. Am. Chem. Soc.* **1990**, *112*, 479−482. (c) Jonsson, M.; Lind, J.; Eriksen, T. E.; Merényi, G. *J. Chem. Soc., Perkin Trans. 2* **1993**, 1567−1568. (d) Bordwell, F. G.; Zhang, X.-M.; Satish, A. V.; Cheng, J.-P. *J. Am. Chem. Soc.* **1994**, *116*, 6605−6610. (e) Wayner, D. D. M.; Lusztyk, E.; Ingold, K. U.; Mulder, P. *J. Org. Chem.* **1996**, *61*, 6430−6433. (f) Dorrestijn, E.; Laarhoven, L. J. J.; Arends, I. W. C. E.; Mulder, P. *J. Anal. Appl. Pyrol.* **2000**, *54*, 153−192. (g) Pratt, D. A.; de Heer, M. I.; Mulder, P.; Ingold, K. U. *J. Am. Chem. Soc.* **2001**, *123*, 5518−5526.

(13) (a) Jonsson, M.; Lind, J.; Merényi, G.; Eriksen, T. E. *J. Chem. Soc., Perkin Trans. 2* **1994**, 2149−2154. (b) Wu, Y.-D.; Lai, D. K. W. *J. Org. Chem.* **1996**, *61*, 7904−7910. (c) Brinck, T.; Haeberlein, M.; Jonsson, M. *J. Am. Chem. Soc.* **1997**, *119*, 4239−4244. (d) DiLabio, G. A.; Pratt, D. A.; LoFaro, A. D.; Wright, J. S. *J. Phys. Chem. A* **1999**, *103*, 1653−1661. (e) DiLabio, G. A. *J. Phys. Chem. A* **1999**, *103*, 11414−11424. (f) Pratt, D. A.; DiLabio, G. A.; Valgimigli, L.; Pedulli, G. F.; Ingold, K. U. *J. Am. Chem. Soc.* **2002**, *124*, 11085−11092.

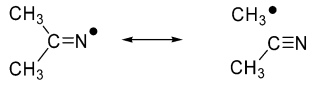
(14) Cochran, E. L.; Adrian, F. J.; Bowers, V. A. *J. Chem. Phys.* **1962**, *36*, 1938−1942. Brivati, J. A.; Root, K. D. J.; Symons, M. C. R.; Tingling, D. J. A. *J. Chem. Soc. A.* **1969**, 1942−1945. Symons, M. C. R. *Tetrahedron* **1973**, *29*, 615−619.

(15) Fischer, H. In *Free Radicals*; Kochi, J. K., Ed.; Wiley: New York, 1973; Vol. 2, p 439.

see Table 3. The rate constant for decomposition of the *O*-phenyl ether derived from acetone (**3**) is comparable to that for the ether derived from benzophenone (Table 3). The compound derived from cyclohexanone (**4**) decays roughly five times more rapidly than that derived from acetone (**3**), while the compound derived from bicyclononan-9-one (**5**) decays roughly 20 times faster than **3**. This order is consistent with the stabilization of ketiminyl radicals by hyperconjugation (**13**), which will increase along the series involving a formal contribution from a methyl radical (**14**), a primary alkyl radical (**15**), and a secondary alkyl radical, (**16**):

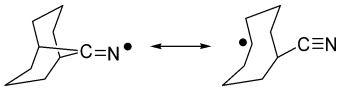


12 **13**



14

15



16

Two brief attempts to explore further the relation between the thermal stabilities of *O*-phenyl ketoxime ethers, RR′C═NOPh, and the inductive effects of R and R′ were not successful:

(i) $(4\text{-MeOC}_6H_4)_2C$═NOPh was expected to be less stable than Ph_2C═NOPh (**1**) because of the strong ED effect of 4-MeO groups. The compound was successfully synthesized although the reaction of $(4\text{-MeOC}_6H_4)_2CO$ with $PhONH_2$ was extremely sluggish at room temperature (ca. 10% yield after 48 h). Heating to 100 °C caused the desired product to decompose (which would not have occurred so rapidly with **1**), yet still a large amount of the starting ketone was recovered. The crude $(4\text{-MeOC}_6H_4)_2C$═NOPh turned dark brown in air at room temperature and could not be purified. (ii) $Ph(C_6F_5)C$═NOPh was expected to be very stable because of the strong EW effect of the five fluorine atoms. Unfortunately, the ketone did not react with $PhONH_2$ at room temperature, and after heating to 100 °C for 5 h, there was none of the desired product (MS) yet still some of the starting ketone. Further exploration of the relation between thermal stabilities and inductive effects was deemed an inappropriate use of resources at the present stage in the development of RR′C═NOPh and related compounds into reagents useful for organic synthesis.

