102. Photo-induced Molecular Transformations

Part 123[1])

One-Step Synthesis of 1*H*-Benz[*f*]indole-4,9-diones by a New Regioselective Photoaddition of 2-Amino-1,4-naphthoquinone with Various Alkenes and Its Application to One-Step Synthesis of Kinamycin Skeleton

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Dedicated to Prof. *Kurt Schaffner* on the occasion of his 60th birthday

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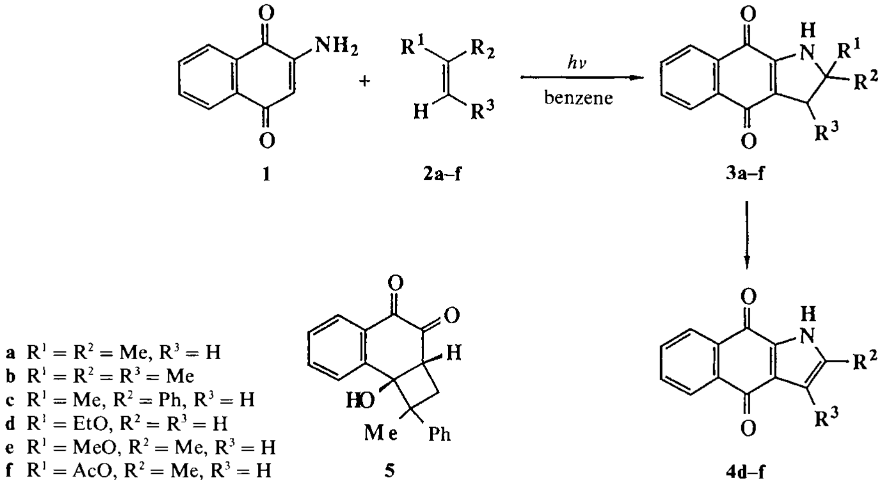
2,3-Dihydro-1*H*-benz[*f*]indole-4,9-diones are formed in one-step in 45–82% yields by an unprecedented [2+3]-type regioselective photoaddition of 2-amino-1,4-naphthoquinone with various electron-rich alkenes and the [2+3] adducts derived from aminonaphthoquinone with vinyl ethers and vinyl acetate to give 1*H*-benz[*f*]indole-4,9-diones including a benzindole-dione with a kinamycin skeleton in 33–72% yields. A probable pathway leading to the formation of the dihydroindole-dione involving air oxidation of an intermediary hydroquinone is proposed.

In [2], we have reported a one-step formation of 2,3-dihydronaphtho[2,3-*b*]furan-4,9-diones in high yields by a new [2+3]-type regioselective photoaddition of 2-hydroxy-1,4-

Scheme 1



a $R^1 = R^2 = Me, R^3 = H$
b $R^1 = R^2 = R^3 = Me$
c $R^1 = Me, R^2 = Ph, R^3 = H$
d $R^1 = EtO, R^2 = R^3 = H$
e $R^1 = MeO, R^2 = Me, R^3 = H$
f $R^1 = AcO, R^2 = Me, R^3 = H$

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[1]) Part 122: [1].

naphthoquinones with a variety of alkenes and its application to a two-step synthesis of natural quinone, maturinone.

Here, we wish to report on a new one-step synthesis of 2,3-dihydro-1*H*-benz[*f*]indole-4,9-diones and 1*H*-benz[*f*]indole-4,9-diones by a new [2+3]-type regioselective photoaddition of 2-amino-1,4-naphthoquinone (**1**) with a variety of cyclic and acyclic alkenes, as outlined in *Scheme 1*.

1*H*-Benz[*f*]indole-4,9-diones comprise an important group of heterocyclic quinones to which several physiologically active quinones, such as kinamycins [3], belong. Methods so far reported for the synthesis of this class of compounds, however, are not necessarily simple and require several reaction steps [4].

