Photoinduced Molecular Rearrangements. Some Investigations of the Photochemical Behavior of 3-(Acylamino)-1,2,5-Oxadiazoles (Furazans)

Silvestre Buscemi and Nicolò Vivona*

Dipartimento di Chimica Organica, Università di Palermo, Via Archirafi 20, 90123 Palermo, Italy

Tullio Caronna

Dipartimento di Chimica, Politecnico di Milano, Via Mancinelli 7, 20131 Milano, Italy

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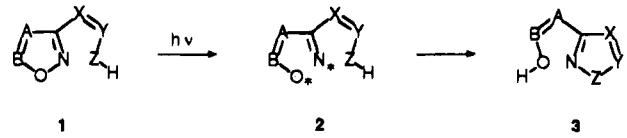
Mechanistic investigations of the photochemical behavior of some 3-(acylamino)-1,2,5-oxadiazoles (furazans) are reported. Irradiations of 3-(aroylamino)-4-methyl- and 3-(acetylamino)-4-phenylfurazans at λ = 254 nm in methanol, and in methanol containing pyrrolidine, are considered. Photochemical processes follow different routes depending on the actual chromophore in the photoreaction. In the irradiation of 3-(aroylamino)-4-methylfurazans, two photochemical pathways involving a different multiplicity of excited states are suggested: cleavage of the ring O(1)–N(5) bond *via* a singlet excited state (developing into nitrile oxides or carbodiimides, from which final products arise), or preliminary ring-closure involving the aroylamino group *via* a triplet excited state, respectively. In the irradiation of 3-(acetylamino)-4-phenylfurazan, photolytic intermediates arising from the cleavage of both the O(1)–N(2) and O(1)–N(5) bonds develop into the final products by reaction with the nucleophilic species present.

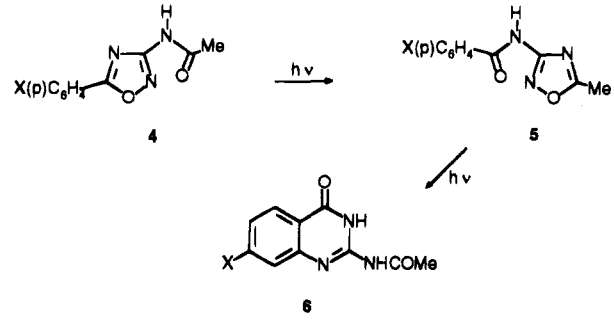
Introduction

Molecular rearrangements of suitably substituted azoles constitute a widely used approach to the synthesis of heterocyclic compounds.[1] Among these reactions, a general trend can be seen in molecular rearrangements of five-membered rings containing certain three-atom side-chains.[2,3] From this trend, an intriguing approach to rearrangements of O–N bond-containing azoles may be anticipated according to the photochemical mechanism shown in Scheme 1.[3] An intermediate species (**2**; zwitterion or diradical) arising from the photolysis of the ring collapses into rearranged product **3** through a heterocyclization with the XYZ side group. In accord with this framework, we have pointed out photoinduced rearrangements of 1,2,4-oxadiazoles containing various side-chains.[4] Interestingly, 3-(acetylamino)-5-aryl-1,2,4-oxadiazoles **4** and their ring-degenerate counterparts 3-(aroylamino)-5-methyl derivatives **5** gave different photochemical reactivities which have been related to different chromophores (the 5-aryl-substituted heterocycle on one hand, and the 3-aroylamino group on the other) and to the different multiplicity of excited states.[5] For example, 3-(aroylamino)oxadiazoles **5** undergo photorearrangement into **6**, likely *via* an initial ring-closure involving the aroylamino group. Photolysis of 3-(acetylamino)oxadiazoles **4** produce compounds **6** as well, but likely *via* a photolytic intermediate, which then collapses into the (aroylamino)oxadiazoles **5** (Scheme 2). In contrast, 3-(aroylamino)-5-methylisoxazoles did not show any photoreactivity involving ring-closures at the aroylamino group.[6]

Scheme 1



Scheme 2



During the pursuit of this approach to molecular rearrangements of five-membered rings,[7] we became interested in the photochemistry of substituted 1,2,5-oxadiazoles (furazans). Particularly, in order to generalize the photoreactivity of 3-(acylamino)-1-oxa-2-azoles, we considered the 3-(acylamino)furazans **9**. Although potentially rearrangeable according to the Boulton/Katritzky pattern,[2a] compounds **9** do not rearrange into the oxadiazole oximes **8**. In contrast, compounds **8** spontaneously rearrange[2,3,8] into the (acylamino)furazans **9**, thus

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(1) See for example: van der Plas, H. C. *Ring Transformations of Heterocycles*; Blomquist, A. T., Wasserman, H., Eds.; Vol. 1, Academic Press: London and New York, 1973. See also specific categories of ring transformations reviewed in *Comprehensive Heterocyclic Chemistry*; Katritzky, A. R., Rees, C. W., Eds; Pergamon Press: Oxford, 1984; Vols. 1–8.

(2) (a) Boulton, A. J.; Katritzky, A. R.; Hamid, A. M. *J. Chem. Soc. C* **1967**, 2005. (b) Boulton, A. J. *Lect. Heterocycl. Chem.* **1974**, *2*, 45. (c) Ruccia, M.; Vivona, N.; Spinelli, D. *Adv. Heterocycl. Chem.* **1981**, *29*, 141. (d) L'abbé, G. *J. Heterocycl. Chem.* **1984**, *21*, 627.

