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Base-induced photorearrangements from 3-styrylfurans to 2-methylnaphthalenes

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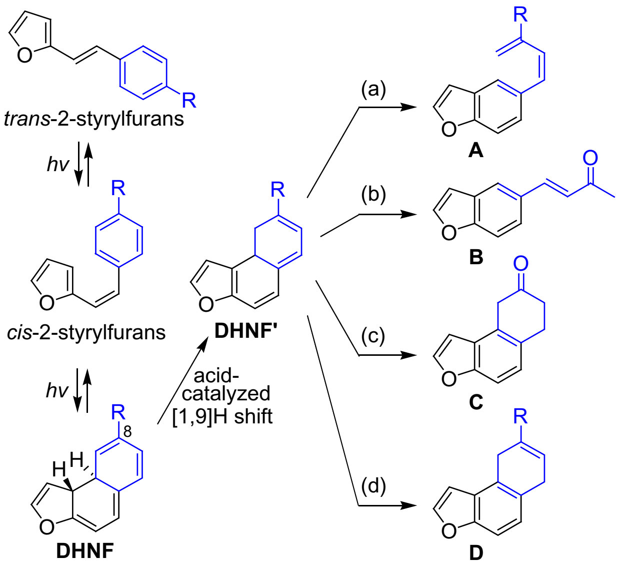
ABSTRACT

Irradiation of 3-(4-substituted styryl)furans in basic media yielded a series of 7-substituted-2-methylnaphthalenes, including methoxy, isopropyl, ethyl, methyl, fluoro, and cyano substituents. This base-induced photorearrangement involves *cis–trans* photoisomerization, 6e photocyclization, base-induced elimination, and a Norrish Type I photoreaction and is a novel method to synthesize unsymmetrical 2,7-disubstituted naphthalenes.

The reactive intermediates of the photocyclization of stilbenes, *trans*-4a,4b-dihydrophenanthrenes,[1] can undergo a variety of reactions, such as oxidative photocyclization,[2] eliminative photocyclization,[3] hydrogen shift reactions,[4] and rearrangement reactions.[5]

Styrylfurans are analogs of stilbene and also undergo numerous photoreactions.[6] 2-Styrylfurans can undergo the photocyclization to give *trans*-9a,9b-dihydronaphtho[2,1-*b*]furans **DHNF** intermediates (Scheme 1). These intermediates can not only react with iodine or oxygen to give naphtho[2,1-*b*]furans,[7] but can also undergo photorearrangement to give benzofurans[6e–g] with proper substituents on carbon 8 of **DHNF**. In Ho's studies of acid-catalyzed photorearrangements, acids promoted the acid-catalyzed [1,9]H shift to transform **DHNF** into **DHNF**′. Subsequently, **DHNF**′ could react to yield four different types of products depending on the substituents and solvent conditions used. These reactions involved the benzene ring (blue part) of **DHNF**′, including ring-opening reactions to give type **A** and **B** products, hydrolysis of the vinyl ether to give a type **C** product, or a [1,3]H shift to give a type **D** product.

Unlike 2-styrylfurans, 3-styrylfurans are much less studied. In our preliminary research, irradiation of 3-styrylfurans in acid media gave no photorearrangement products except for 3-(4-methoxystyryl)furan,[5a] but these reactions did yield a series of 2-methylnaphthalenes in basic media (Scheme 2). According to our expectations, the photocyclization intermediates of 3-styrylfurans, *trans*-9a,9b-dihydronaphtho[1,2-*b*]furans **DHNF**″, may undergo a base-induced elimination reaction to break the furan ring (red part) and to generate the naphthalene ring. Then, a deformylation occurred to give 2-methylnaphthalenes. Herein, we would like to report this base-induced photorearrangement of 3-styrylfurans.



(a) R = Alkyl, F, Cl in CH_2Cl_2 or R = Alkoxy in C_6H_6
(b) R = Alkoxy in CH_2Cl_2 or R = F in 0.5 M HCl/CH_3CN
(c) R = OCH_3 in 0.5 M HCl/CH_3CN
(d) R = F, Cl, Br in 0.5 M HCl/CH_3CN

Scheme 1. Overview of the acid-catalyzed photorearrangement of 2-styrylfurans.

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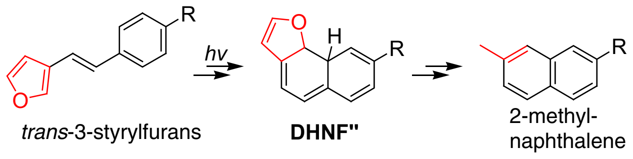
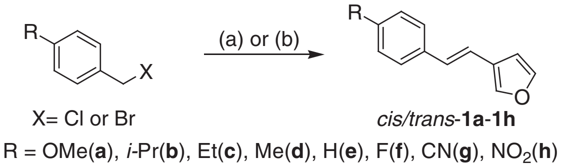


Scheme 2. Base-induced photorearrangement of *trans*-3-styrylfurans.



