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Synthesis and Chemiluminescence of 3,3-Diisopropyl-4-methoxy-4-(2-naphthyl)-1,2-dioxetanes

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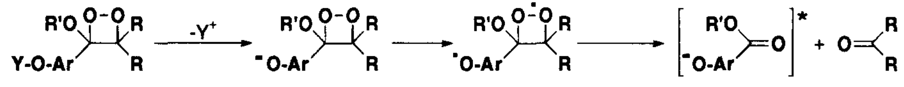
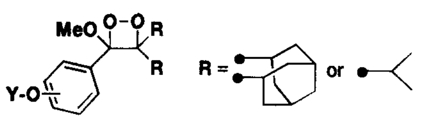
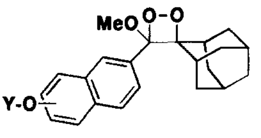
Abstract: Six isomeric 3,3-diisopropyl-4-methoxy-4-(2-naphthyl)dioxetanes (**4**) were synthesized and their F^--induced chemiluminescences were examined in DMSO. Dioxetane **4b** is a new type of chemiluminescent substrate which affords intense flash light. The other isomeric naphthyldioxetanes (**4c** - **4f**) exhibit chemiluminescent properties in agreement with the '*odd/even*' relationship.

Dioxetanes bearing a fluorescent electron donor such as phenoxide anion are unstable and decompose rapidly to emit light by an intramolecular electron (charge) transfer mechanism (CIEEL mechanism).[1-6] The position of an oxyanion on the aryl ring relative to the attachment point to the dioxetane influences significantly the chemiluminescent properties and an '*odd/even*' relationship[7,8] has been observed for dioxetanes (**1**), which release a phenoxide on treatment with F^-; (**1a**) with a *meta* (*odd*)-substitution gives more intense but longer half-life emission than (**1b**) with a *para* (*even*)-substitution and its *ortho* (*even*)-isomer.[2,3,9,10] The '*odd/even*' relationship has very recently been reported to hold also for dioxetanes (**2a** and **2b**) bearing a naphthol moiety.[8,11] These facts bring on a rather simple but important aspect of the synthesis, namely whether a CIEEL-active dioxetane emitting light with high efficiency as well as short half-life can be realized by designing a fluorescent electron donor.[12] We report here that: 1) 3-[4-(*tert*-butyldimethylsiloxy)-2-naphthyl]-4,4-diisopropyl-3-methoxy-1,2-dioxetane (**4b**) is a new type of dioxetane affording intense flash light, and 2) the other isomeric naphthyldioxetanes (**4c** - **4f**) exhibit chemiluminescent properties in agreement with the above '*odd/even*' relationship.



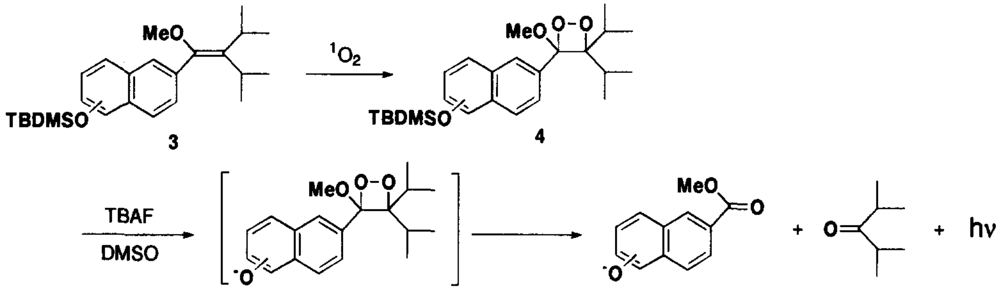


1a: Y-O- = 3-(*t*-Bu(Me)$_2$SiO)-
1b: Y-O- = 4-(*t*-Bu(Me)$_2$SiO)-



2a: Y-O- = 7-(Na$_2$O$_2$P(O)O)-
2b: Y-O- = 6-(Na$_2$O$_2$P(O)O)-

First, we synthesized 3-[4-(*tert*-butyldimethylsiloxy)-2-naphthyl]-4,4-diisopropyl-3-methoxy-1,2-dioxetane (**4b**) and examined its chemiluminescent properties because of its formal structural resemblance to **1a** with respect to the positional relationship (*odd*) between a trigger and the attachment point to the dioxetane ring. A solution of 1-[4-(*tert*-butyldimethylsiloxy)-2-naphthyl]-2,2-diisopropyl-1-methoxyethylene (**3b**) (100 mg) and tetraphenylporphin (TPP) (1.5 mg) in CH_2Cl_2 (10 ml) was externally irradiated with a Na lamp (180 W) under an oxygen atmosphere at 0 °C for 2 h. After concentrating the photolysate, the residue was chromatographed on silica gel and eluted with hexane-ethyl acetate to give a dioxetane (**4b**) as a pale yellow viscous oil[13] in a 52 % isolated yield. When a solution of **4b** in DMSO (1.0×10^{-5} mol dm^{-3}, 1ml) was added to a TBAF (tetrabutylammonium fluoride) solution in DMSO (1.0×10^{-2} mol dm^{-3}, 2ml) at 25 °C, **4b** emitted flash intense light (λ_{max} = 496 nm, $\Phi_{CL} = 5.2 \times 10^{-2}$, $t_{1/2}$ = 0.08 s).

