Polyquinane Synthesis

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One-Step Synthesis of Benzotetra- and Benzopentacyclic Compounds through Intramolecular [2+3] Photocycloaddition of Alkenes to Naphthalene**

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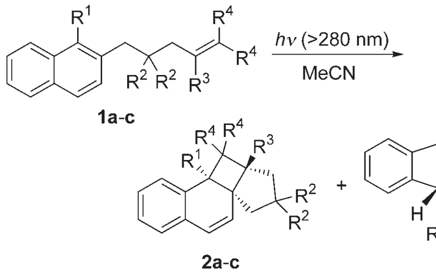
Photocycloaddition of unsaturated compounds to aromatic rings is a useful and convenient method for the construction of polycyclic compounds in organic synthesis.[1–7] In particular, the inter- and intramolecular metaphotocycloaddition of alkenes to benzene rings has been extensively developed from the synthetic and mechanistic points of view in recent decades.[1,2] Wender et al. first reported the synthesis of natural products by using an intramolecular *meta*-photocycloaddition as a key step.[2] However, little is known about the [2+3] photocycloaddition of alkenes to naphthalene at the 1,3-positions, except the relatively inefficient intermolecular photocycloaddition of cyclooctene to naphthalene.[6] We now report a novel intramolecular [2+3] photocycloaddition of 1-cyano-2-(4-pentenyl)naphthalene derivatives to give benzotetra- and benzopentacyclic compounds with tri- and tetraquinane skeletons in a highly selective manner.[7,8]

Irradiation of an acetonitrile solution containing **1a** (0.03 M) with a high-pressure mercury lamp through a Pyrex filter (> 280 nm) and under an argon atmosphere exclusively gave a benzotetracyclic product (**3a**) in 70% yield (Scheme 1). The ^{1}H NMR spectrum of **3a** showed four aromatic and nine aliphatic protons, but no olefinic protons; the ^{13}C NMR spectrum showed nine nonequivalent unsaturated carbon signals in the $\delta = 100$–150 ppm region and nine nonequivalent aliphatic carbon signals. The IR, UV, and mass spectra clearly showed the existence of a cyano group, the lack of a styrene chromophore, and the identical molecular weight to **1a**, respectively. Since these data are not sufficient to establish the structure of **3a**, the structure was determined by X-ray crystallography analysis. Similar irradiation of **1b** and **1c** afforded the corresponding products **3b** and **3c** in good yields (Table 1).



	R1	R2	R3	R4
1a-3a	CN	CN	H	H
1b-3b	CN	CN	H	Me
1c-3c	CN	CO$_2$Me	Me	Me

Scheme 1. Intramolecular photocycloadditions of **1a–c**.

In the initial stages (less than 20% conversion) of these photoreactions, intramolecular [2+2] photocycloadducts **2a–c**, formed by reaction at the 1,2-positions, were obtained as the major products. For example, the rate for the formation of **2b** is 10 times faster than that for **3b**. However, prolonged irradiation afforded **3b** as the sole product in a highly

Table 1: Intramolecular photocycloadditions of **1a–c**, **4a,b**, and **6a–e** in acetonitrile.

Compound	t[a] [h]	Yield of 1,2-adduct[b] [%]	Yield of 2,4-adduct[b] [%]
1a	20	0	70
1b	10	0	74
1b[c]	3	10	41
1c	160	0	64
4a	25	0	74
4b	10	0	85
6a	40	0	84
6b	40	0	60
6c[c]	20	39	52
6d[c]	100	trace	33
6e	160	6[d]	18[d]

[a] Irradiation time. [b] Yields of isolated products. [c] Reaction performed in benzene. [d] Yields were determined by GC analysis.

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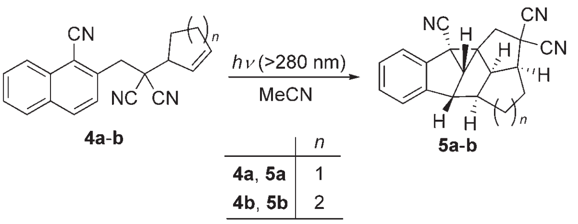
regioselective manner. Irradiation of isolated **2b** quickly gave **1b**; clearly, the [2+2] cycloaddition in this system is reversible. Therefore, the selective formation of **3a**–**c** can be reasonably explained by efficient cycloreversion of **2a**–**c** to **1a**–**c** and gradual accumulation of **3a**–**c**.

This photoreaction was applied to the synthesis of benzopentacyclic compounds **5a**,**b** from **4a**,**b** (Scheme 2). Irradiation of **4a**,**b** in acetonitrile gave exclusively **5a**,**b** in good yields (Table 1). The structures of **5a**,**b** were confirmed by X-ray crystallography analyses (Figure 1).[9]



	n
4a, **5a**	1
4b, **5b**	2

Scheme 2. Intramolecular photocycloadditions of **4a**, **b**.

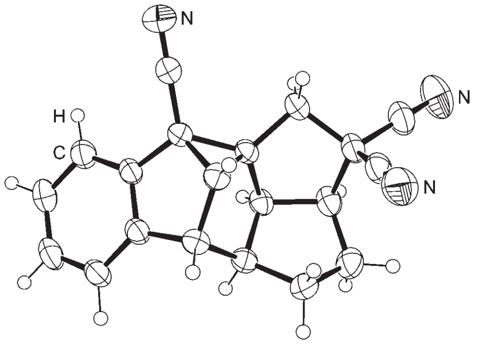
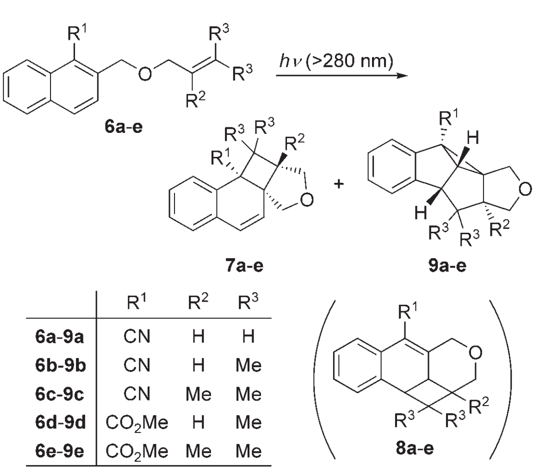


Figure 1. ORTEP drawing of **5a**.