Scheme 3. Syntheses of 3-styrylfurans **1a**–**1h**. Reactions and conditions: (a) Wittig–Horner reaction: (1) $POEt_3$, (2) CH_3ONa, 3-fural; (b) Wittig reaction: (1) PPh_3, (2) K_2CO_3, 3-fural.

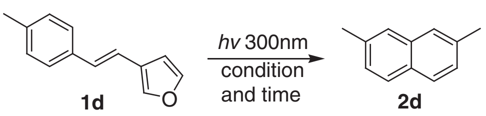
The reactants, 3-(4-substituted styryl)furans **1a**–**1h**, were synthesized from 4-substituted benzyl halides and 3-fural (Scheme 3) by the Wittig or Wittig–Horner reaction.[8] The general synthetic procedures are described in the Supplementary data.

The optimal irradiation conditions for 0.005 M 3-(4-methylstyryl)furan **1d** are shown in Table 1. First, neutral solvents, including methanol, acetonitrile, and benzene, were used (entries 1–3), and no rearrangement product **2d** was observed. When we used methanol/water (19:1) with 0.09 M KOH (entry 4), product **2d** was obtained in a 40% yield, and some minor methanol-addition products[9] were also found. To prevent this side reaction, a powder KOH/acetonitrile solvent was used instead of methanol, and product **2d** was obtained in a 41% yield (entry 5). Because of the poor solubility of KOH in acetonitrile, we replaced this base with DBU (1,8-diazabicyclo[5.4.0]undec-7-ene), and the yields of **2d** in DBU/acetonitrile solvent were low (~20%) (entries 6 and 7). These low yields may have been the result of the fact that acetonitrile is a good solvent for electron transfer reactions between stilbene-type compounds and amines.[10] The better electron transfer ability of acetonitrile has been reported in the literature.[11] Finally, we used benzene and DBU (entries 8–10), and we obtained product **2d** with acceptable yields, 56–58%.

The results of the irradiation of **1a**–**1h** in DBU/EtOH/benzene are shown in Table 2. Most reactants, **1a**–**1g**, could undergo the base-induced photorearrangement to give the corresponding 7-substituted-2-methylnaphthalenes **2a**–**2g** in 61–15% yields. Compared with the moderate yields of **1a**–**1e**, the yield of 3-(4-cyanostyryl)furan **1g** was low (15%). The electron transfer between DBU and **1g** may occur and result in an anion radical on **1g**, and this anion radical can be stabilized by the cyano group. Therefore, the photorearrangement of compound **1g** may be retarded. When we irradiated **1g** in CH_3OH/H_2O (19:1) with 0.09 M KOH, the yield of **2g** was 52%. This result indicates that DBU indeed affects the photorearrangement. Reactant **1h** with the nitro group gave no photorearrangement product, possibly because the nitro group retards the formation of the photocyclization intermediate **DHNF″**.[12]

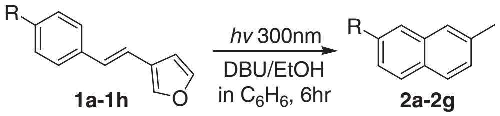
We have proposed a possible mechanism for this base-induced photorearrangement of 3-styrylfurans **1**, as shown in Scheme 4. *cis*-3-Styrylfurans **1** can undergo 6e photocyclization to the intermediate **DHNF″**, and then the elimination reaction occurs between carbons 9a and 9b of **DHNF″** to produce the intermediate **N1**. Subsequently, **N1** can transform into intermediate **N3** via protonation and tautomerization. Finally, a Norrish Type I photoreaction[13] occurs to give product **2**. To confirm the existence of intermediate **N3**, reactant **1d** was irradiated with sodium borohydride in KOH/methanol, and the reductive product **3d** was obtained in a 31% yield (Scheme 5).

Table 1
Photoreactions of 3-(4-methylstyryl)furan **1d** under different conditions



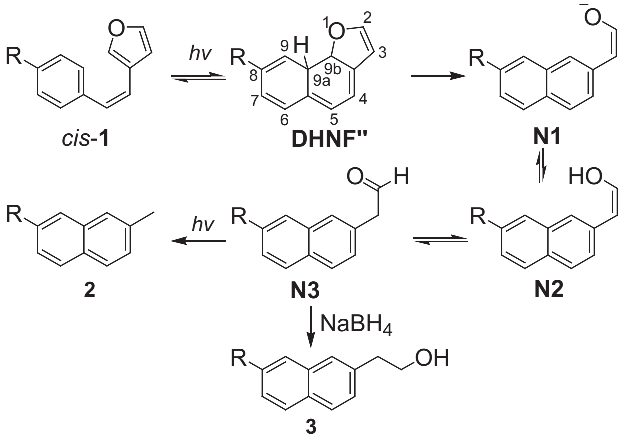
En.	Conditions	Time (h)	Conver. (%)	Yield (%)
1	CH_3OH	3	38	0
2	CH_3CN	3	2	0
3	C_6H_6	3	19	0
4	CH_3OH/H_2O (19:1) + 0.09 M KOH	3	93	40
5	CH_3CN/powder KOH	6	100	41
6	CH_3CN/0.023 M DBU	6	100	20
7	CH_3CN/0.13 M H_2O/0.023 M DBU	6	100	20
8	C_6H_6/0.023 M DBU	6	100	56
9	C_6H_6/0.02 M EtOH/0.023 M DBU	6	100	58
10	C_6H_6/C_2H_5OH (9:1) + 0.023 M DBU	6	100	20