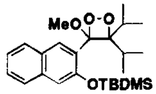
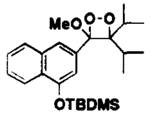
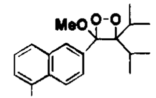
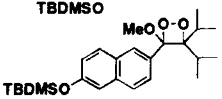
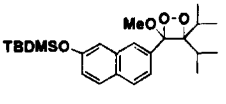
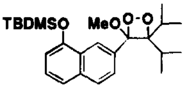


The chemiluminescent properties of **4b** were significantly different from those reported[11] for **2a** (λ_{max} = 550 nm, $t_{1/2}$ = 1380 s) and **2b** (λ_{max} = 463 nm, $t_{1/2}$ = 9 s), though **2a** and **2b** bear an adamantylidene instead of two isopropyls and their chemiluminescent system is in aqueous solution, where the half-life of emission tends to be prolonged.[14] To compare the chemiluminescent properties of **4b** with those of dioxetanes corresponding to **2a** and **2b** under equivalent circumstances, a (6-siloxy-2-naphthyl)dioxetane (**4d**) and a 7-siloxy-analogue (**4e**) were synthesized similarly to **4b** (**4d**: 78 %, **4e**: 73 %). Treatment of **4d** with TBAF in DMSO afforded very weak flash light (λ_{max} = 470 nm, $\Phi_{CL} = 3.2 \times 10^{-6}$, $t_{1/2}$ = 0.15 s), while similar treatment of **4e** emitted glow orange light (λ_{max} = 558 nm, $\Phi_{CL} = 5.6 \times 10^{-2}$, $t_{1/2}$ = 250 s). These results showed that both **4d** and **4e** are in the category of the '*odd/even*' relationship, but **4b** is not.

We further synthesized the remaining three isomers of dioxetanes (**4**) bearing a siloxy-substituted 2-naphthyl by singlet oxygenation of the corresponding naphthylethylenes (**3**) (isolated yield **4a**: 58 %, **4c**: 42 %, and **4f**: 72 %).[15] The F^--induced chemiluminescent properties of these dioxetanes are summarized in Table 1 together with those of **4b**, **4d** and **4e**. Table 1 shows that: 1) upon treatment with TBAF, all the dioxetanes (**4**) except for **4a** emitted light with longer wave length than the case of **1**, 2) chemiluminescent efficiencies (Φ_{CL}) of **4** are classified into two groups; **4b**, **4c** and **4e** exhibit high efficiency while **4a**, **4d** and **4f**, especially **4d**, emit very weak light, and 3) for half-life of chemiluminescence, a group of **4b**, **4d**, and **4f** giving flash-like light is distinguished from a group of **4a**, **4c** and **4e** affording glow light. In conclusion, the '*odd/even*' relationship is observed for Φ_{CL} of dioxetanes bearing a 2-naphthyl (**4**) but not for their emission half-lives; the cases of **4a** and **4b** are deviated from the relationship.

Although it is difficult at this time to offer a theoretical explanation of the detailed features of the order of light yields of **4**, the classification of Φ_{CL} for **4** into '*odd / even*' relationship is probably rationalized by the theoretical accounts proposed by McCapra[10] and Bronstein;[8] singlet excited state is effectively formed when an oxyanion on the aromatic ring stabilizes a charge transfer transition in thermal decomposition of aryloxide-substituted dioxetanes formed after triggering. On the other hand, little attempt has been made to account for the relationship between substitution pattern and half-life of emission.[16] The ease of intramolecular electron (charge) transfer from an O^-- substituted aromatic ring to the dioxetane ring should be reflected in the half-life of emission and the rate of decomposition of the dioxetane. Providing that the aromatic carbon (Cα) at the position attached to the dioxetane ring participates in the electron transfer process, the rate of decomposition of the dioxetane (emission rate) would depend on the HOMO electron density at Cα. The evaluation of the HOMO electron density at Cα is expected to provide rationalization for the relation of half-lives between the substitution patterns in a series of the dioxetanes **4**. As shown in Table 1, an HMO calculation,[17] which is simple but still convenient to know qualitatively the regioselectivity of reaction on a π-system for rather simple aromatic hydrocarbons, reveals that the order of the HOMO electron density at Cα is in good agreement with the order of the emission rate (decomposition of the dioxetane) (**4d** > **4f** > **4c** > **4a** > **4e**) except for **4b**, which decomposes more rapidly than the expectation by the calculation.[18] The calculation accounts also for