Thermal Stability of PhO(Ph)C═NOPh, 7. In principle, **7** should provide an additional test of the relation between inductive effects and N−O BDEs because PhO will be inductively more strongly EW than Ph, on which basis **7** would be predicted to be thermally more stable than Ph_2C═NOPh (**1**). However, it appeared possible that **7** would be less stable than **1** because PhO−C bonds are weaker and longer than Ph−C bonds which should favor hyperconjugation, **13** with R′ = Ph, R• = PhO• being more favored than R• = Ph•. In the event, the rate constant for N−O bond homolysis at 90 °C is ca. 20 times smaller for **7** than for **1** (Table 3), a direction and a difference which we interpret as further evidence for the large role of inductive effects on the thermochemistry of iminyl radical reactions.

In one sense, the thermal stability of **7** (intuitively surprising and not predicted by theory, vide infra) proved a "blessing" because this compound was prepared from precursors by heating on a boiling-water bath for 6 h. The half-life for **7** at 100 °C is ca. 3.3 days. If **7** had had the same thermal stability as **1**, the half-life at 100 °C would have been ca. 3.4 h and its synthesis could not have been achieved in reasonable yield. Until a low-temperature synthesis of **7** is reported, "tuning" the thermal stability of PhO(Ph)C═NOAr by addition of substituents to the 4-position of the OAr group can only be in the direction of thermally more stable *N*-phenoxybenzimidic acid aryl esters. This could be achieved using EW substituents, e.g., with Ar = $4\text{-CF}_3C_6H_4$ or $4\text{-MeC(O)}C_6H_4$, etc. However, even with the present synthetic route, the efficiency of β-scission of Ar′O(Ph)C═N• radicals relative to their cyclization to form an oxazole (e.g., **10**) and H-atom abstraction to form the corresponding imine, could be greatly improved over that found for PhO(Ph)C═N• by using an ED 4-substituent on the Ar′O group which would stabilize the Ar′O• and hence weaken the Ar′O−C bond (e.g., Ar′O = 4-MeOC_6H_4O, vide supra).

N−O Bond Scission for 1−7, Activation Enthalpies, and Calculated Bond Dissociation Enthalpies, BDEs. The temperature ranges used in our studies of the kinetics of decomposition of RR′C═NOPh (Table 3) are far too limited to yield reliable Arrhenius parameters for these N−O bond-cleavage reactions. However, the measured rate constants should be fairly reliable, and since 90 °C was a common temperature in our experiments we have used rate constants at 90 °C to estimate the activation enthalpies, E_a, for the reactions. The Arrhenius preexponential factor for N−O bond scission of RR′C═NOPh to RR′C═ N• + PhO• has been *assumed* to be the same as that for C−O bond scission of CH_3OPh to CH_3• + PhO•, viz., $\log(A/s^{-1}) = 15.2$.[12g,16,17] Activation enthalpies calculated with this assumption are given in Table 6. DFT calculated N−O BDEs have been included for comparison. For **1**, the calculated N−O BDE is 1.5 kcal/mol larger than the estimated activation enthalpy while for **2**−**6** the calculated N−O BDEs are 2.8 ± 0.4 kcal/mol larger than the estimated activation enthalpies. The direction of these differences may indicate that the assumed value of $\log(A/s^{-1})$ of 15.2 is too low. However, for PhO(Ph)C═NOPh (**7**), the calculated N−O BDE is 2.4 kcal/mol *lower* than the estimated activation enthalpy. The reason for this "anomalous" BDE remains unclear even after extensive additional computations. In contrast, the calculated N−H BDE in PhO(Ph)C═NH is *stronger* than in Me_2C═NH, just as the E_a for PhO(Ph)C═NOPh is larger than for Me_2C═NOPh (Table 6).

(16) Sato, Y.; Yamakawa, T. *Ind. Eng. Chem. Fundam.* **1985**, *24*, 12−15.

(17) See also: Ciriano, M. V.; Korth, H.-G.; van Scheppingen, W. B.; Mulder, P. *J. Am. Chem. Soc.* **1999**, *121*, 6375−6381.

