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PHOTOINDUCED RING OPENING AND FRAGMENTATION OF ISOMERIC MESOIONIC *ANHYDRO*-4(5)-HYDROXYTHIAZOLIUM HYDROXIDES AND OF *ANHYDRO*-5-HYDROXY-3-METHYL-2-PHENYLOXAZOLIUM HYDROXIDE†

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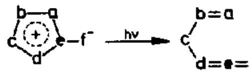
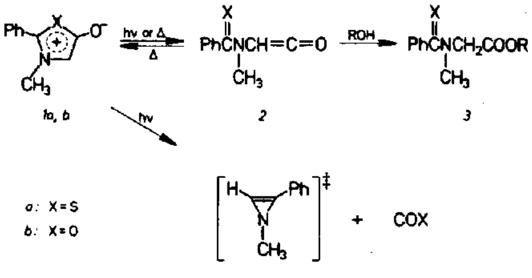
Abstract—Isoelectronic mesoionic thiazoles and oxazoles undergo photochemical ring opening to heterocumulenes as evidenced by trapping experiments with alcohols. A competing photolytic fragmentation to COS and CO_2, respectively, also occurs. Irradiation of the *anhydro*-5-hydroxythiazolium hydroxide system in the presence of O_2 results in the formation of singlet oxygen which undergoes a 1,4-cycloaddition to the thiazolium system. Decomposition of this cycloadduct gives rise to COS.

A number of mesoionic compounds[7] incorporating the oxathiazole[1–3] and thiadiazole[4–6] ring systems has been shown to undergo photolytic ring-opening according to eqn (1). Formation of the heterocumulenes was demonstrated by IR spectroscopy at cryogenic temperatures,[2] by trapping with alcohol,[1,3,4] or by isotope-exchange reactions.[3] Since the photoinduced valence tautomerism may be a general reaction of mesoionic compounds, we have studied several other ring systems in which similar reactions may occur. This publication describes our results with both the *anhydro*-5-hydroxythiazolium and oxazolium hydroxide ring systems which underwent ring opening on irradiation.



(Eqn. 1)

A methanol solution of *anhydro*-5-hydroxy-3-methyl-2-phenylthiazolium hydroxide (**1a**) was irradiated ($\lambda_{ex} = 366 \pm 20$ nm) at room temperature under an argon atmosphere. N-Thiobenzoylsarcosine methyl ester (**3**; R = Me) was isolated[8] from the mixture (83%). No reaction between **1a** and methanol took place in the dark under the same conditions, although some conversion into **3a** was observed on standing for 1 week, a not unexpected methanolytic ring-opening reaction. The formation of **3a** strongly suggests the photolytic generation of the heterocumulene **2a** although it was not possible to detect it directly by IR spectroscopy. At room temperature in the frequency region associated[9] with heterocumulenes (1950–2350 cm^{-1}) no absorption was detected. This may possibly be due to a rapid photochemical or thermal reversion of the heterocumulene to **1a** (Scheme 1), this valence tautomerism also being a significant pathway[10] in the mass spectral fragmentation of **1a**. Attempts to detect **2** spectroscopically by cooling to −196° were unsuccesfull since the quantum yield dropped to around zero under these conditions.



Scheme 1.

IR monitoring of the photolysis of **1a** in the presence of O_2, using carefully dried MeCN or CH_2Cl_2 solvents, detected absorption bands at 2060 and 2350 cm^{-1}. These disappeared when the solution was purged with argon for a few minutes. Carrying out the photolysis in an argon atmosphere, or by using KBr discs, still retained the absorption at 2060 cm^{-1}. In semi-preparative scale runs, the photolytically formed gases in either oxygen or argon atmospheres were collected in hexane solutions of piperidine. A ready precipitate of piperidinium oxythiocarbamate (λ_{max} 230 nm) confirmed[11] the presence of the photolytically-induced COS, consistent with the absorption at 2060 cm^{-1}. The amount of piperidinium oxythiocarbamate formed on photolysis of **1a** in the presence of O_2 corresponds to 8–9% COS. Under argon the photolytic decomposition of **1a** was about 40 times slower than

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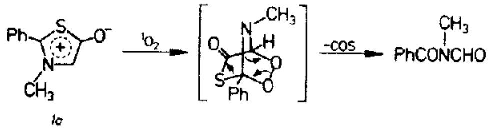
†"Mesoionic Compounds". Part 46.

‡No attempt was made to trap **4** which is probably formed together with COX.

in oxygen and, although isolated, no quantitative estimation of COS was made.