Typically, a solution of **1** [5] (85 mg, 0.49 mmol) and isobutene (**2a**; 0.55 g, 9.8 mmol) in benzene (70 ml) is irradiated through a *Pyrex*-filter with a 500-W high-pressure Hg arc in a N_2 atmosphere for 1 h at room temperature. The usual workup and purification by preparative TLC exclusively give 2,3-dihydro-2,2-dimethyl-1*H*-benz[*f*]indole-4,9-dione (**3a**; 91 mg, 82%).

The photoaddition of naphthoquinone **1** with other alkenes, such as 2-methylbut-2-ene (**2b**), and α-methylstyrene (**2c**), also took place regioselectively to give 2,3-dihydro-2,2,3-trimethyl-1*H*-benz[*f*]indole-4,9-dione (**3b**) and 2,3-dihydro-2-methyl-2-phenyl-1*H*-benz[*f*]indole-4,9-dione (**3c**), respectively. Photoaddition with **2c** resulted in an accompanying formation of the $2\pi+2\pi$ adduct **5** in 23% yield.

The photoaddition of naphthoquinone **1** with vinyl ethers and vinyl acetate, such as ethyl vinyl ether (**2d**), 2-methoxypropene **2e**, and vinyl acetate (**2f**), on the other hand, gave 1*H*-benz[*f*]indole-4,9-dione **4d–f**, respectively, [4b] in 33–72% total yields under the above-mentioned conditions and the reaction scale outlined in *Scheme 1*. The results are summarized in the *Table*.

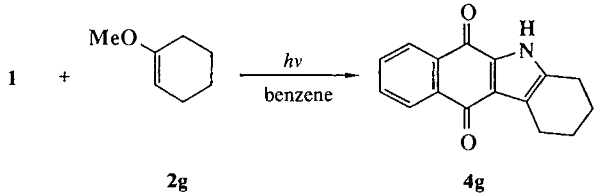
Table. *Results of Photoadditions of 2-Amino-1,4-naphthoquinone* (**1**) *with Alkenes*

Alkene[a])	Irradiation time [h]	Product[b])	M.p. [°C]	Yield[c]) [%]
2a	1	**3a**	200 (dec.)	82
2b	12	**3b**	205–207	66
2c	2	**3c**[d])	162–165	45
2d	1.5	**4d**	297–299	33
2e	3	**4e**[e])	300	72
2f	4.5	**4e**	(dec.)	47
2g	2.5	**4g**	290 (dec.)	68

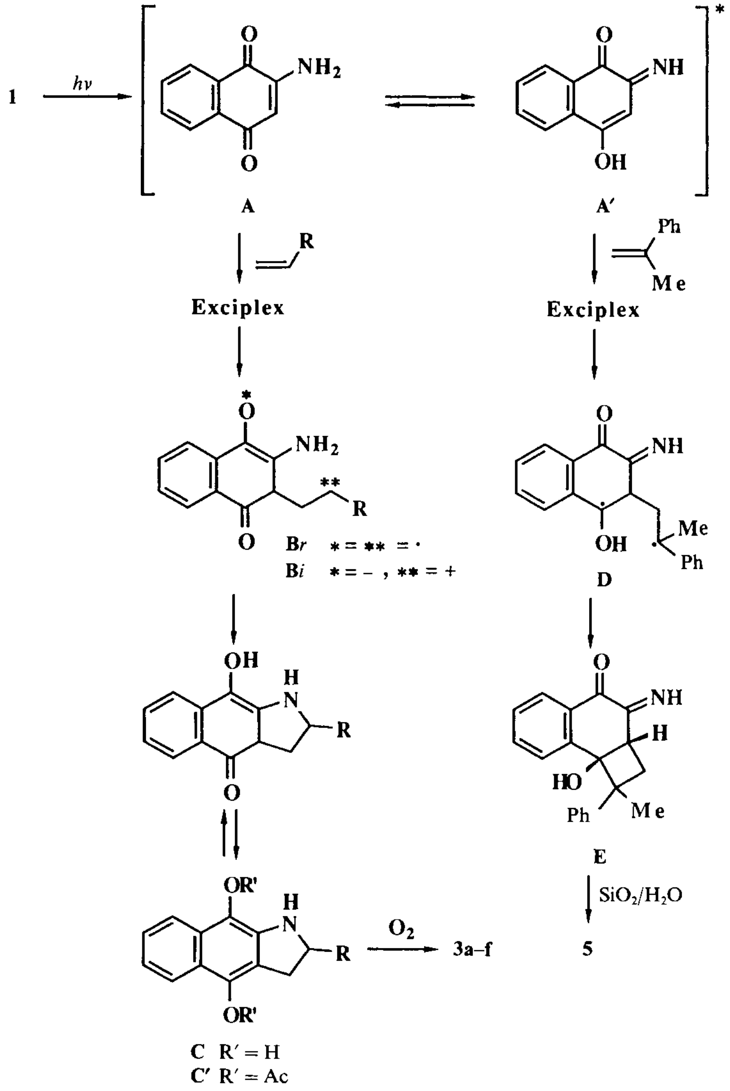
[a]) The molar ratio: alkene/2-amino-1,4-naphthoquinone 1:20.
[b]) Satisfactory analytical and spectral results were obtained for all the products.
[c]) Total yield.
[d]) $2\pi+2\pi$ adduct **5** (23%) is an accompanying product.
[e]) [3b]: 304–305 °C (dec.)

