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The key intermediates that interact with the fluorophores in the peroxyoxalate chemiluminescence reaction of 2,4,6-trichlorophenyl *N*-aryl-*N*-tosyloxamates

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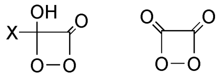
Received (in Cambridge, UK) 3rd January 2003, Accepted 11th February 2003
First published as an Advance Article on the web 25th February 2003

A kinetic study of peroxyoxalate chemiluminescence reactions employing 2,4,6-trichlorophenyl *N*-aryl-*N*-tosyloxamates supports the 1,2-dioxetanones still bearing the eliminating group as the key intermediates that interact with the fluorophores rather than 1,2-dioxetanedione.

Peroxyoxalate chemiluminescence[1] has received continuous attention so far since its discovery,[2] and it is being applied to practical uses such as chemical lights or analytical reagents because of its convenience and high emission efficiency. The chemiluminescent reactions consist of the reaction of hydrogen peroxide and the activated oxalates bearing the good eliminating groups,[3] from which light emission with various wavelengths due to the fluorescence of the fluorophores is produced. According to the relationship established between the emission efficiencies and the oxidation potentials of the fluorophores, the CIEEL (Chemically Initiated Electron Exchange Luminescence) process[4] between the high-energy intermediates and the fluorophores is applied to explain the high emission efficiencies,[5] or at least a contribution of a charge transfer interaction may be considered.[6] In spite of accumulating knowledge of this chemiluminescence reaction,[7] there still remains a question of which is the key intermediate that interacts with the fluorophores. Of the key intermediates proposed so far,[8] the most probable peroxides are 1,2-dioxetanones (**I**)[9] bearing eliminating groups and 1,2-dioxetanedione (**II**),[10] both of which are strained four-membered cyclic peroxides and tend to interact with fluorophores to provide chemiluminescence based on a structural similarity to the chemiluminescent α-peroxylactones and related dioxetanes.[11] This study was undertaken to provide a more unambiguous view of this subject by exploring the chemiluminescence of the newly prepared oxamates (**1**), the structural hybrids of oxalates and oxamides.

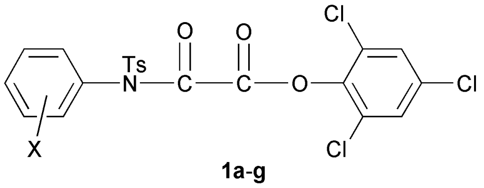


X = eliminating group

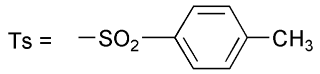
I **II**

The sequential reactions of oxalyl chloride with substituted *N*-tosylanilides and then with 2,4,6-trichlorophenol (TCPOH) in the presence of triethylamine in benzene gave the 2,4,6-trichlorophenyl *N*-tosyl-*N*-aryloxamates (**1a–g**), which displayed chemiluminescence lasting several hours when reacted with aqueous H_2O_2 in tetrahydrofuran (THF) in the presence of fluorescent 9,10-diphenylanthracene (DPA).

The reactions of **1a–c**, **1f** and **1g** with aqueous H_2O_2 in deuterated THF were monitored by ^{1}H and ^{13}C NMR, in which the signals of the starting oxamates gradually decreased and completely disappeared after several hours along with an increase in the signals of the liberated TCPOH and the tosylanilides,[12] but no signal corresponding to any intermediate was detected. Since the reaction of PhNTsCOCONTsPh is known to be almost unreactive against H_2O_2 under the same conditions,[5c] the initial nucleophilic acyl substitution by H_2O_2 expels TCPOH to form labile hydroperacids which readily decompose into tosylanilides and CO_2 *via* cyclic peroxides. In contrast, the reaction of ethyl 2,4,6-trichlorophenyl oxalate (**2**), EtOCOCOOTCP, with aq. H_2O_2 under the same conditions gave ethyl *O*-hydrogen monoxalate, EtOCOCOOH, with the loss of an oxygen atom from the initially formed ethyl *O*,*O*-hydrogen monoperoxyoxalate, EtOCOCOOOH.[13] In this reaction, no light emission was detected in the presence of DPA.



1a-g



a, X = H; **b**, X = *p*-Me; **c**,X = *m*-Cl;
d, X = *p*-Cl; **e**, X = *m*-OMe; **f**, X = *p*-OMe;
g, X = *p*-Me_2N

