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Synthesis and Chemiluminescence of a Protected Peroxyoxalate.

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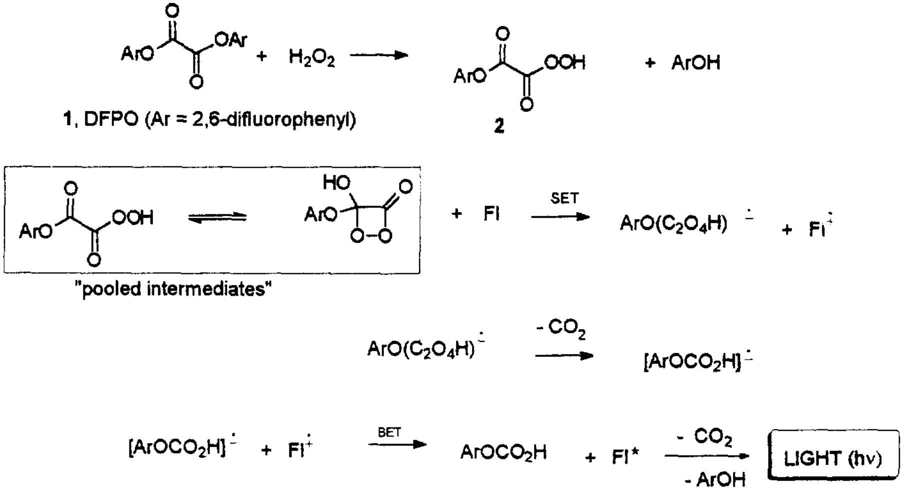
Abstract: Triisopropylsilylperoxy (**5a**), triisobutylsilylperoxy oxalate (**5b**) have been synthesized and their chemiluminescence examined. Upon treatment with fluoride ion, a solution of **5b** and 9,10-diphenylanthracene produces a short burst of chemiluminescence which decays with mixed order kinetics characteristic of the emission seen from the reaction of diaryl oxalates, H_2O_2 and the fluorophore. Copyright © 1996 Elsevier Science Ltd

The reactions of aryl oxalates (**1**) with hydrogen peroxide in the presence of a fluorophore have been studied extensively[1] due to their intrinsic ability to produce light. Applications of these reactions in analytical chemistry for trace analysis and for detection in HPLC and flow injection analysis are well known.[2] However, the mechanism of these chemiluminescent reactions remains uncertain[3] owing to the complexity of the aryl oxalate reaction with the oxidizing agent and fluorophores. Several proposed mechanisms involve initial formation of a highly reactive half-ester, peroxy acid intermediate **2** (Scheme **1**) which has been detected,[1d,f] but to date has not been isolated or fully characterized. Significant mechanistic insight could be achieved if this intermediate were prepared by an independent route.

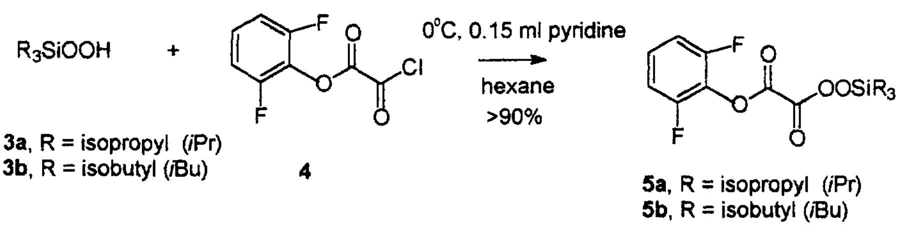
Scheme 1



Fl=fluorophore (9,10-diphenylanthracene); SET= Single Electron Transfer; BET= Back Electron Transfer

The trialkylsilyl protected 2,6-difluorophenyl peroxyoxalate ester **5** was targeted for synthesis because it was anticipated that it would be a stable precursor to the half-ester peroxy acid **2** which then could be readily converted to the peroxyoxalate **2** with fluoride ion. The two trialkyl derivatives that have been synthesized are the triisopropylsilylperoxyl and triisobutylsilylperoxyl 2,6-difluorophenyl oxalates (**5a** and **5b**, respectively) and their chemiluminescent reactions studied.