Additional information on the formation of COS and CO_2 was obtained from the following experiments. The *anhydro*-5-hydroxythiazolium hydroxide **1a** was photolyzed in CH_2Cl_2 in the presence of methylene blue and oxygen under conditions where only methylene blue absorbs light ($\lambda > 530$ nm). Singlet oxygen, O_2 ($^1\Delta_g$), is produced under these conditions by energy transfer from methylene blue to triplet oxygen, as shown by independent experiments. The evolved gases were trapped in CH_2Cl_2 at −78° and, at room temperature, showed strong IR absorptions at 2350 and 2060 cm^{-1}, indicating the formation of CO_2 and COS, respectively. These bands were absent when the irradiation was carried out under an argon atmosphere and, under these conditions, the *anhydro*-5-hydroxythiazolium hydroxide **1a** was recovered unchanged. The amount of COS present in the mixture was found to be 9% by the procedure described above. It was also observed that COS was not oxidized to CO_2 under the prevailing reaction conditions. These experiments indicate that COS is being formed by two independent pathways, one involving the fragmentation of **1a** as shown in Scheme 1, and the other involving a 1,4-cycloaddition of singlet oxygen[12] to the thiazolium system as shown in Scheme 2. Photolytic formation of singlet oxygen from **1a** in the presence of oxygen was demonstrated independently (See Experimental).

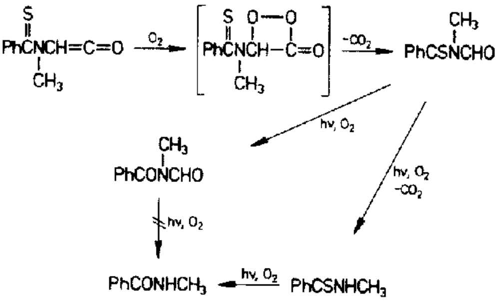


Scheme 2.

N-Formyl-N-methylbenzamide was obtained in 12% yield in a preparative photolysis ($\lambda > 330$ nm) in the presence of air, together with N-methylthiobenzamide (10%), N-methylbenzamide (22%) and N-formyl-N-methylthiobenzamide (5%) (Scheme 3). Addition of O_2 to ketenes is well established[13] and accounts for the formation of CO_2 and N-formyl-N-methylthiobenzamide. The latter, absorbing in the visible region, is then converted into N-methylthiobenzamide, probably as the result of an oxidation. N-Methylthiobenzamide was independently found to undergo photooxidation to N-methylbenzamide, and it should be noted that N-formyl-N-methylbenzamide (λ_{max} 235 nm) is not converted into N-methylbenzamide under these photolytic conditions.

When *anhydro*-5-hydroxy-3-methyl-2-phenyloxazolium hydroxide (**1b**) was irradiated ($\lambda > 330$ nm) in $CHCl_3$ in an argon atmosphere and monitored by IR spectroscopy, a strong band was observed at 2350 cm^{-1}. This was assigned to CO_2, indicating fragmentation had taken place according to Scheme 1. Strong support for the intermediacy of heterocumulene **2b** was obtained from the isolation of the ester **3b**. Thus irradiation ($\lambda >$ 330 nm) of a solution of **1b** in 5% EtOH:$CHCl_3$ at −50° for 41 hr resulted in 76% conversion of **1b** and the ester **3b** was isolated[8] in 38% yield. No reaction between ethanol and **1b** was observed when a sample was kept in the dark under identical reaction conditions. However, transformation of **1b** into **3b** occurred within a few hours at room temperature, presumably due to thermal ring opening of the oxazole.[14] The much slower photolytic conversion of **1b** into **3b** at −50° provides support for the photolytic formation of **3b** by reaction of the intermediate heterocumulene **2b** and ethanol rather than from a reaction between excited **1b** and ethanol.

The behavior of the isomeric *anhydro*-4-hydroxythiazolium hydroxide system **5** on photolysis is also of interest, as it may undergo a valence tautomerism with subsequent elimination of sulfur to form a β-lactam.[15]

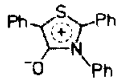


Scheme 3.

In the example studied, *anhydro*-4-hydroxy-2,3,5-triphenylthiazolium hydroxide (**5**), the three phenyl substituents depress the photochemical reactivity of the system to the extent that very complicated reaction mixtures result, no simple fragmentation nor the formation of phenyl isocyanate or diphenylacetylene being observed. In ethanol solution and under an atmosphere of N_2, N-phenylthiobenzamide (9%) and N-phenylbenzamide (44%) were obtained, together with a number of unidentified products. The nature of the two isolated products suggests that redox processes are important in this system and, in view of the results obtained with a variety of 2-thiosubstituted derivtives of this ring system,[15] this study was not pursued further.

EXPERIMENTAL

A medium pressure Hg-lamp (Hanau Q-700) was used for the preparative scale photolysis. For $\lambda > 330$, $\lambda > 390$ and $\lambda >$ 530 nm filters consisting of 1 cm solns of acetone, 1 cm solns of acetone saturated with anthracene, and 1 cm solns of acetone saturated with eosin, respectively, were used. Samples were cooled by tap water during photolysis. For small scale experiments a Bausch and Lomb SP-200 mercury point-source equipped with monochromator (typical band width 20 nm) was used. IR spectra were recorded on a Perkin–Elmer model 337 Grating Infrared Spectrophotometer and visible-UV absorption spectra on a Pye Unicam SP 1800 Ultraviolet Spectrophotometer. Satisfactory elemental analyses (±0.4% C, H, N) were obtained for all new compounds.