The kinetic NMR study, measuring the amount of liberated tosylanilides, revealed that a Hammett relationship was established in the reactions of **1a–f** but not for **1g**[12] under pseudo-first order conditions, from which the ρ-value was estimated to be +1.75 as shown in Fig. 1(a). In addition, a Hammett relationship could be also applied to the correlation between the initial chemiluminescence intensities (I_0) enhanced by DPA and the substituent constants, the σ-values, as shown in Fig. 1(b) and (c). As I_0 is proportional to the rate of the interaction between the high-energy intermediate and the fluorophore,[14] it can also be regarded as a criterion for the generation rate of the high-energy intermediates. While the ρ-value was estimated to be +2.66 under neutral conditions, it decreased to +1.20 under basic conditions in the presence of sodium carbonate. These results, no light emission from **2** and the Hammett relationship for the light emission of **1**, show that the crucial intermediate interacting with DPA to generate its excited state is not a peracid such as ArTsNCOCOOOH. The larger ρ-value for the light emission than for the liberation of the tosylanilides suggests that **I** is more favorable as the key intermediate than **II**, because the proton transfer from the hydroxyl group of **I** to the nitrogen atom should be involved in order to generate **II** by liberation of the tosylanilides from **I**. Due to the essentially negative ρ-value for the proton transfer to the nitrogen atoms, the ρ-value for the emission must have been lower than that observed if **II** interacts with the fluorophores to emit light. In other words, the interaction of the crucial intermediate generating the excited fluorophores takes place before the liberation of the tosylanilides. The difference between the ρ-values for the nucleophilic addition of hydroxide ion to the amide carbonyl and the liberation of the anilide groups was well documented by Bender *et al.*[15] for the alkaline hydrolysis of *N*-substituted acetanilides.

Next, oxamate (**3**) having an *N*-2-naphthyl-*N*-tosylamide group as a fluorescent residue was employed to obtain further

DOI: 10.1039/b300079f

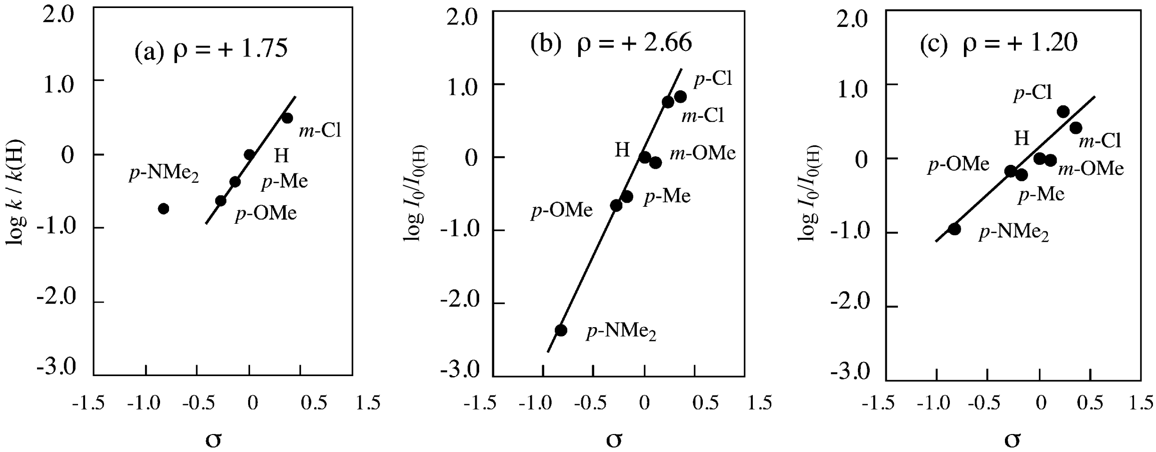


Fig. 1 The Hammett relationship in the chemiluminescence reaction of oxamates (**1**). (a) Product formation. (b) Light emission under neutral conditions. (c) Light emission under basic conditions.

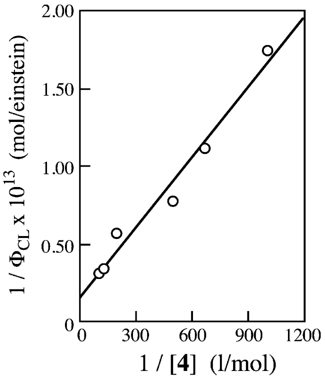
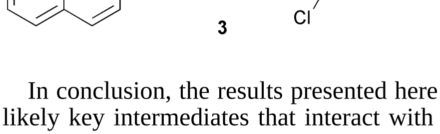


Fig. 2 Double reciprocal plot of Φ_{CL} of **3** *vs.* [**4**].

information about the intermediate. The reaction of **3** with aq. H_2O_2 in THF showed only a feeble chemiluminescence, but the addition of *N*-2-naphthyl-*N*-tosylamide (**4**) to the reaction system led to enhanced chemiluminescence, and an emission spectrum which was in good agreement with the fluorescence spectrum of **4** having a fluorescence maximum at 402 nm. The double reciprocal plot of the relative Φ_{CL} *vs.* the concentration of **4** was found to be linear as shown in Fig. 2, establishing a bimolecular reaction process[8] between **4** and the key intermediate. This relation holds even when the concentration of **4** is less than that of **3**. Consequently, the light emission does not arise from **4** liberated from **3** but from **4** externally added. If 1,2-dioxetanedione (**II**) is the crucial intermediate, the emission should be observed without the addition of the external **4**, and the emission intensity should not depend on the concentration of the added **4**.



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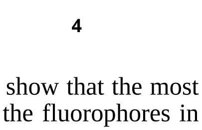

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In conclusion, the results presented here show that the most likely key intermediates that interact with the fluorophores in the present oxamate chemiluminescence system are 1,2-dioxetanones (**I**) still bearing the eliminating group rather than 1,2-dioxetanedione (**II**). We believe that this mechanistic view can also be applicable to general peroxalate chemiluminescence.

This work was supported by a Grant-in-Aid for the 21st Century COE Research (14B1-30) by the Ministry of Education, Culture, Sports, Science and Technology of Japan.

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