(3) Vivona, N.; Buscemi, S.; Frenna, V.; Cusmano, G. *Adv. Heterocycl. Chem.* **1993**, *56*, 49.

(4) (a) Buscemi, S.; Cicero, M. G.; Vivona, N.; Caronna, T. *J. Heterocycl. Chem.* **1988**, *25*, 931. (b) Buscemi, S.; Vivona, N. *J. Heterocycl. Chem.* **1988**, *25*, 1551. (c) Buscemi, S.; Cusmano, G.; Gruttadauria, M. *J. Heterocycl. Chem.* **1990**, *27*, 861.

(5) (a) Buscemi, S.; Vivona, N. *Heterocycles* **1989**, *29*, 737. (b) Buscemi, S.; Macaluso, G.; Vivona, N. *Heterocycles* **1989**, *29*, 1301. (c) Buscemi, S.; Vivona, N. *J. Chem. Soc., Perkin Trans. 2* **1991**, 187.

(6) Buscemi, S.; Frenna, V.; Vivona, N. *Heterocycles* **1991**, *32*, 1765.

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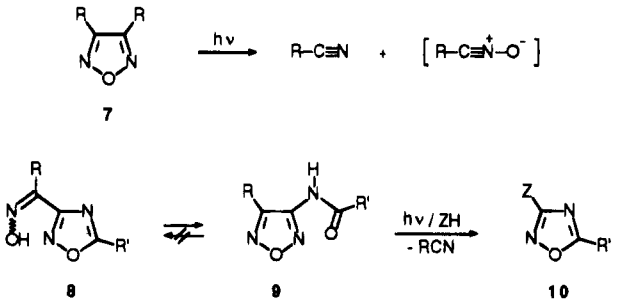
Scheme 3



illustrating the higher tendency of the 1,2,4-oxadiazole moiety to rearrange (or the higher stability of the furazan heterocycle toward these reactions).[2c,3]

Regarding the photochemical reactivity, preliminary studies involved irradiations at $\lambda = 254$ nm of **9** in the presence of ammonia, and primary or secondary amines (ZH in the Scheme 3).[9] This photoreaction gave 3-substituted 1,2,4-oxadiazoles **10**, where the substituent at C(3) arises from the reagent used. These results have been rationalized on the basis of the documented photochemistry of 3,4-disubstituted furazans **7**[10] (or benzofurazans[11]), which undergo photoinduced ring-fragmentation into nitriles and nitrile oxides. In the case of compounds **9**, the reaction of ZH with the nitrile oxide fragment arising from cleavage of the O(1)–N(5) bond of the ring, followed by a base-induced ring-closure of the resulting *N*-acylamidoxime intermediate, would explain the final products.

In order to generalize the scope and limitations of this photochemical pattern, we undertook mechanistic investigations of the photoreactivity of 3-(acylamino)furazans at $\lambda = 254$ nm. Selected compounds for this study were 3-(aroylamino)-4-methylfurazans (**11a–d**) and 3-(acetylamino)-4-phenylfurazan (**22**). The choice of these compounds is of some significance. Compounds **11a–d** are characterized by a methyl-substituted furazan ring and an aroylamino side-group containing either an electron-donor or an electron-withdrawing substituent. Compound **22** contains an acetylamino side-chain linked to a phenyl-substituted heterocycle. It was anticipated that these structural changes would affect both the actual chromophore and the nature of the excited state involved, and consequently the photochemical results.

Results and Discussion

Emission spectra allowed us to determine the singlet and triplet energies for **11a** to be 104 and 78 kcal/mol, and those for **22** to be 105 and 75 kcal/mol, respectively. Similar values were obtained for compounds **11b** (91 and 73 kcal/mol), **11c** (101 and 75 kcal/mol), and **11d** (105 and 71 kcal/mol). The 3-(aroylamino)furazans **11a–d** showed phosphorescence emission of more intensity than 3-acetylamino compound **22**. Moreover, among the aroylamino compounds, the *p*-cyano-substituted substrate **11d** showed the strongest phosphorescence emission.

Irradiation of 3-(Aroylamino)-4-methylfurazans. As anticipated,[9] irradiation of the 3-(benzoylamino)-4-methylfurazan (**11a**) at 254 nm in methanol containing an excess of pyrrolidine gave the 3-pyrrolidinyloxadiazole **19a**. This photoreaction was extended to the 3-aroylamino compounds **11b–d**, which behaved similarly and produced the corresponding pyrrolidinyloxadiazoles **19b–d**. Taking into account our previous results,[9] this transformation constitutes a new methodology for the synthesis of 3-(*N*-substituted amino)-5-aryl-1,2,4-oxadiazoles.

To define the mechanistic aspects of this photoreactivity, we irradiated the (aroylamino)furazans **11a–d** in methanol in the absence of amines. In this case we isolated mixtures of the 3-methoxyoxadiazoles **16** and the *O*-aroylamidoximes **18** (arbitrary configuration). In turn, according to the well known behavior of *O*-acylamidoximes,[12] compounds **18** can be cyclized thermally into oxadiazoles **16**. However, separate photochemical experiments showed that both oxadiazoles **16** and amidoximes **18** were the primary photoproducts in the irradiation of furazans **11**. In fact, in a typical experiment we did not observe photochemical interconversion between **18a** and **16a** under our irradiation conditions.

The formation of compounds **16** and **18** can be rationalized on the basis of previously proposed photochemical pattern of furazans. The nitrile oxide fragment **14** arising from cleavage of the O(1)–N(5) bond (and extrusion of MeCN) will be stabilized by reaction with the solvent to give the *N*-acylamidoximes **15** which, in turn, can be considered precursors of the oxadiazoles **16**. On the other hand, **14** can also be converted into carbodiimide **17** with which methanol will then react to give **18**.

