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THE 1,4-CYCLOADDITION OF SINGLET OXYGEN TO 2-VINYLTHIOPHENES

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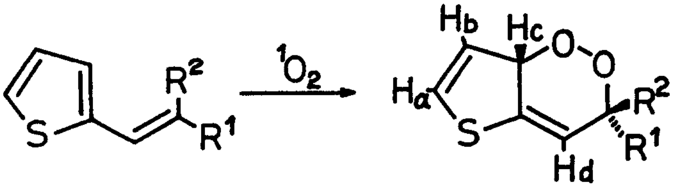
Thiophenes and naphthalenes with electron-donating substituents undergo a sensitized photooxygenation, though an unsubstituted thiophene or naphthalene is inactive.[1] On the other hand, we have recently found that, for 1-vinylnaphthalenes, an aromatic double bond in conjugation with extranuclear unsaturation produces an active diene system capable of undergoing the 1,4-cycloaddition of singlet oxygen ($^1O_2$).[2] These facts prompted us to investigate the sensitized photooxygenation of 2-vinylthiophenes.

The stereospecific 1,4-cycloaddition of $^1O_2$ to 2-vinylthiophenes occurred on the β-carbon of the vinyl and the 3-position of the thiophene nucleus to give thermally stable 1,4-endoperoxides

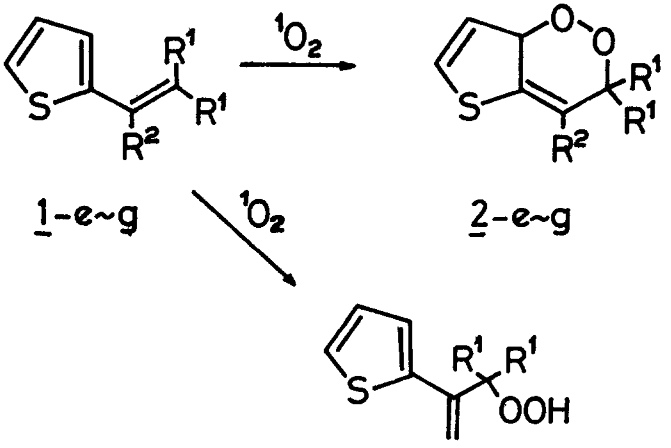
A solution of 1 00 g of 2-(2-methyl-1-propenyl)thiophene (1-a) and 5 mg of tetraphenylporphine in 70 ml of carbon tetrachloride was irradiated externally with eight 60-W low-pressure sodium vapor lamps (National SOI-60) under an oxygen atmosphere until an equimolar amount of oxygen was taken up (ca 30 min.) After irradiation, the photolysate was condensed under reduced pressure and chromatographed on alumina (Woelm neutral) previously treated with 20% water. Subsequent elution with n-hexane afforded a 1,4-endoperoxide, 2-a, as colorless oil in 75% yield.[3] The NMR spectrum (in $CDCl_3$) of 2-a displayed two singlets, at 1.21 (3H, axial $CH_3 = R^2$) and 1.42 (3H, equatorial $CH_3 = R^1$), and four multiplets, centered at δ5.52 (1H, H_d), 5 58 (1H, H_b), 5.84 (1H, H_c), and 6.37 (1H, H_a) ppm: their coupling constants were as follows; J_{ab}= 6.5, J_{ac}= 2.5, J_{bc}= 2 5, J_{bd}= 0.8, and J_{cd}= 3 0 Hz. The other physical properties of 2-a were as follows: ir (liquid film) 3030, 2945, 1643, 1052, 989, 890, and 853 cm^{-1}, m/e 170 (M^+, 9), 138 (22), 127 (16), 58 (24), 45 (33), and 43 (100). Anal ($C_8H_{10}O_2S$) C 56.56, H 6.04, S 19.03.

Similarly, 2-vinyl- (1-b), trans-2-(1-propenyl)- (1-c), and trans-2-styrylthiophene (1-d) were irradiated. The thiophene 1-b gave the corresponding 1,4-endoperoxide 2-b,[4] which was a distillable liquid at 40°/0.3 mm, in 10% yield. The olefin 1-c afforded only one of the two possible stereoisomers, it was assigned to be 2-c (oil, 51%) by the analysis of its NMR spectrum.[5] The olefin 1-d was also converted stereospecifically to the corresponding peroxide, 2-d (colorless needles from methanol; mp 83°) in 72% yield.