These benzindole-diones are formed by a spontaneous elimination of an alcohol or AcOH from the initial adducts, 2,3-dihydro-1*H*-benz[*f*]indole-4,9-diones **3d–f**, in the course of the reaction or separation by preparative TLC. A similar photoaddition of naphthoquinone **1** with 1-methoxycyclohexene (**2g**) gave 7,8,9,10-tetrahydrobenzo[*b*]carbazole-5,11-dione (**4g**), a framework of kinamycin [3], in one-step in 68% yield (*Scheme 2*).

Scheme 2



Scheme 3



No photoaddition took place with electron-deficient olefins, such as methyl methacrylate, or with *N*-substituted 2-aminonaphthoquinones, such as commercially available 2-(phenylamino)-1,4-naphthoquinone and 2-(benzylamino)-1,4-naphthoquinone [6].

The probable overall reaction path of the presented photoaddition leading to 2,3-dihydro-1*H*-benz[*f*]indole-4,9-diones is outlined in *Scheme 3*. The initial stage in this photochemical addition can be explained within the framework of an accepted model of $2\pi + 2\pi$ photochemical additions (for reviews, see [7]). Irradiation of naphthoquinone **1** in benzene may well generate tautomeric excited triplet **A** and **A′**. The excited tautomer **A** may then form preferentially an exciplex with alkene to give a biradical **B***r* or an ionic intermediate **B***i* generated by an electron transfer. It seems likely that the biradicals **B***r* have a appreciable polar character or are ionic intermediates such as **B***i*. The regioselectivity found in the present addition is a strong indication of the involvement of a more stabilized biradical or ionic intermediate, such as **B***r* and **B***i*, in the formation of 2,3-dihydro-1*H*-benz[*f*]indole-4,9-diones **3a–f**. An intramolecular cyclization of the intermediate gives a hydroquinone **C′** analogous to the formation of 2,3-dihydronaphtho[2,3-*b*]-furan-4,9-diones by the photoaddition of 2-hydroxy-1,4-naphthoquinones with various alkenes [2]. We were, however, not successful in isolating the corresponding diacetate **C′** by acetylating the hydroquinone corresponding to **3a** immediately after the photoadditions. 2,3-Dihydro-1*H*-benz[*f*]indole-4,9-diones **3a–f** are formed by rapid air oxidation of the hydroquinone during the workup, since we found that a yellow-colored hydroquinone corresponding to **3a**, prepared by a reduction of quinone **3a** by catalytic hydrogenation with Pd/C as a catalyst, turned rapidly into a purple-colored quinone **3a** as soon as hydroquinone was exposed to air. A by-product **5** may be formed by a $2\pi + 2\pi$ addition from an excited enol form **A′** through intermediate **D** and **E**, followed by hydrolysis of the resulting imino-ketone **E**.

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