As reported[13] earlier for **16a**, compound **15** is the presumed intermediate in the synthesis of 3-methoxyoxadiazoles from the reaction of iminothiolcarbonates **20** and hydroxylamine. In repeating this reaction (for substrates **20a,b,d**), we observed that the final products, as expected were oxadiazole **16** together with some of the corresponding *O*-aroylamidoxime **18**. Monitoring the reactions by HPLC showed an intermediate species (which one can reasonably assign to be the presumed **15**), the concentration of which at first increased to a maximum and then decreased while the concentration of **16** and **18** increased. Of course, a common oxadiazoline-type intermediate could explain development of **15** into **16** and **18**. As expected, the reaction of iminothiolcarbonate **20a** with *O*-methylhydroxylamine gave the *O*-methyl-*N*-benzoylamidoxime **21** (Scheme 5).

(7) A widely investigated area in the photochemistry of heterocyclic compounds concerns photoisomerizations of five-membered heterocycles involving interchange of the annular atoms. See, *inter alia*: Lablache-Combier, A. *Photochemistry of Heterocyclic Compounds*; Buchardt, O., Ed.; Wiley: New York, 1976. Padwa, A. *Rearrangements in Ground and Excited States*; De Mayo, P., Ed.; Academic Press: New York, 1980; Vol. 3, p 501. Baltrop, J. A.; Day, A. C. *J. Chem. Soc., Chem. Commun.* **1975**, 177. Baltrop, J. A.; Day, A. C.; Moxon, P. D.; Ward, R. W. *J. Chem. Soc., Chem. Commun.* **1975**, 786. Sauers, R. R.; Hadel, L. M.; Scimone, A. A.; Stevenson, T. A. *J. Org. Chem.* **1990**, *55*, 4011. Pavlik, J. W.; Kurzweil, E. M. *J. Org. Chem.* **1991**, *56*, 6313. Pavlik, J. W.; Pandit, C. R.; Samuel, C. J., Day, A. C. *J. Org. Chem.* **1993**, *58*, 3407.

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(9) Buscemi, S.; Frenna, V.; Vivona, N. *Heterocycles* **1992**, *34*, 2313.

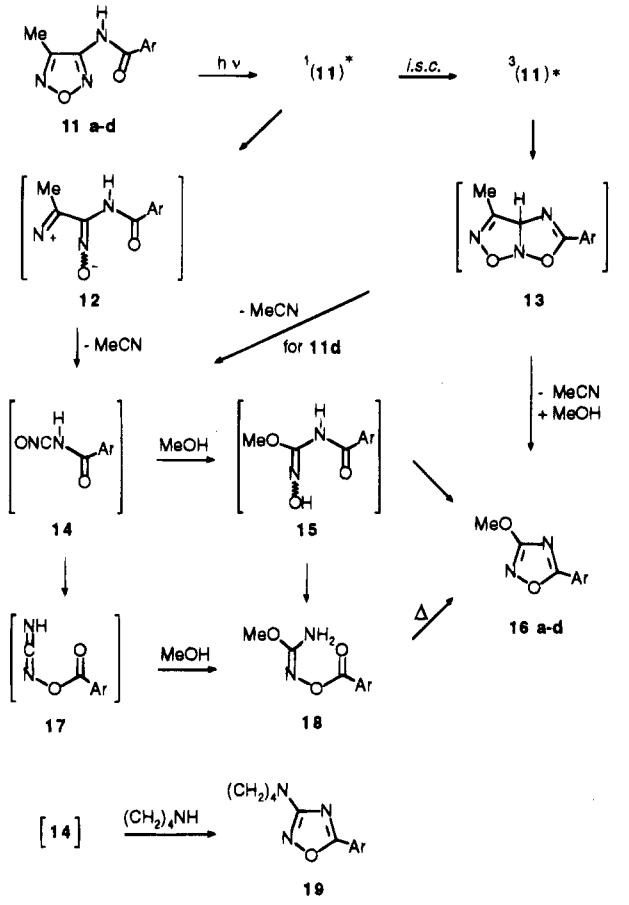
(10) (a) Cantrell, T. S.; Haller, W. S. *J. Chem. Soc., Chem. Commun.* **1968**, 977. (b) Mukai, T.; Oine, T.; Motsubara, A. *Bull. Chem. Soc. Jpn.* **1969**, *42*, 581.

(11) (a) Mukai, T.; Nitta, M. *J. Chem. Soc., Chem. Commun.* **1970**, 1192. (b) Georgarakis, M.; Rosenkranz, H. I.; Schmid, H. *Helv. Chim. Acta* **1971**, *54*, 819. (c) Yavari, I.; Esfandiari, S.; Mostashari, A. J.; Hunter, P. W. *J. Org. Chem.* **1975**, *40*, 2880. (d) Heinzelmann, W.; Gilgen, P. *Helv. Chim. Acta* **1976**, *59*, 2727.

(12) (a) Eloy, F. *Fortschr. Chem. Forsch.* **1965**, *4*, 807. (b) Clapp, L. B. *Adv. Heterocycl. Chem.* **1976**, *20*, 65. (c) Sim Ooi, N.; Wilson, D. A. *J. Chem. Soc., Perkin Trans. 2* **1980**, 1792.