TABLE 6. Thermodynamic Parameters for RR′C═NOPh, 1−7, and RR′C═NH[a]

	R	R′	E_a [b]	N−O BDE [c]	N−H BDE [d]
1	Ph	Ph	33.4	34.9	91.7
2	9-fluorenyl		34.2	37.0	92.4
3	Me	Me	33.4	35.8	90.2 [e]
4	cyclohexyl		32.3	34.9	89.7
5	bicyclononanyl		31.2	34.4	89.0
6-*E*	Ph	Me	33.7	36.1	91.4
7	PhO	Ph	35.5	33.1	97.7

[a] Units, kcal/mol. [b] Rate constants used are at 90 °C and are taken from Table 3 for experiments with no added XH; for homolysis a $\log(A/s^{-1}) = 15.2$ is taken; see text. [c] DFT-computed N−O BDE using (RO)B3P86/6-311G(d,p)//(U)B3P86/6-311G(d,p) as in ref 22. [d] DFT-computed imine N−H BDE using (RO)B3LYP/6-311+G(2d,2p)//(U)B3LYP/6-31G(d) as in ref 13e. [e] 90.0 kcal/mol by CBS-QB3.

The thermolysis of all seven of the *O*-phenyl oxime ethers, **1**−**7**, involves a "clean" homolysis of the N−O bond and release of the resonance-stabilized phenoxyl radical, reaction 3. Interestingly, the N−O BDEs for **1**−**7** are all less than the O−O BDEs of dialkyl peroxides (38−40 kcal/mol). Such weak N−O bonds are consistent with the detection by EPR spectroscopy of iminyl radicals during the thermolyses of certain thionocarbonates[19] (reaction 9) and the strong ^{31}P CIDNP

$$RR'C{=}NOC(S)NMe_2 \xrightarrow{\Delta} RR'C{=}N^{\bullet} (+ Me_2NC(S)O^{\bullet}) \quad (9)$$

effects seen during the rearrangement of $Ph_2C{=}NOPPh_2$ at 0 °C[20] (reaction 10). The N−O BDEs

$$Ph_2C{=}NOPPh_2 \longrightarrow [Ph_2C{=}N^{\bullet}\ {}^{\bullet}OPPh_2] \longrightarrow Ph_2C{=}NP(O)Ph_2 \quad (10)$$

for *O*-alkyl oxime ethers are expected to be stronger than those of *O*-phenyl oxime ethers by about the difference between the O−H BDE for alcohols, 104.2 ± 0.9 kcal/mol,[18] and the O−H BDE for phenol, 87.3 ± 1.5 kcal/mol,[18] i.e., by 16.9 ± 2.4 kcal/mol. Our calculations of N−O BDEs for some $RR'C{=}NOCH_2Ph$[2] show that this expectation is fulfilled, i.e., for the same RR′ groups the N−O ΔBDE ($RR'C{=}N{-}OCH_2Ph$ − $RR'C{=}N{-}OPh$) varies from 15.2 (**5**, RR′ = bicyclononanyl) to 16.6 (**2**, RR′ = 9-fluorenyl) kcal/mol. There are no reliable experimental N−H BDEs for imines. Our calculations (Table 6) indicate that they are roughly 55 kcal/mol stronger than the N−O BDEs of the corresponding RR′C═NOPh compounds. Relatively weak imine N−H bonds are consistent with the facile generation of iminyl radicals for EPR spectroscopic study by reaction 11,[9]

$$Me_3CO^{\bullet} + RR'C{=}NH \longrightarrow Me_3COH + RR'C{=}N^{\bullet} \quad (11)$$

but the only reported N−H BDE for an imine of which we are aware is Bordwell and Ji's[21] value of 117 kcal/mol for $Ph_2C{=}NH$. This value was based on the imine's equilibrium acidity in DMSO and the oxidation potential of its conjugate base. However, it is obviously much too large because 117 kcal/mol is not only 9 kcal/mol stronger than the N−H BDE in NH_3,[18] but also 117 kcal/mol would make reaction 11 endothermic by ca. 13 kcal/mol, in which case this reaction could not have provided iminyl radicals for spectroscopic studies. The σ structure of iminyl radicals is reflected in the similar magnitudes of the quantities listed in the various columns in Table 6, viz., k, E_a, N−O BDE, and N−H BDE.

We are currently exploring the utility of *O*-phenyl ketoxime ethers as low-temperature thermal sources of iminyl radicals for organic synthesis.