1-a~d 2-a~d

a: R^1, R^2 = CH_3
b: R^1, R^2 = H
c: R^1 = CH_3, R^2 = H
d: R^1 = C_6H_5, R^2 = H



1-e~g 2-e~g

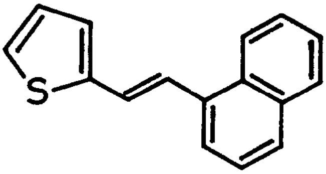
e: R^1 = H, R^2 = CH_3
f: R^1, R^2 = CH_3
g: R^1 = H, R^2 = C_6H_5

3-e,f

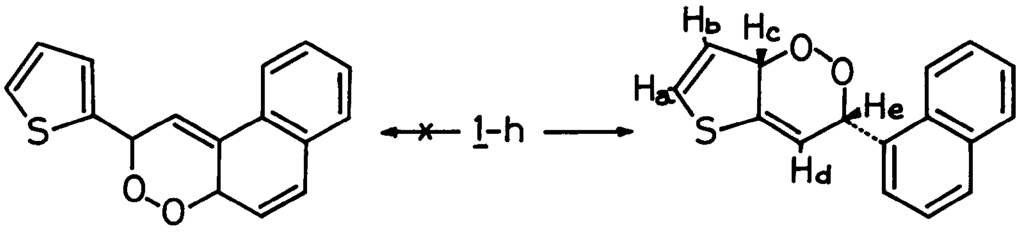
When 2-isopropenylthiophene (1-e) was similarly photooxygenated, the corresponding 1,4-endoperoxide, 2-e, was obtained as a colorless oil (27%), together with an allylic hydroperoxide, 3-e (10%). The sensitized photooxygenation of 2-(1,2-dimethyl-1-propenyl)thiophene (1-f) also gave a mixture of 1,4-endoperoxide, 2-f (25%), and hydroperoxide, 3-f (28%). Furthermore, 2-(1-phenylvinyl)thiophene (1-g) was photooxygenated to afford an endoperoxide, 2-g, as colorless plates (from n-hexane, mp 72°) in 15% yield.

These results were significantly different from those for the naphthalene analogs; an α-substituent on the side chain of the vinylnaphthalenes completely inhibits the 1,4-cycloaddition of $^1O_2$ to the aromatics. These differences may be due to steric and electronic factors. For 1-vinylnaphthalenes with an α-substituent on the side chain, a steric repulsion between the peri-hydrogen and the α-substituent may hinder the favorable conformation of the side chain for 1,4-cycloaddition. On the other hand, in the cases of 2-vinylthiophenes, such steric repulsion need not be considered and the carbons in both the β-position of the side chain and the 3-position of the thiophene nucleus may be activated toward electrophiles such as $^1O_2$, more than the corresponding carbons in the naphthalene analogs, by the sulfur atom.

In order to confirm the electronic factor in these reactions, the sensitized photooxygenation of trans-1-(1-naphthyl)-2-(2-thienyl)ethylene (1-h)[6] was finally attempted. Careful analysis of the NMR spectrum[7] revealed that the product obtained as colorless plates (from ether, mp 117 - 118°) in 77% yield, was not the endoperoxide 4 but the peroxide 2-h. The result clearly demonstrates that the electron-donating effect of sulfur atom in thiophene ring preferentially favors the 1,4-cycloaddition of $^1O_2$ onto the 3-position of thiophene ring and the corresponding β-carbon in the ethylene unit.



1-h



4 2-h

References and Notes

1. For a review, see R. W. Denny and A. Nickon, "Organic Reactions," Vol. 20, John Wiley & Sons, New York, N. Y., 1973, p 133.
2. M. Matsumoto and K. Kondo, Tetrahedron Letters, in press.
3. All the yields were based on the consumed oxygen.
4. In the NMR spectra of the peroxides, 2, the peaks of the methyl attached to the carbon adjacent to the oxygen atom were at 1.21 and 1.42 for 2-a, at 1.47 for 2-c, and 1.21 and 1.45 ppm for 2-f. On the other hand, in the cases of the endoperoxides of 1-vinylnaphthalenes, the corresponding axial methyl peak and the equatorial one were at 1.21 - 1.25 and 1.51 ppm respectively.[2] From these facts, 2-c was assigned to have an equatorial methy.
5. All the endoperoxides obtained in this work gave satisfactory analytical data.
6. In addition reaction of $^1O_2$ to 1-h to afford 4, the steric factor might be scarecely important, since the sensitized photooxygenation of trans-1-(2-arylvinyl)naphthalene such as trans-1-styrylnaphthalene affords the corresponding endoperoxide in good yield.[2]
7. The NMR spectrum (in $CDCl_3$) of 2-h displayed six multiplets centered at δ 5.59 (1H, H_b), 5.94 (1H, H_d), 6.16 (1H, H_c), 6.26 (1H, H_e), 6.40 (1H, H_a), and 7.5 (7H, aromatic) ppm: their coupling constants were as follows; J_{ab}= 6.5, J_{ac}= 2.3, J_{bc}= 2.5, J_{bd}= 0.8, J_{cd}= 3.0, J_{ce}= 3.0, and J_{de}= 3.0 Hz.