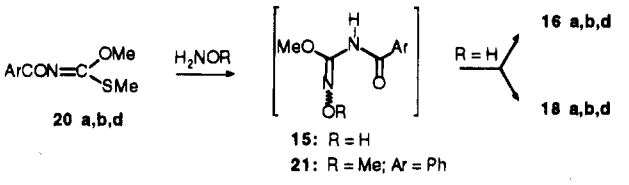
(13) (a) Katritzky, A. R.; Wallis, B.; Brownlee, R. T. C.; Topsom, R. D. *Tetrahedron* **1965**, *21*, 1681. (b) Nash, B. W.; Newberry, R. A.; Pickles, R.; Warburton, W. K. *J. Chem. Soc. C* **1969**, 2794.

Scheme 4



a: Ar = Ph; **b**: Ar = *p*-MeOC$_6$H$_4$; **c**: Ar = *p*-CF$_3$C$_6$H$_4$; **d**: Ar = *p*-CNC$_6$H$_4$

Scheme 5



15: R = H
21: R = Me; Ar = Ph

a: Ar = Ph; **b**: Ar = *p*-MeOC$_6$H$_4$; **d**: Ar = *p*-CNC$_6$H$_4$

These observations raised the question of whether intermediates could have been detectable in the irradiation of **11**. To address this, we performed analytical photoreactions. In order to distinguish photochemical and thermal processes, samples were analyzed soon after they were irradiated, and then at incremental time points at room temperature. In this manner, using the beforementioned reaction between **20** and hydroxylamine as a standard, in the case of the irradiation of **11a,b,d** we succeeded in detecting intermediates likely to be the presumed **15**. This pattern can reasonably be extended to the irradiation of **11c**, for which HPLC did not give clear-cut results. Analysis of the HPLC results (see Experimental Section) showed that (i) the presumed **15** thermally develops into both **16** (chiefly), and **18** (little, if any); this could mean that the final **18** mainly arises from a concomitant precursor (likely the carbodiimide **17**), rather than from **15**; (ii) compound **16** isolated at the end of the reaction, discounting the thermal transformation of **15** (essentially), should arise to some extent from an additional photochemical pathway.

Some quenching experiments carried out in the presence of a large excess of penta-1,3-diene (piperylene) as a triplet quencher (E_t = 58 kcal/mol^{-1})[14] appear to support this hypothesis. In particular, upon irradiating compounds **11a–c**, photochemical formation of 3-methoxyoxadiazoles **16a–c** was partially quenched, whereas the concomitant formation of **18a–c**, was *not*. This result suggests that the excited state of the starting furazans **11** collapses into final products by distinct photochemical routes. Our opinion is that photochemically-formed oxadiazoles **16** could arise from a triplet excited state involving the aroylamino group chromophore, presumably *via* a bicyclic intermediate such as **13**. In contrast, the presumed **15** and products **18** should result from a singlet excited state of the furazan chromophore, which collapses through cleavage of the O(1)–N(5) bond of the ring to give **12** (Scheme 4). These findings agree with the suggestion that the photoinduced cleavage of the furazan ring proceeds *via* a singlet excited state.[10a]

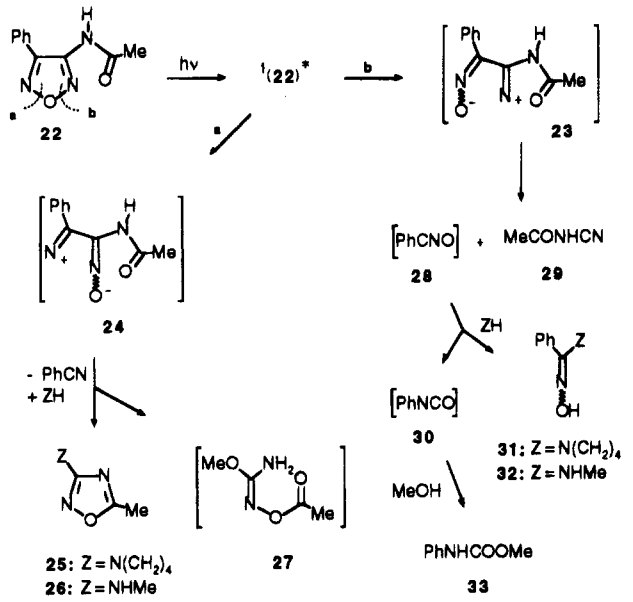
A significant substituent effect was observed in the case of the *p*-cyano-substituted substrate **11d**.[15] In this case, quenching experiments showed that the formation of both **16d** and **18d** (as well as the disappearance of **11d**) was quenched, thus suggesting triplet states in the photochemical pathway. Although a complete understanding will require appropriate spectroscopic studies and further photochemical investigations, our opinion is that in this case the actual photoreactive excited state could be the triplet state involving the aroylamino group. The higher phosphorescence emission observed for **11d** supports this explanation.

To come back to the irradiation of (aroylamino)furazans **11** in the presence of pyrrolidine, in this case the photoreaction may involve the furazan ring chromophore in a photocleavage of the O(1)–N(5) bond. The nitrile oxide fragment **14** will then react quickly with pyrrolidine to give open-chain intermediates from which a base-induced ring-closure would give compounds **19** (Scheme 4). It appears reasonable that acid–base interaction between pyrrolidine and the substrate, or charge-transfer complexes between aroylamino compounds and pyrrolidine, could determine the photoreactive species. The effect of the substituent in the conversion of **11** into **19** (which reflects the effect on the acidity of the NH) can be considered to support this hypothesis. Further investigations of this point, however, are necessary.