Experimental Section

General Procedure for the Synthesis of *O*-Phenyl Oxime Ethers 1−6, Exemplified with 9-Fluorenone Oxime Ether, 2. *O*-Phenylhydroxylamine hydrochloride (1.0 g, 6.87 mmol) was dissolved in anhydrous pyridine (20 mL) under N_2 at room temperature, and 9-fluorenone (1.24 g, 6.87 mmol) was added to the solution in one portion. The resulting solution was stirred at room temperature overnight, and the progress of the reaction was monitored by TLC (hexane/ethyl acetate = 10:1). Upon completion, the reaction mixture was poured into distilled water (40 mL) and extracted with EtOAc (3 × 30 mL), and the combined organic phases were washed several times with saturated, aqueous $CuSO_4$ solution to remove any traces of pyridine. The solution was then dried ($MgSO_4$) and concentrated on a rotavap, and the desired product, **2**, was purified by column chromatography (hexane/ethyl acetate = 10:1): yellow solid (1.60 g, 86%); mp 95 °C; ^{1}H NMR δ_H 7.15−8.53 (m); ^{13}C NMR δ_C 115.3, 120.5, 122.7, 123.4, 128.5, 128.8, 129.9, 130.3, 130.8, 131.0, 132.1, 135.7, 141.1, 142.3, 155.0, 160.0; HRMS calcd for $C_{19}H_{14}ON$ 272.1075, found 272.1088.

***O*-Phenyl benzophenone oxime ether, 1:** mp 53 °C; ^{1}H NMR δ_H 7.04−7.08 (m, 1H), 7.27−7.52 (m, 12H), 7.63−7.65 (m, 2H); ^{13}C NMR δ_C 115.3, 122.7, 128.5, 128.7, 128.9, 129.6, 129.8, 130.4, 133.3, 136.4, 160.0, 160.3; HRMS calcd for $C_{19}H_{16}ON$ 274.1154, found 274.1232.

***O*-Phenyl acetone oxime ether, 3:** liquid; ^{1}H NMR δ_H 2.05 (s, 3H), 2.09 (s, 3H), 6.99−7.34 (m, 5H); ^{13}C NMR δ_C 16.6, 22.3, 115.0, 122.1, 129.6, 158.9, 159.9; HRMS calcd for $C_9H_{12}ON$ 150.0919, found 150.0990.

***O*-Phenyl cyclohexanone oxime ether, 4:** mp 42−44 °C; ^{1}H NMR δ_H 1.64−1.81 (m, 6H), 2.36−2.39 (m, 2H), 2.67−2.71 (m, 2H), 6.98−7.33 (m, 5H); ^{13}C NMR δ_C 26.2, 26.3, 26.4, 27.5, 32.6, 115.0, 122.0, 129.6, 160.0, 164.3; HRMS calcd for $C_{12}H_{16}ON$ 190.1232, found 190.1185.

***O*-Phenyl bicyclo[3.3.1]nonan-9-one oxime ether, 5:** mp 63−64 °C; ^{1}H NMR δ_H 1.58−1.64 (m, 2H), 1.91−2.02 (m, 8H), 2.03−2.15 (m, 2H), 2.70 (s, 1H), 3.68 (s, 1H), 6.97−7.34 (m, 5H); ^{13}C NMR δ_C 21.6, 30.6, 32.6, 34.0, 34.8, 36.5, 114.9, 121.8, 129.6, 160.1, 171.4; HRMS calcd for $C_{15}H_{20}ON$ 230.1545, found 230.1560.

***O*-Phenyl acetophenone oxime ether, 6: 6**-*E*:**6**-*Z* = 5:1; ^{1}H NMR δ_H for isomer (a) 2.49 (s, 3H), 7.30−7.83 (m, 10H); for isomer (b) 2.38 (s, 3H), 7.05−7.79 (m, 10H); ^{13}C NMR δ_C for the mixture of isomers: 13.8, 22.3, 115.0, 115.17, 115.22, 122.2, 122.4, 122.6, 126.9, 128.4, 128.6, 128.9, 129.6, 129.7, 130.1, 136.4, 158.0, 158.2, 160.0; HRMS calcd for $C_{14}H_{14}ON$ 212.1075, found 212.1081.

Note: All the *O*-phenyl oxime ethers appear to be light sensitive, especially in solution. Presumably, it is light sensi-

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tivity that causes all these compounds to become more strongly colored than the crude materials after two or three column purifications!