Triisopropylsilyl hydroperoxide[4] (**3a**), triisobutylsilyl hydroperoxide (**3b**) and 2,6-difluorophenyl oxalyl chloride (**4**) were prepared by known procedures. Reaction of a 30% excess of a hexane solution of the silyl hydroperoxide with 2,6-difluorophenyl oxalyl chloride in pyridine (equation 1) yielded the protected hydroperoxy esters (**5a** or **5b**)[5] in nearly quantitative yield. The product oils (*e.g.*,. **5b**) displayed strong carbonyl absorptions at 1790 and 1745 cm^{-1}; mass spectral peaks (CI/NH_3) at m/z 418, 289, 232, and 216; and ^{1}H NMR multiplets at δ 7.25 (t, 1H), 7.03 (dd, 2H), 1.88 (m, 3H), and 0.98 (d, 18H) as well as a doublet at 0.70 (d, 6H). Both protected hydroperoxy esters were unstable at room temperature, even decomposing over a 4 day period at 4°C. Consequently, efforts to purify these esters by chromatography led only to extensive decomposition.



(eq. 1)

Typical chemiluminescence studies were performed by combining a 0.95 mL (1 mM) solution of the trialkylsilyl peroxyoxalate ester in dimethyl phthalate (DMP) or acetonitrile with 0.95 mL (1 mM) 9,10-diphenylanthracene (DPA). Tetrabutylammonium fluoride (TBAF; 0.10 mL (1.0 M in THF diluted to 100 mM in DMP or 1:1 acetonitrile:H_2O)) was injected into the mixture and the emission monitored by a luminometer. In all cases, the decay of the chemiluminescence emission was very rapid, much faster than the corresponding diaryl oxalate decay profile. Controls using the individual reagents, excluding TBAF, or replacing **5** with trialkylsilylhydroperoxide **3a** did not produce chemiluminescence.

A typical chemiluminescence decay curve for **5a** in DMP (Figure 1) shows a rapid decay during the first 10 seconds followed by a much slower decay lasting over 90 seconds. A similar, but much brighter chemiluminescence pattern was observed for **5b**. While the origin of the two distinctive decay modes is uncertain at this time, we speculate that the initial burst results from and is controlled by the rate of release of the peroxyoxalate which then reacts rapidly with the flourophore. The weaker background chemiluminescence is possibly due to a slower decay process from CO_2 emission.[6] These decay profiles can be fitted to biexponential rate curves and accord with the "pooled" intermediate model (Scheme 1) developed earlier in these laboratories[1,2,7] in which one activator decays rapidly giving way to a second, longer lived activator.

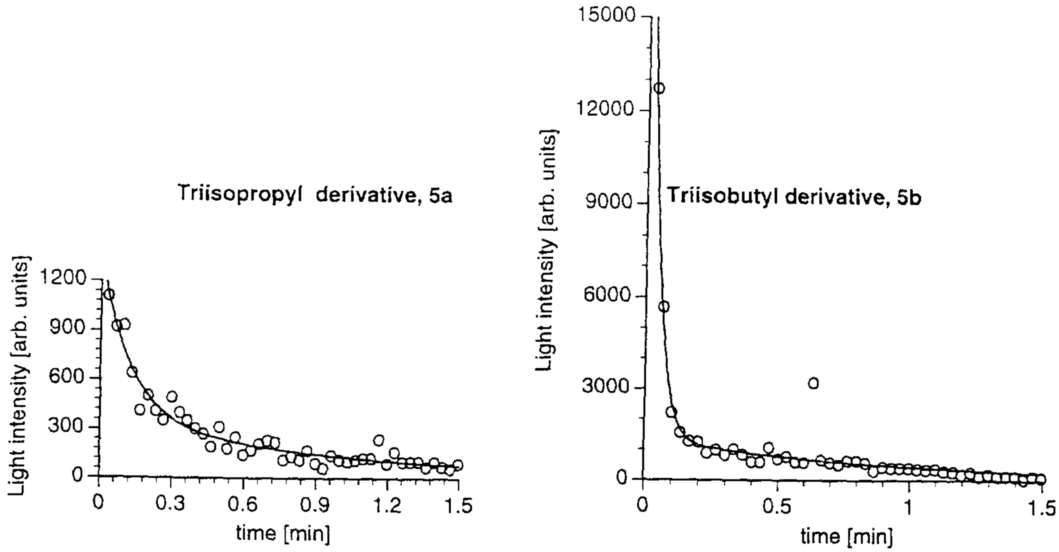
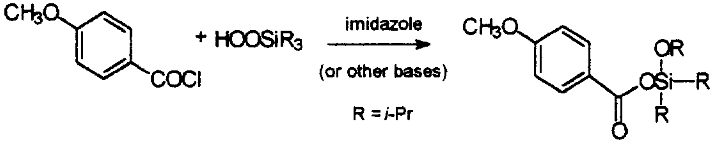