Irradiation of 3-(Acetylamino)-4-phenylfurazan. Irradiation of 3-(acetylamino)-4-phenylfurazan (**22**) in methanol produced a complex photoreaction from which we isolated significant amounts of benzonitrile, phenylcarbamate **33**, and acetylcyanamide (**29**). Attempts to detect the expected *O*-acetylamidoxime **27** and/or 3-methoxy-5-methyl-1,2,4-oxadiazole failed presumably because of the occurrence of concomitant hydrolysis of their precursors. Upon irradiation of **22** in the presence of an excess of piperylene, none of the above photoproducts were quenched, suggesting that the photoreactions originate from a common singlet excited state involving the phenyl-substituted furazan chromophore. Irradiation of **22** in the presence of pyrrolidine, together with benzonitrile and acetylcyanamide, gave the 3-pyrrolidinyloxadiazole **25** and the pyrrolidinyl-oxime **31**.

(14) Murov, S. L. *Handbook of Photochemistry*; Marcel Dekker: New York, 1973.
(15) See for example: Rao, C. J.; Agosta, W. C. *J. Org. Chem.* **1994**, *59*, 2125, and refs cited therein.

Scheme 6



In order to rationalize these results, one may suppose that both the O–N bonds of the furazan ring must be involved (Scheme 6). Of course, this behavior differs from that observed in the irradiation of 3-aroylamino compounds **11**, in which only the participation of the O(1)–N(5) bond was seen. The literature on the photochemistry of furazans[10] reports cleavage of an undetermined O–N bond of the ring, since symmetrically 3,4-disubstituted substrates have generally been studied. In contrast, mass spectra of 3-amino-4-phenylfurazan indicated the occurrence of cleavage of both the ring O–N bonds under electron impact.[16]

Cleavage of the O(1)–N(5) bond (Scheme 6, path a) explains the formation of benzonitrile and the 3-pyrrolidinyloxadiazole **25**. In order to explain compounds **29**, **31**, and **33**, cleavage of the O(1)–N(2) bond (Scheme 6, path b) must be considered. Here, pyrrolidine will react quickly with the benzonitrile oxide **28**, to provide **31**. In the absence of pyrrolidine, **28** slowly isomerizes into the phenyl isocyanate **30** which methanol then captures.

The results of the irradiation of **22** in the presence of pyrrolidine stimulated the exploitation of this photoreaction for the synthesis of 3-(*N*-substituted amino)-5-methyl-1,2,4-oxadiazoles. Thus, irradiation of **22** in the presence of an excess of ethanolic methylamine, besides the expected other products, provided the 3-(methylamino)-5-methyl-1,2,4-oxadiazole (**26**). This behavior appears of interest since 3-(*N*-substituted amino)-5-alkyl-1,2,4-oxadiazoles are not always easily accessible.[17] On the whole, one can look at this photochemical approach as a new methodology for the synthesis of target 1,2,4-oxadiazoles. One restriction is the requirement of an appropriate nucleophile. A more significant factor could be recognized on the subsequent photoreactivity of the resulting 1,2,4-oxadiazole.[4,5,18]

Experimental Section

Material and Methods. For instruments and general procedures see our previous papers.[5,9] ^{1}H NMR (250 MHz) spectra were taken with TMS as internal standard. HPLC analyses were performed using a C-18 SIL-X-10 column (25 cm × 4.6 mm diameter) eluting with water/acetonitrile in varying ratios. Flash chromatography was performed with light petroleum/ethyl acetate mixtures. Anhydrous MeOH, pyrrolidine, ethanolic (33%) methylamine, penta-1,3-diene (piperylene; mixture of isomers), 4-(trifluoromethyl)benzoyl and 4-cyanobenzoyl chlorides were obtained from Aldrich Chemical Co.

Compounds **11a**,[19] **11b**,[9] **20a**,[13] and **22**[20] were prepared as reported. Similarly to **11b**, 3-amino-4-methylfurazan[21] furnished (70%) **11c** and **11d**. **3-{[4-(Trifluoromethyl)benzoyl]-amino}-4-methylfurazan (11c)**: mp 133 °C (from benzene); IR 3240, 1665 cm^{-1}; ^{1}H-NMR (DMSO-d_6) δ 2.43 (s, 3H), 8.01–8.04 and 8.26–8.29 (2m, 4H), 11.57 (s, 1H). Anal. Calcd for $C_{11}H_8F_3N_3O_2$: C, 48.72; H, 2.97; N, 15.49. Found: C, 48.60; H, 2.90; N, 15.60. **3-[(4-Cyanobenzoyl)amino]-4-methylfurazan (11d):** mp 174 °C (from EtOH); IR 3250, 2220, 1680 cm^{-1}; ^{1}H-NMR (DMSO-d_6) δ 2.40 (s, 3H), 8.00–8.30 (m, 4H), 11.60 (s, 1H). Anal. Calcd for $C_{11}H_8N_4O_2$: C, 57.89; H, 3.53; N, 24.55. Found: C, 58.10; H, 3.40; N, 24.60. Similar to **20a**, methylation of ***O*-methyl *N*-(4-methoxybenzoyl)-thiocarbamate** [prepared as usual,[13] (50%), mp 101 °C (from aqueous methanol); IR 3240, 1710 cm^{-1}; ^{1}H-NMR (DMSO-d_6) δ 3.76 and 3.95 (2s, 6H), 6.93–6.97 and 7.77–7.85 (2m, 4H), 11.81 (s, 1H). Anal. Calcd for $C_{10}H_{11}NO_3S$: C, 53.32; H, 4.92; N, 6.22. Found: C, 53.40; H, 4.80; N, 6.10.] gave **20b** (70%). **Dimethyl [*N*-(4-methoxybenzoyl)imino]monothiolcarbonate (20b)**: mp 69 °C (from light petroleum); ^{1}H-NMR ($CDCl_3$) δ 2.38, 3.85, and 4.08 (3s, 9H), 6.89–6.93 and 8.10–8.15 (2m, 4H). Anal. Calcd for $C_{11}H_{13}NO_3S$: C, 55.21; H, 5.48; N, 5.85. Found: C, 55.30; H, 5.40; N, 5.70. Furthermore, methylation of ***O*-methyl *N*-(4-cyanobenzoyl)thiocarbamate** [prepared as above (50%), mp 127 °C (from aqueous methanol); IR 3240, 3260, 2230, 1715 cm^{-1}; ^{1}H-NMR ($CDCl_3$) δ 4.20 (s, 3H), 7.76–7.82 and 7.92–7.95 (2m, 4H), 9.15 (s, 1H). Anal. Calcd for $C_{10}H_8N_2O_2S$: C, 54.53; H, 3.66; N, 12.72. Found: C, 54.70; H, 3.50; N, 12.60.] gave (**20d**) (50%). **Dimethyl[*N*-(4-cyanobenzoyl)imino]monothiolcarbonate (20d)** mp 141 °C (from light petroleum); ^{1}H-NMR ($CDCl_3$) δ 2.45 (s, 3H), 4.17 (s, 3H), 7.27–7.76 and 8.27–8.31 (2m, 4H). Anal. Calcd for $C_{11}H_{10}N_2O_2S$: C, 56.40; H, 4.30; N, 11.96. Found: C, 56.60; H, 4.40; N, 12.20.