Table 1 F^--Induced chemiluminescence of 3,3-diisopropyl-4-methoxy-4-(2-naphthyl)-1,2-dioxetanes (4)[a]

Dioxetane		λ_{max} / nm	Φ_{CL}[b]	$t_{1/2}$ / s	k / s^{-1}	HOMO electron density at Cα[c]
4a		460	2.7×10^{-4}	7.3	0.095	0.023
4b		496	5.2×10^{-2}	0.08	8.7	0.046
4c		569	7.4×10^{-3}	4.8	0.14	0.034
4d		470[d]	3.2×10^{-6}	0.15	4.6	0.186
4e		558	5.6×10^{-2}	250	0.0028	0.014
4f		560	3.7×10^{-4}	0.24	2.9	0.126

a) Measured at 25 °C. Unless otherwise stated, a solution of a dioxetane (4) in DMSO (1.0×10^{-5} mol dm^{-3}, 1 ml) was added to a TBAF solution in DMSO (1.0×10^{-2} mol dm^{-3}, 2 ml). b) Relative quantum yield based on the value for 1a (ref. 2): λ_{max} = 470 (465) nm, Φ_{CL} = 0.25, $t_{1/2}$ = 5 (5) s; values in parentheses were obtained in the present work.
c) HMO calculation on naphthoxide anions using parameters cited in ref.17. d) A dioxetane (4d) (1.0×10^{-3} mol dm^{-3}, 1 ml) and TBAF (1.0×10^{-1} mol dm^{-3}, 2 ml) were used.

the fact that half-lives for **4a** and **4b** are reversed from the viewpoint of the '*odd*/*even*' relationship.

References and Notes

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6. Schuster, G. B. *Acc. Chem. Res.* **1979**, *12*, 366 - 373. See also Catalani, L. H.; Wilson, T. *J. Amer. Chem. Soc.* **1989**, *111*, 2633 - 2639.
7. Bronstein and her co-workers[8] have called the substitution pattern of a naphthyl of **2a** '*odd*'; an '*odd*' pattern is one in which the donor's(O-) point of attachment to the acceptor (dioxetane ring or C=O of emitter formed by the decomposition of a naphthyldioxetane) is such that the total number of ring carbon atoms separating these points, including the atoms at the point of attachment, is an odd whole number. According to the above definition, *m*-phenoxide-substituted dioxetane (**1a**) is 'odd' patterned.
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9. Matsumoto, M.; Suganuma, H.; Azami, M.; Aoshima, N.; Mutoh, H. *Heterocycles* **1995**, *41*, 2419-2422.
10. McCapra, F. *Tetrahedron Lett.* **1993**, *34*, 6941-6944. See also ref. therein.
11. Edwards, B.; Sparks, A.; Voyta, J. C.; Strong, R.; Murphy, O.; Bronstein, I. *J. Org. Chem.* **1990**, *55*, 6225 - 6229.
12. It has very recently been found that, for thermally stable dioxetanes bearing a phenolic substituent, introduction of an alkoxymethyl at the *vicinal* position causes emission of flash-like intense light; Matsumoto, M.; Watanabe, N.; Kobayashi, H.; Suganuma, H.; Matsubara, J.; Kitano, Y.; Ikawa; H.*Tetrahedron Lett.* **1996**, *37*, 5939 - 5942.
13. All the dioxetanes synthesized here gave satisfactory spectral data and were stable enough to permit handling at room temperature and could be stored in a refrigerator without decomposition for > 1 y.
14. Matsumoto, M.; Watanabe, N.; Arai, N. *Tetrahedron Lett.* **1996**, in press. See also ref. 3.
15. Synthesis of a (1-siloxy-2-naphthyl)-substituted dioxetane could not be attained, unfortunately, because the McMurry coupling of methyl naphthalene-2-carboxylate bearing a 1-oxy-functionality such as methoxyl with diisopropyl ketone afforded an ethylene bearing an unsubstituted 2-naphthyl and only a trace amount of the corresponding ethylene.
16. McCapra has described briefly on explanation for the difference in half-life of emission between dioxetanes such as **1a** and **1b** in ref. 10.
17. The parameters cited in the following report were used; Klemm, L. H.; Shamtai, J.; Taylor, D. R. *J. Org. Chem.* **1968**, *33*, 1480 - 1488.
18. The HOMO electron density at the adjacent carbons of Cα may also participate for the charge transfer.

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