

行政院國家科學委員會專題研究計畫 成果報告

含鹵素苯乙烯雜環及第三胺之光轉位反應

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含鹵素苯乙烯雜環及第三胺之光轉位反應

Photorearrangement of Halostyrylfuran and Tertiary Amines

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中文摘要

研究一系列的含鹵素苯乙烯及雜環化合物之光酸催化之反應時發現了一種新的光環化反應產物-4,7 二氫菲化合物(2), 此種化合物是經由一種新的[1,3]氫轉位反應所得來, 另外又發現一種新的鹵化丁二烯之水解反應(5→3)可以得到化合物 3(一種丁烯酮之化合物)。此種化合物是經由一種新雜環的鹵化丁二烯(化合物 5)之水解反應而來。產物之相對產率與鹵素之種類有關。另外把化合物 5 經過照光反應可以生成化合物 2。當鹵素由氟改變為氯及溴時, 產物 4 之產量增加, 而產物 3 之產率則降低。兩種苯乙烯雜環化合物

(thiophene and furan)具有類似之光化學反應。至於二苯烷基胺之光化學反應發現當二苯胺其中之苯基若具有立體阻礙性之鄰位甲基時則會防止[1,3]氫轉位而使得化合物進行開環反應而產生新的光化學產物-2 丁二烯酮 indole 化合物。

關鍵詞：鹵化二苯乙烯, 光轉位反應, [1,3]氫轉移, [1,5]氫轉移。

Abstract

To study the proton acid assisted photorearrangements of a series of halogen substituted styrylfurans (**1a-1d**) and styrylthiophenes (**1e-1f**). Due to the

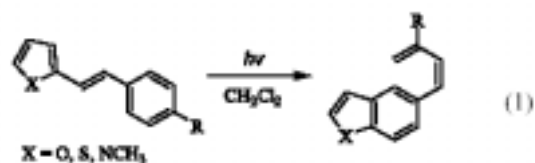
competing formal [1,3]hydrogen shift and ring opening of dihydrophenanthrene intermediate **7**, a new product **2** and a new hydrolysis product **3** are observed. The product ratio is dependent on the halogen substituents. It is also shown that photolysis of **5** can reversibly transferred back to **2**. Halogen substituent effects indicate that yields of products **4** increase while product **3** decrease from fluorine to bromine. The bromine derivative **1c** gives highest yield for product **4**. Finally it is also found that similar behavior between the styrylthiophenes and styrylfurans is observed in terms of their photoresponse both to the acids and to the halogen substituent effects. The study of diphenylmethylaniline photoreactions, it is observed that when there is one or two methyl groups located at one of the phenyl ring will prevent the acid-catalyzed formal [1,3]hydrogen shift thus open up a new product.

Keywords: halostyrylheterocycles, [1,3]hydrogen shift, [1,5]hydrogen shift.

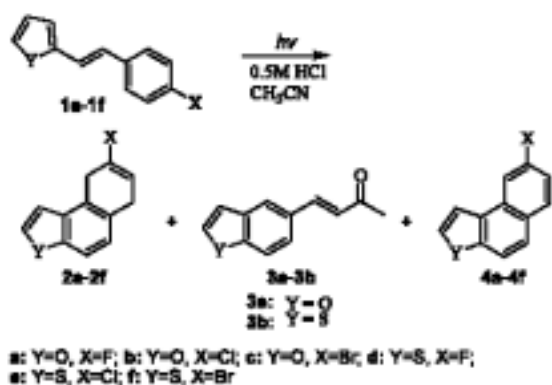
Results

The photorearrangement of stilbenes can be changed completely by acid-catalyzed hydrolysis of the reactive intermediates. The competition between the two reaction pathways can be controlled by adjusting the concentration of hydrochloric acid. In this work, we report the substituent dependent photo-chemical reaction of

4'-halostyrylfurans **1a–c** and 4'-halostyrylthiophenes **1d–f**.



An N₂-deoxygenated acetonitrile solution containing 5×10^{-3} M 4'-fluorostyrylfuran **1a** and 0.5 M hydrochloric acid was irradiated with a Rayonet apparatus at 350nm for 3.5 h. After the acid was neutralized and the solvent was evaporated, two products, 8-fluoro-6,9-dihydronaphtho[2,1-b]furan **2a** (17% yield) and (E)-4-(oxinden-5-yl)but-3-en-2-one **3** (83% yield) were isolated. The new compound **2a**¹ shows ¹H NMR at δ 3.64–3.57 (m; Ar-CH₂-CH=CF), 3.73–3.68 (m; Ar-CH₂-CF) and 5.48 (dm, $J_{H-F}=16.9$ Hz; Ar-CH₂-CH=CF), and shows ¹³C NMR at δ 156.4 (d, $J_{C-F}^1=248.9$ Hz, C-F) similar to the spectral data reported for 1,4-dihydrophenanthrenes.² The photoreactions of the other 4'-halostyrylheterocycles **1b–f** were also studied (Scheme 1), phenanthrene type products **4** being formed in addition to products of type **2** and **3**. The conversions and yields of the photoreactions are listed in Table 1.