General Procedure for Photochemical Reactions. Photochemical reactions were carried out in anhydrous MeOH (or in MeOH containing an excess of freshly distilled pyrrolidine) in quartz tubes using a Rayonet RPR-100 photoreactor, fitted with 16 RPR-2537 Å (λ = 254 nm) low-pressure Hg lamps and a merry-go-round apparatus. In the case of preparative photoreactions, the solvent was removed, and the residue chromatographed. In the case of analytical photoreactions, quantitative determinations were accomplished by HPLC.

Irradiation of 3-(Aroylamino)-4-methylfurazans 11b–d in the Presence of Pyrrolidine. A sample (0.5 g) of **11b**, **11c**, or **11d**, respectively, in MeOH (100 mL) containing 2 mL of pyrrolidine was irradiated for 2 h (for **11b,d**) or 1 h (for **11c**). Compound **11b** returned starting material (0.15 g, 30%) and gave **19b** (0.30 g, 57%). Compound **11c** gave starting material (0.30 g, 60%) and **19c** (0.15 g, 29%). Compound **11d** gave starting material (0.30 g, 60%) and **19d** (0.1 g, 20%). **3-Pyrrolidinyl-5-(4-methoxyphenyl)-1,2,4-oxadiazole (19b)**: mp 108 °C (from light petroleum); ^{1}H-NMR ($CDCl_3$) δ 1.95–2.05 and 3.45–3.50 (2m, 8H), 3.85 (s, 3H), 6.95–7.00 and

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8.00–8-05 (2m, 4H); MS *m/z* 245 (M^+). Anal. Calcd for $C_{13}H_{15}N_3O_2$: C, 63.66; H, 6.16, N, 17.13. Found: C, 63.50; H, 6.25; N, 17.20. **3-Pyrrolidinyl-5-[4-(trifluoromethyl)phenyl]-1,2,4-oxadiazole (19c):** mp 77 °C (from light petroleum); ^{1}H-NMR ($CDCl_3$) δ 2.00–2.05 and 3.48–3.53 (2m, 8H), 7.74–7.78 and 8.19–8.23 (2m, 4H); MS *m/z* 283 (M^+). Anal. Calcd for $C_{13}H_{12}F_3N_3O$: C, 55.13; H, 4.27; N, 14.83. Found: C, 55.20; H, 4.40; N, 14.70. **3-Pyrrolidinyl-5-(4-cyanophenyl)-1,2,4-oxadiazole (19d):** mp 165–166 °C (from light petroleum); IR 2200 cm^{-1}; ^{1}H-NMR ($CDCl_3$) δ 2.00–2.05 and 3.48–3.53 (2m, 8H), 7.78–7.82 and 8.18–8.21 (2m, 4H); MS *m/z* 226 (M^+). Anal. Calcd for $C_{13}H_{12}N_4O$: C, 69.01; H, 5.35; N, 18.57. Found: C, 69.20; H, 5.20; N, 18.70.

Irradiation of 3-(Benzoylamino)-4-methylfurazan (11a) in MeOH. Irradiation of **11a** (1 g) in MeOH (200 mL) for 90 min returned starting material (0.4 g, 40%) and gave **16a** (0.25 g, 29%) and **18a** (0.25 g, 26%). **3-Methoxy-5-phenyl-1,2,4-oxadiazole (16a):** mp 59 °C (from light petroleum) (lit.[13] mp 59 °C). ***O*-Benzoylamidoxime 18a:** mp 126 °C (from light petroleum); IR 3420, 3300, 3180, 1730 cm^{-1}; ^{1}H-NMR (DMSO-d_6) δ 3.75 (s, 3H), 6.45 (s, 2H), 7.30–8.20 (m, 5H); MS *m/z* 194 (M^+), 176 (M – 18). Anal. Calcd for $C_9H_{10}N_2O_3$: C, 55.67; H, 5.19; N, 14.43. Found: C, 55.50; H, 5.30; N, 14.50. By melting at 150 °C, **18a** gave **16a** (80%).