Table 2
Photoreactions of 3-styrylfurans **1a**–**1h** in C_6H_6/0.02 M EtOH/0.023 M DBU

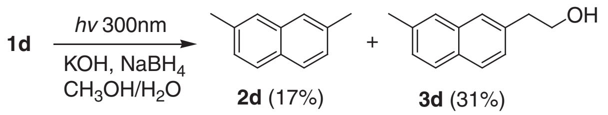


En.	React.	Substituent	Conver. (%)	Product.	Yield (%)
1	**1a**	OMe	100	**2a**	41
2	**1b**	*i*-Pr	100	**2b**	61
3	**1c**	Et	100	**2c**	46
4	**1d**	Me	100	**2d**	58
5	**1e**	H	100	**2e**	42
6	**1f**	F	100	**2f**	35
7	**1g**	CN	100	**2g**	15 (52)[a]
8	**1h**	NO_2	28	–	0

[a] Irradiation of **1g** in CH_3OH/H_2O (19:1) with 0.09 M KOH for 3 h resulted in a reaction with 76% conversion and 52% yield.



Scheme 4. Mechanism of the formation of 2-methylnaphthalene **2** and 2-naphth-2-yl-ethanol **3**.



Scheme 5. Reduction of the intermediate **N3** with $NaBH_4$.

In the elimination reaction of **DHNF″** that yields **N1**, the oxygen atom O1 on carbon 9b of **DHNF″** can be regarded as a leaving group. This concept, using the heteroatom of a heterocycle as a leaving group in the 6e photocyclization intermediate, has been shown in some cases, such as the photorearrangements of 3,3′-bis(arylbenzofurans),[14] 3-styryl-1,2,4-oxadiazoles,[15] and 3-furylalkene imine.[16] In some cases, phenolate has been reported to be a leaving group[14,17] during irradiation. It is a relatively weak base, and its conjugate acid has a pK_a value around 10. For the 3-styrylfurans, the enthenolate part of intermediate **N1** has a similar pK_a value of its conjugate acid.[18] Therefore, we believe that the enthenolate could be a leaving group in the elimination reaction. In addition, the aromatization of the naphthalene ring would also be a driving force for this elimination reaction.

To confirm the necessity of irradiation, a 6-hour thermal reaction of **1d** in DBU/benzene solution at 40 °C in the dark was completed. There was no photorearrangement product, and only 60% of the reactant would be recovered. This may be the reason that the yield of **2d** when using irradiation is limited to approximately 60%. Our attempts to further improve the yields by changing the solvent, base, wavelength, and temperature all failed. One possible explanation for this decomposition may be that 3-styrylfurans have a more acidic hydrogen on the furan ring,[19] which may lead to unexpected and complicated side reactions.

Many synthetic methods for the production of substituted naphthalenes have been developed.[20] Several 2,7-disubstituted naphthalenes have been synthesized successfully, for example, 2,7-dimethylnaphthalene,[21] 2-cyano-7-methylnaphthalene,[22] 2-methoxy-7-nitronaphthalene,[23] and 2-methoxy-7-methylnaphthalene.[24] Most methods involve elaborate synthetic routes and yield only specific unsymmetrical 2,7-disubstituted naphthalenes, and are not used for the production of a series of substituents. Some of those reaction conditions are harsh or environmentally unfriendly, such as the usage of strong reagents, very low temperatures, or transition metal catalysts. In some cases, two isomers are obtained. Compared with these methods, our approach has some merits: (1) it can synthesize a series of 7-substituted-2-methylnaphthalenes without yielding other isomers; (2) 3-styrylfurans can be prepared from symmetrical commercial chemicals; and (3) the reaction conditions, including those of the Wittig reactions and photorearrangements, are mild and environmentally friendly.

In summary, we have successfully synthesized a series of 7-substituted-2-methylnaphthalenes **2a**–**2g** by the irradiation of 3-(4-substituted styryl)furans **1a**–**1g** in basic media. This photorearrangement involves three major steps: 6e photocyclization, base-induced elimination, and a Norrish Type I photoreaction. The key step is the base-induced elimination reaction of the **DHNF″** intermediate, which breaks the furan ring to generate a naphthalene instead of a phenanthrenoid.

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Supplementary data

Supplementary data (experimental procedures for the syntheses and the irradiations of **1a**–**1h**, and spectral data and ^1H and ^{13}C NMR spectra of products **2a**–**2g** and **3d**) associated with this article can be found, in the online version, at doi:10.1016/j.tetlet.2011.10.141.

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