***N*-Phenoxybenzimidic Acid Phenyl Ether, 7.** This synthesis is based on that of Taylor and Kienzle.[4]

Potassium Benzohydroxamate. Benzohydroxamic acid (10.00 g, 73 mmol) was dissolved in hot anhydrous EtOH (60 mL), and a hot solution of KOH (4.1 g, 73 mmol) in anhydrous EtOH (50 mL) was added portionwise with mixing. A white precipitate formed immediately. Once all the KOH was added, the mixture was stirred for another 30−60 min, cooled, and filtered. The filtrate was partially evaporated, and the newly formed precipitate was filtered as well. The combined solids were dried under vacuum (1 Torr) for 2 h to give the salt (7.35 g). Additional product was recovered from the remaining mother liquor and recrystallized from EtOH.

***N*-Phenoxybenzamide.** Diphenyliodonium chloride (9.48 g, 31.2 mmol) and potassium benzohydroxamate (5.46 g, 31.2 mmol) were placed in a 250 mL round-bottom flask. The flask was purged with nitrogen, and *t*-BuOH (125 mL) was added. The mixture was stirred and refluxed under nitrogen for 4 h, filtered, and evaporated. The residue was taken up in diethyl ether (50 mL) and extracted with 1 M aq NaOH (4 × 15 mL). The extracts were combined and acidified with dilute HCl. The precipitate was filtered and dried to give (4.0 g, 60%) of crude material. This product was sufficiently pure for the next step, but nevertheless was recrystallized from a mixture of hexane and ethyl acetate: ESI-MS 214.

***N*-Phenoxybenzimidic Acid Chloride.** *N*-Phenoxybenzamide (1.88 g, 8.82 mmol) and PCl_5 (1.94 g, 9.30 mmol) were dissolved in CCl_4 (68 mL), cooled to 0 °C, and stirred under nitrogen for 6 h. The solvent was evaporated, and the residue was taken up in diethyl ether (27 mL) and washed twice with water (7 and 3 mL). After evaporation, the syrupy residue solidified in the freezer. The product was triturated under 5 mL of cold 50% aq EtOH, the solvent was then removed by pipet, and the residue was dried under vacuum (1 Torr) for 2 h to give pale, semisolid material (1.59 g, 78%): ESI-MS 232.

***N*-Phenoxybenzimidic Acid Phenyl Ether, 7.** *N*-Phenoxybenzimidic acid chloride (1.59 g, 6.89 mmol), sodium phenoxide trihydrate (1.17 g, 6.89 mmol), and DMSO (4.5 mL) were stirred and heated under nitrogen on a boiling-water bath for 6 h. The mixture was cooled, taken up in diethyl ether (40 mL), and extracted with water (4 × 5 mL). The ether layer was evaporated, and the residue was dissolved in hexane (4 mL) and separated on a silica column using hexane/ethyl acetate (97:3) as eluent. The oily product (1.4 g), which solidified in the fridge, was taken up in EtOH (20 mL). This solution was warmed to 50 °C, water was added, and the mixture was cooled. The solid was filtered, dried, and dissolved at 50 °C in a mixture of EtOH (30 mL) and H_2O (6 mL) and recrystallized to afford white crystals of the title compound (0.9 g, 45%, which nevertheless contained ≤1% of 2,4,6-triphenyl-1,3,5-triazine, the benzonitrile trimer (see ref 4), as an impurity which was not removed): mp 54−55 °C; ESI-MS 290; IR ν/cm^{-1} 1588, 1490, 1324, 1301, 1199, 1162, 1069, 1024, 1000, 966, 924, 767, 752, 688; ^{1}H NMR δ_H 7.01−7.12 (4H, m), 7.18−7.22 (2H, m), 7.27−7.35 (4H, m), 7.41−7.48 (3H, m), 7.89−7.93 (2H, m); ^{13}C NMR, 114.8, 116.6, 122.7, 123.4, 127.5, 128.8, 129.4,129.7, 129.8, 130.0, 131.1, 153.6, 155.8, 159.2.

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Supporting Information Available: General (analytical) methods, ^{13}C NMR spectra of compounds **1**−**7**. Additional kinetic data for the decomposition of compounds **1**−**7**, Tables S1−S9. Geometries in Cartesian coordinates, electronic energies, thermochemical corrections, and enthalpies of all structures computed and presented in Table 6 or in the text, Tables S10−S13. This material is available free of charge via the Internet at http://pubs.acs.org.

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