Irradiation of 3-[(4-Methoxybenzoyl)amino]-4-methylfurazan (11b) in MeOH. Irradiation of **11b** (1 g) in MeOH (200 mL) for 75 min gave starting material (0.2 g, 20%), **16b** (0.40 g, 45%), and **18b** (0.25 g, 26%). **3-Methoxy-5-(4-methoxyphenyl)-1,2,4-oxadiazole (16b):** mp 103 °C (from light petroleum); ^{1}H-NMR ($CDCl_3$) δ 3.85 and 4.10 (2s, 6H), 6.95–7.05 and 7.95–8.05 (2m, 4H); MS *m/z* 206 (M^+). Anal. Calcd for $C_{10}H_{10}N_2O_3$: C, 58.25; H, 4.89; N, 13.59. Found: C, 58.10; H, 4.80; N, 13.40. ***O*-(4-methoxybenzoyl)amidoxime 18b:** mp 117 °C (from light petroleum); IR 3420, 3300, 3280, 1720 cm^{-1}; ^{1}H-NMR (DMSO-d_6) δ 3.70 and 3.85 (2s, 6H), 6.50 (s, 2H), 7.00–7.10 and 8.00–8.10 (2m, 4H); MS *m/z* 224 (M^+), 206 (M – 18). Anal. Calcd for $C_{10}H_{12}N_2O_4$: C, 53.57; H, 5.39; N, 12.49. Found: C, 53.65; H, 5.50; N, 12.35. By melting at 150 °C, **18b** gave **16b** (80%).

Irradiation of 3-{[4-(Trifluoromethyl)benzoyl]amino}-4-methylfurazan (11c) in MeOH. Irradiation of **11c** (1 g) in MeOH (200 mL) for 45 min gave starting material (0.6 g, 60%), **16c** (0.10 g, 11%), and **18c** (0.20 g, 21%). **3-Methoxy-5-[4-(trifluoromethyl)phenyl]-1,2,4-oxadiazole (16c):** mp 144 °C (from light petroleum); ^{1}H-NMR ($CDCl_3$) δ 4.13 (s, 3H), 7.78–7.82 and 8.21–8.25 (2m, 4H); MS *m/z* 244 (M^+). Anal. Calcd for $C_{10}H_7F_3N_2O_2$: C, 49.19; H, 2.89; N, 11.47. Found: C, 49.30; H, 3.00; N, 11.30. ***O*-[4-(Trifluoromethyl)benzoyl]-amidoxime 18c:** mp 140 °C (from benzene); IR 3460, 3340, 1720 cm^{-1}; ^{1}H-NMR (DMSO-d_6) δ 3.79 (s, 3H), 6.67 (s, 2H), 7.94–7.97 and 8.35–8.38 (2m, 4H); MS *m/z* 262 (M^+), 244 (M – 18). Anal. Calcd for $C_{10}H_9F_3N_2O_3$: C, 45.81; H, 3.46; N, 10.68. Found: C, 45.70; H, 3.60; N, 10.50. Melting of **18c** gave **16c** (80%).

Irradiation of 3-[(4-Cyanobenzoyl)amino]-4-methylfurazan (11d) in MeOH. Irradiation of **11d** (1 g) in MeOH (200 mL) for 90 min gave starting material (0.5 g, 50%), **16d** (0.05 g, 6%), and **18d** (0.25 g, 26%). Some amounts of methyl 4-cyanobenzoate, arising from solvolysis of **18d**, were also recovered. **3-Methoxy-5-(4-cyanophenyl)-1,2,4-oxadiazole (16d):** mp 202 °C (from methanol); IR 2220 cm^{-1}; ^{1}H-NMR ($CDCl_3$) δ 4.10 (s, 3H), 7.80–7.90 and 8.20–8.30 (2m, 4H); MS *m/z* 201 (M^+). Anal. Calcd for $C_{10}H_7N_3O_2$: C, 59.70; H, 3.51; N, 20.89. Found: C, 59.80; H, 3.60; N, 20.80. ***O*-(4-cyanobenzoyl)amidoxime 18d:** mp 170 °C (from benzene); IR 3480, 3370, 2220, 1730 cm^{-1}; ^{1}H-NMR (DMSO-d_6) δ 3.70 (s, 3H), 6.60 (s, 2H), 7.95–8.05 and 8.20–8.30 (2m, 4H); MS *m/z* 219 (M^+), 201 (M – 18). Anal. Calcd for $C_{10}H_9N_3O_3$: C, 54.80; H, 4.14; N, 19.17. Found: C, 54.70; H, 4.10; N, 19.10. Melting of **18d** gave **16d** (60%).

Reaction of Dimethyl *N*-(Aroylimino)monothiolcarbonates 20 with Hydroxylamine. To a solution of **20a** (3.1 g, 15 mmol) in EtOH (20 mL) was added hydroxylamine free base [from 1.1 g (16 mmol) of the hydrochloride and equimolar amounts of sodium acetate in 20 mL of EtOH]. After standing 24 h at rt, removal of the solvent and chromatography gave **16a** (1.3 g, 50%) and **18a** (0.7 g, 25%). Similarly, compound **20b** gave **16b** (60%) and **18b** (30%); compound **20d** gave **16d** (31%) and **18d** (45%). Monitoring of the reaction by HPLC showed the intermediacy of a species (to which we reasonably assigned the presumed structure **15**) the concentration of which at first increases until a maximum and then decreases while final products increase. By reacting with *O*-methylhydroxylamine free base as above, **20a** (1 g) gave ***N*-Benzoyl-*O*-methylamidoxime 21** (0.6 g, 60%) mp 36–38 °C (from light petroleum) (lit.[4a] mp 35–38 °C).