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Photolysis of anhydro-*5-hydroxy-3-methyl-2-phenylthiazolium hydroxide* (**1a**) *in* KBr *or in methanol.* A soln of **1a** [λ_{max} (MeOH) 236, 280 and 358 nm (log ϵ 3.71, 3.32 and 3.59)][16,17] (5×10^{-3} M) in MeOH (100 ml) was irradiated ($\lambda >$ 330 nm) for 3 hr under argon. The solvent was removed *in vacuo* and the residue purified by preparative tlc (petroleum ether/acetone: 2/1) affording **3a**, m.p. 74–76° (83%). Increase in irradiation time to 24 hr did not increase the yield of **3a**. A solid soln of **1a** in KBr was irradiated ($\lambda > 330$ nm) and the reaction monitored by IR spectroscopy. No bands were observed in the heterocumulene region (1950–2350 cm^{-1}) apart from a weak band at 2060 cm^{-1} (COS).

Synthesis of N-*thiobenzoylsarcosine methyl ester* (**3a**). A soln of diazomethane in Et_2O (0.24 mol/ml) was added dropwise and with stirring to a soln of N-thiobenzoylsarcosine[16] in Et_2O at 0°. The solvent was removed *in vacuo* and the residue recrystallized from hexane affording **3a** as colorless needles, m.p. 74–76° (90%); λ_{max} (CH_3OH) 280 nm, log ϵ 3.91.

Formation of singlet oxygen from anhydro-5-*hydroxy*-3-*methyl*-2-*phenylthiazolium hydroxide* (**1a**). A soln of **1a** (2.5×10^{-2} M) and 1,1,2,2-tetramethylethylene (2 ml) in $CHCl_3$ (5 ml) was irradiated ($\lambda > 330$ nm) for 2.5 h while the soln was purged with O_2. The mixture was treated with trimethylphosphite (2.6 ml) and analysed for its content of 2,3-dimethyl-3-buten-2-ol by the glc procedure of Foote.[18] The observed formation of the alcohol in 80% yield based on **1a** (electronic integration and comparison with standard curves) indicates the formation of singlet O_2 by energy transfer from **1a** to triplet O_2.

Reaction of anhydro-5-*hydroxy*-3-*methyl*-2-*phenylthiazolium hydroxide* (**1a**) *with singlet oxygen*. A soln of **1a** (10^{-2} M) in CH_2Cl_2 was irradiated ($\lambda > 330$ nm) until completion of the reaction while the soln was purged with O_2. The mixture was worked up by preparative tlc to give the products listed in the preceeding text (below Scheme 2), identified by comparison with authentic material.

Photolysis of anhydro-5-*hydroxy*-3-*methyl*-2-*phenyloxazolium hydroxide* (**1b**) *in ethanol*. A soln of **1b** (7×10^{-4} M) in 5% ethanolic $CHCl_3$ was irradiated ($\lambda > 330$ nm) at −50° for 41 hr. The conversion of **1b**, estimated by means of UV-spectroscopy, was 76%. The mixture was worked up by preparative tlc (benzene/acetone: 2/1) affording the ester **3b** in 38% yield based on the converted **1b**. The ester was identified by comparison with an authentic sample.[19]

Photolysis of anhydro-4-*hydroxy*-2,3,5-*triphenylthiazolium hydroxide* (**5**). A soln of **5** (1.5×10^{-3} M) in EtOH (2 L) was irradiated with an immersion lamp for 10 hr ($\lambda > 390$ nm), the soln being purged with N_2 before irradiation for 15 min. After removal of the solvent *in vacuo*, the residue was worked up by preparative tlc (silica gel, benzene/chloroform: 2/1) and afforded N-phenylbenzamide[20] (44%) and N-phenylthiobenzamide[21] (9%) identified by comparison with authentic material.

Quantitative determination of COS. Authentic piperidinium oxythiocarbamate was prepared[11] and its extinction coefficient determined. A soln of **1a** (10^{-2} M) in CH_2Cl_2 was irradiated ($\lambda_{ex} > 330$ nm) until complete disappearance of **1a** occurred as O_2 was bubbled slowly through the soln and then, used as a carrier gas, through piperidine (1 ml) in hexane (10 ml) placed in an ice/salt bath. Flusing with O_2 was continued for about 1 hr after irradiation. The solvents were removed *in vacuo* and the amount of piperidinium oxythiocarbamate estimated by means of UV-spectroscopy.

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