Figure 1. Biexponential chemiluminescent decay curves for triisopropylperoxy (**5a**) and triisobutylperoxy 2,6-difluorophenyl oxalate (**5b**) in DMP at room temperature. Curves are the least squares biexponential best fit. For **5a**, the biexponential expression is $I = 985e^{-8.17t} + 381e^{-1.07t}$ ($r^2 = 0.945$); for **5b**, the expression is $I = 31018e^{-31.5t} + 1403e^{-1.18t}$ ($r^2 = 0.958$).

This very rapid decay of the chemiluminescence produced with **5** as the "activator" of the fluorophore in comparison with the much more prolonged emission from the aryl oxalates and H_2O_2 suggests that the peroxidolysis of the aryl oxalate is the emission controlling process and is significantly slower than the fluoride-ion induced cleavage of the trialkylsilyl peroxide bond. This provides an additional method for controlling the rate of emission from chemiluminescent reactions. A more rapid decay profile was observed in acetonitrile:H_2O which suggests that hydrolysis of the peroxyoxalate may be a more serious problem than previously indicated.

These results would appear at first to contrast with a very recent report by Stevani, *et al*[1f] in which it was reported that *p*-chlorophenyl peroxyoxalate did not produce chemiluminescence until a base was present. In fact, the chemiluminescent reaction is pH dependent as amply demonstrated by others[1,2] and in our laboratories[7]. The exact role of base remains to be determined, but it is certain that the peroxyoxalate is a precursor to the chemiluminescent process.

Finally, it is of interest to speculate why the chemiluminescence intensity from the triisobutylsilyl peroxyoxalate **5b** is greater than that observed from the triisopropyl derivative **5a**. One factor which may contribute to the lower emission yield from **5a** is a competing rearrangement to an alkoxydialkylsilyl oxalate (eq 2). In attempts to synthesize the trisiopropylsilylperoxy ester of anisic acid, for example, triisopropylsilyl hydroperoxide (**3a**) was added to *p*-methoxybenzoyl chloride in the presence of a variety of bases. The major product was the rearranged silyl ester 7, as evidenced by the spectral data (*e.g.*, ^{1}H NMR ($CDCl_3$,δ, ppm) 8.03 (d, 2H), 6.93 (d,2H), 4.42 (m, 1H), 3.9 (s, 3H), and 1.40 - 1.00 (m, 20H) and ^{13}C NMR 165.9, 163.9, 132.7, 124.0, 114.0, 66.5, 55.8, 26.0, 17.5, and 12.9). The same rearrangement was also observed for **5** as well as with other 2° and 3° alkylsilyl derivatives when treated with base. Niether 7 nor these other derivatives chemiluminesced. Additional investigations of this reaction and the application of the protected peroxyoxalates to other chemiluminescent processes are in progress.



(eq 2)

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