The related intramolecular photocycloaddition of **6c** was reported by McCullough et al. to give two types of [2+2] photocycloadducts, **7c** and **8c**, with **7c** as the major product (Scheme 3).[4] We had previously studied the related reactions of **6a**–**e** and obtained products to which we originally assigned structures **7a**–**e** and **8a**–**e**, by analogy with the assignment of McCullough et al.[5] We have found recently that the product ratios of both product types in the photoreactions of **6a**–**e** are dependent on additives and solvents. In addition, the major products **7a**–**e** gradually reverted to the starting compounds **6a**–**e**, but the minor products were stable under the reaction conditions.

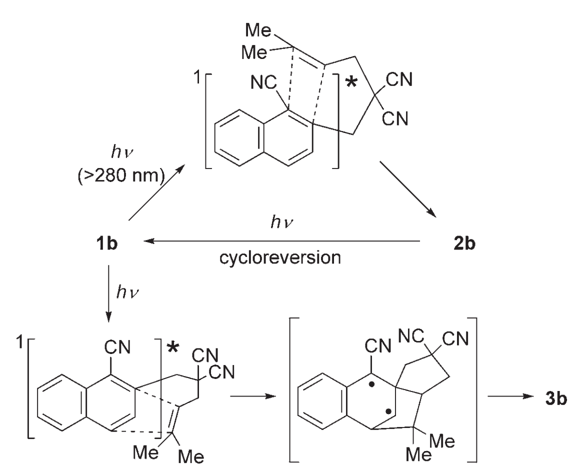
Based on our finding that [2+3] cycloadducts were formed from **1a**–**c**, we reinvestigated the structures of the cycloadducts that had been assigned structures of type **8**. The X-ray crystallography analyses of these adducts showed unambiguously that the second type of adduct has the benzotetracyclic structure of type **9** (Table 1). All spectral properties of these adducts support the newly assigned structure type.

The formation of the benzotetracyclic compound **3b** was not sensitized by triplet sensitizers, such as benzophenone and Michler's ketone, and was not quenched by 2-methyl-1,3-butadiene. The monomer fluorescence typically observed for 1-cyanonaphthalene chromophores such as **1b** was replaced by a weak exciplex emission at longer wavelengths than that of the monomer emission, a result indicating intramolecular quenching by the alkenyl group. Based on these results, we propose an exciplex mechanism for the formation of the benzotetra- and benzopentacyclic compounds by intramolecular [2+3] photocycloaddition of **1**, **4**, and **6**, in competition with the formation of intramolecular [2+2] photocycloadducts (Scheme 4). Both cycloadducts seem to be controlled by Hirayama's $n=3$ rule.[10] The position of the cyano or ester group on the naphthalene skeleton seems to be important for the excellent regioselectivity.[11] In general, the nature of an exciplex is represented by both charge-transfer and exciton resonance forms. In the series of photoreactions reported here, an intramolecular charge-transfer interaction between naphthalene derivatives bearing electron-withdrawing groups and electron-donating alkenes in their excited singlet states is quite important for [2+3] photocycloaddition; however, polar intermediates are not observed at this stage.[12] In fact, the photoreaction of 2-(2-oxa-4-pentenyl)naphthalene did not give any isolable cycloadducts at all.



	R^1	R^2	R^3
6a-9a	CN	H	H
6b-9b	CN	H	Me
6c-9c	CN	Me	Me
6d-9d	CO_2Me	H	Me
6e-9e	CO_2Me	Me	Me

Scheme 3. Intramolecular photocycloadditions of **6a**–**e**.



Scheme 4. Proposed mechanism for the intramolecular photocycloaddition of **1b**.

In conclusion, we have obtained intramolecular [3+2] photocycloadducts in a highly selective manner. The scope and limitations of these photocycloadditions are now under investigation.

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[9] A colorless block crystal of $C_{20}H_{15}N_3$ with approximate dimensions of $0.70 \times 0.50 \times 0.30$ mm^3 was mounted on a glass fiber. All measurements were made on a Rigaku Raxis Rapid imaging plate area detector with graphite monochromated Mo$_{K\alpha}$ radiation. The data were collected at a temperature of 23 ± 1 °C to a maximum 2θ value of 55.0°. Cell constants and an orientation matrix for data collection corresponded to a primitive triclinic cell with dimensions: $a = 6.803(4)$, $b = 10.585(6)$, $c = 11.665(9)$ Å; $\alpha = 67.57(3)$, $\beta = 74.27(3)$, $\gamma = 85.95(2)°$; $V = 746.8(8)$ Å^3. The space group was determined to be $P\bar{1}$ (no. 2). $\rho_{calcd} = 1.322$ g cm^{-3}. The structure was solved by direct methods (SIR88) and expanded by using Fourier techniques. The non-hydrogen atoms were refined anisotropically. Hydrogen atoms were refined by using the riding model. The final cycle of full-matrix least-squares refinement on F was based on 2590 observed reflections ($I > 5.00\sigma(I)$) and 224 variable parameters and was converged with unweighted and weighted agreement factors of $R = 0.0383$ and $R_w = 0.0421$.

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