Analytical Photoreactions. On the basis of ϵ values at λ = 254 nm for **11a** (8200), **11b** (16 700), **11c** (14 300), and **11d** (17 200), solutions of substrates were made to have the same absorbance. In a typical experiment, solutions of **11a** (40.0 mg), **11b** (22.6 mg), **11c** (30.8 mg), or **11d** (21.8 mg), respectively, in 20 mL of MeOH were apportioned in two sets of four samples (10 mL each). To a set of samples (**11a**, **11b**, **11c**, and **11d**) was added pyrrolidine (0.05 mL). All the samples were then irradiated simultaneously for 10 min in a merry-go-round apparatus, and the resulting photolysates were analyzed quantitatively by HPLC. In the case of the irradiations in methanol, each sample was analyzed; (i) soon after it was irradiated (clear-cut results only in the case of **11a**, **11b**, and **11d**); (ii) successively, after the photolysate was left at rt (12 or 20 h). The presumed intermediates **15** were recognized on the basis of before-tested reactions between **20** and hydroxylamine; since unavailability of correction factors of **15**, values were estimated by differential analysis. Compositions (%) of the photoreaction mixtures (A: samples in MeOH; B: samples containing pyrrolidine) were as follows:

	A							B	
	Immediate HPLC analysis				Delayed HPLC analysis				
	11	**15**	**18**	**16**	**15**	**18**	**16**	**11**	**19**
11a	65	18	10	7	0	11	24	72	28
11b	52	30	9	9	0	10	38	52	48
11c	56	-	-	-	0	19	25	81	19
11d	54[a]	16	23	8	0	27	16	85	15

[a] Some amounts of solvolytic methyl 4-cyanobenzoate are also present.

Quenching Experiments. A solution of **11a** (40 mg) in MeOH (20 mL) was apportioned in two quartz tubes. A sample was treated with an excess of piperylene (until attaining a molar ratio of 1/6; in this condition more than 95% of light is absorbed by the furazan), and then both samples were simultaneously irradiated for 10 min in a merry-go-round apparatus. Quantitative HPLC analyses carried out soon after the irradiation allowed to estimate the following Φ_0/Φ ratios: **15a** (≈0.9), **18a** (≈0.9), **16a** (≈4.0). Compounds **11b** and **11c** gave similar results. On irradiating **11d** (20 mg in 20 mL of MeOH, apportioned as before) for 10 min, HPLC analysis gave the Φ_0/Φ ratios: **15d** (≈2), **18d** (≈2.5), **16d** (≈7.0). As for the conversion of starting material, the Φ_0/Φ ratios were: **11a–c** (≈1.0), **11d** (≈2.5).

Irradiation of 3-(Acetylamino)-4-phenylfurazan (22) in MeOH. Irradiation of **22** (1 g) in MeOH (200 mL) for 50 min, together with starting material (0.2 g, 20%) and some amounts of unidentifiable minor products, gave **benzonitrile** (0.1 g, 20%), the **phenylcarbamate 33** (0.2 g, 27%), mp 45 °C (lit.[22] mp 47 °C), and finally (by eluting with methanol–ethyl acetate) syrupy **acetylcyanamide 29**.[23] Irradiation of **22** in the presence of an excess of piperylene carried out as before failed to quench the formation of any of the above photoproducts (by HPLC).

Irradiation of 3-(Acetylamino)-4-phenylfurazan (22) in the Presence of Pyrrolidine. Irradiation of **22** (1 g) in

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MeOH (200 mL) containing an excess of pyrrolidine (4 mL) for 2.5 h, gave benzonitrile (0.15 g, 30%), **25** (0.2 g, 27%), **31** (0.15 g, 16%), and then some acetylcyanamide. **3-Pyrrolidinyl-5-methyl-1,2,4-oxadiazole (25)**: viscous oil; ^{1}H-NMR ($CDCl_3$) δ 1.94–2.00 and 3.39–3.44 (2m, 8H), 2.45 (s, 3H); MS *m/z* 153 (M^+). Anal. Calcd for $C_7H_{11}N_3O$: C, 54.89; H, 7.24; N, 27.43. Found: C, 54.80; H, 7.10; N, 27.30. **Pyrrolidinyl phenyl oxime 31**: mp 130 °C (from MeOH) (lit.[24] mp 130 °C).

Irradiation of 3-(Acetylamino)-4-phenylfurazan (22) in the Presence of Methylamine. Irradiation of **22** (1 g) in MeOH (200 mL) containing an excess of ethanolic (33%) methylamine (10 mL) for 1.5 h, together with benzonitrile and acetylcyanamide, gave **26** (0.25 g, 45%) and **32** (0.1 g, 14%). **3-(Methylamino)-5-methyl-1,2,4-oxadiazole (26)**: mp 75–76 °C (from light petroleum); IR 3290 cm^{-1}; ^{1}H-NMR (DMSO-d_6) δ 2.43 (s, 3H), 2.73 (d, J = 4.5, 3H; singlet after exchange with D_2O), 6.63 (unresolved q, 1H); MS *m/z* 113 (M^+). Anal. Calcd for $C_4H_7N_3O$: C, 42.47; H, 6.24; N, 37.15. Found: C, 42.60; H, 6.30; N, 37.25. ***N*-Methyl-benzamidoxime 32**: mp 163 °C (from MeOH) (lit.[25] mp 163 °C).

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