Scheme 1.

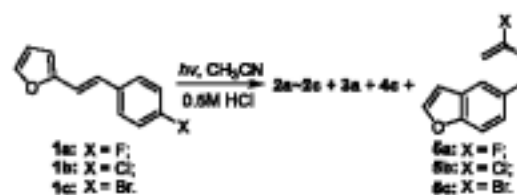
When the irradiation time is shortened, the intermediates **5a–c** could be isolated and were stable in neutral solution (Scheme 2). Some intermediates (*cis*-**5a** and *trans*-**5b**) have been reported³ as stable products in neutral conditions (Eq. (1)). The product distribution and yields for shorter irradiation time are listed in Table 2. The product distribution for the photoreaction of **1a** is similar to that in Table 1. For the photolysis of **1b** at short times (Table 2), the yields of **4b** and **5b** are 0 and 30%, respectively. Product **5b** can be converted into **3a** and **4b** if the irradiation time is increased. For the photoreaction of **1c**, prolonged photolysis converts **5c** exclusively to **2c** and **3a**. Thus, the reaction pathway is dependent upon the halogen substituent. Based on these results, the mechanism shown in Scheme 3 is proposed to explain the formation of products.

The mechanism involves the irradiation of the *trans*-4'-halostyryl heterocycles to produce *cis*-**1**, then the dihydrophenanthrene intermediate **6** is formed via photocyclization.

An acid-catalyzed formal [1,9] hydrogen shift from carbon 9b to 9 of intermediate **6**

Table 1. Conversions and yields for photoreactions of **1a–f** in the presence of 0.5 M hydrochloric acid

Reactants	<i>hν</i> time (h)	Conversion	Yields (%)		
			2	3	4
1a	3.5	92	17	83	0
1b	18	100	55	25	19
1c	24	100	49	11	40
1d	21	78	12	75	13
1e	48	87	56	14	24
1f	48	90	36	11	54



Scheme 2.

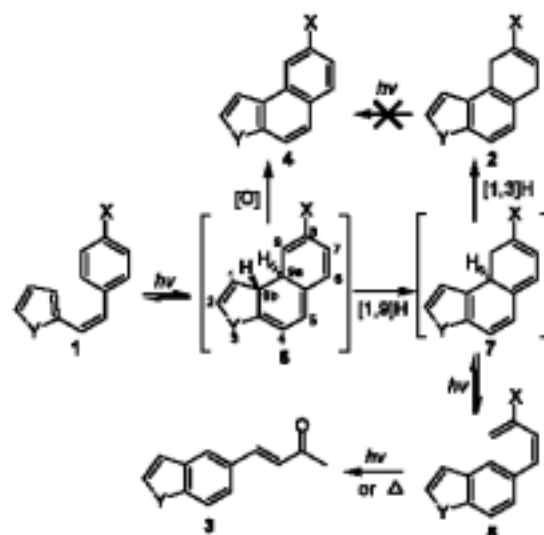
Table 2. Conversions and yields for photoreactions of **1a–c** in the presence of 0.5 M hydrochloric acid during shorter irradiation time

Reactants	<i>hν</i> time (h)	Conv.	Yields (%)			
			2	3	4	5
1a	1	77	14	79	0	<5
1b	3.5	61	53	14	0	30 ^a
1c	3.5	92	34	7	42	17

^a The product is *cis/trans* (4:1) mixture.

produces intermediate **7**. In accord with this proposal, PM3 calculations indicate that carbon 9 of **6** possess a partial negative charge. For the intermediate **7**, there are two competing reaction pathways. One is the acidcatalyzed formal [1,3] hydrogen shift that can occur to give compound **2**. The other is the ring-opening reaction to produce **5**. After hydrolysis of haloalkenyl group of **5**, the reaction leads to the formation of product **3**. The acid-catalyzed [1,9] hydrogen shift is a 10 electrons process it is probably a thermal process. The [1,3] hydrogen shift is four electron process and could be a photochemical allowed. Detailed experimental supported is further needed.

Even with the presence of a heavy bromine element in compound **1b**, the reaction is still a singlet state reaction. It is not sensitized by triplet sensitizer and the reaction is not quenched by suitable triplet quencher (e.g. piperylene). The dihydrophenanthrene intermediate **6** of *p*-bromostilbene is reported to come directly from the singlet *cis*-stilbene by Saltiel.⁴ This is inconsistent with our system that the reaction is in the singlet manifold.



Scheme 3.

Irradiation of 8-chloro-6,9-dihydronaphtho[2,1-*b*]furan **2b** in 0.5 M hydrochloric acid/acetonitrile solution shows no photoreaction. Thus, the formation of oxidative photocyclization products **4** may come directly from the redox reaction of the intermediate **6** and hydrochloric acid. This result is similar to the photoreaction of the stilbene and hydrochloride in dichloromethane.⁵ Because the formation of cyclized products will compete with the acid-catalyzed formal [1,9] hydrogen shift, the yields of photocyclization products increased as the rate of hydrogen shift decreased. For the fluoro substituent, the carbon 9 of intermediate **6** bears higher partial negative charge (-0.30) than chloro (-0.16) and bromo (0.04) substituents. The reaction rate of [1,9] hydrogen shift for **1a** might be faster than the oxidative photocyclization reaction can not compete with it, so there is no cyclized product **4** in this case.

The product distributions between products **2** and **3** are also dependent on the substituents. Because the ringopening step is photoreversible,⁶ the formation rate of (*E*)-4-arylbut-3-en-2-one **3** will be effected by the acidcatalyzed hydrolysis of haloalkenyl group of **5**. For further illustration, intermediate *cis*-**5b** was isolated and irradiated in different acid concentrations. Photolysis of *cis*-**5b** with 0.5 M hydrochloric acid give both products **2b** and **3**, but it only gives product **2b** in 0.005 M hydrochloric acid with the same irradiation period. Compared to the reported case of 2-halopropenes,⁷ the hydrolysis rate for 2-fluoropropene is 860 times greater than that of 2-bromopropene. Since the hydrolysis rate is accelerated by the fluorine atom, intermediate **5a** must be hydrated rapidly to product **3a**. Thus the yield of product **3a** from irradiation of **1a** is higher than that of the other cases (**1b** and **1c**). The conversion

of **5** to **3** can either be photochemical or thermal depending on the halogen substituents.

In summary, we have demonstrated that new rearrangement is possible for the halogen substituted styrylheterocycles when photolysis is carried out in the presence of a protic acid. Due to the competing formal [1,3]hydrogen shift and ring opening of dihydrophenanthrene intermediate **7**, a new product **2** and a new hydrolysis product **3** are observed. The product ratio is dependent on the halogen substituents. It is also shown that photolysis of **5** can reversibly be transferred back to **2**. Halogen substituent effects indicate that yields of products **4** increase while products **3** decrease from fluorine to bromine. The bromine derivative **1c** gives highest yield for product **4**. Finally, it is interesting to note that similar behavior between the styrylthiophenes and styrylfurans is observed in terms of their photoresponse both to the acids and to the halogen substituent effects.

References

1. The spectral data for compound **2a**: ^1H NMR (300 MHz, CDCl_3): δ 7.64 (d, $J=2.2$ Hz, 1H), 7.36 (d, $J=8.6$ Hz, 1H), 7.09 (d, $J=8.6$ Hz, 1H), 6.73 (d, $J=2.2$ Hz, 1H), 5.52–5.44 (dm, $J=16.9$ Hz, 1H), 3.73–3.68 (m, 2H), 3.64–3.57 (m, 2H). ^{13}C NMR (75 MHz, CDCl_3): δ 156.4 (d, $J^1_{\text{C-F}}=248.9$ Hz), 153.1, 145.0, 126.5, 126.2 (d, $J^3_{\text{C-F}}=3.2$ Hz), 124.8, 124.7, 109.8, 104.6, 100.1 (d, $J^2_{\text{C-F}}=16.3$ Hz), 28.8 (d, $J^3_{\text{C-F}}=8.0$ Hz), 27.8 (d, $J^2_{\text{C-F}}=27.9$ Hz). MS (70 eV, EI): 188 (M^+ , 100), 186 (55), 168 (16), 159 (88), 157 (35). HRMS ($\text{C}_{12}\text{H}_9\text{FO}$): calcd 188.0637, found 188.0633.
2. Buquet, A.; Couture, A.; Lablache-Combier, A. *J. Org. Chem.* **1979**, *44*, 2300.
3. Ho, T.-I.; Wu, J.-Y.; Wang, S.-L. *Angew. Chem., Int. Ed.* **1999**, *38*, 2558.
4. Saltiel, J.; Chang, D. W.-L.; Megarity, E. *J. Am. Chem. Soc.* **1974**, *96*, 6521.
5. Kaupp, G.; Ringer, E. *Chem. Ber.* **1986**, *119*, 1525.
6. In thermal reaction of intermediate *cis*-**5b** in 0.5 M hydrochloric acid/acetonitrile solution at ca. 60°C for 3 h, only hydrolysis reaction occurs to give the product **3a**.
7. Allen, A. D.; Tidwell, T. T. *J. Am. Chem. Soc.* **1982**, *104*, 3145.