



## Improved Synthesis of 1,4-Phenanthrenequinones from Diels-Alder Cycloadditions of 2-(*p*-Tolylsulfinyl)-1,4-benzoquinone

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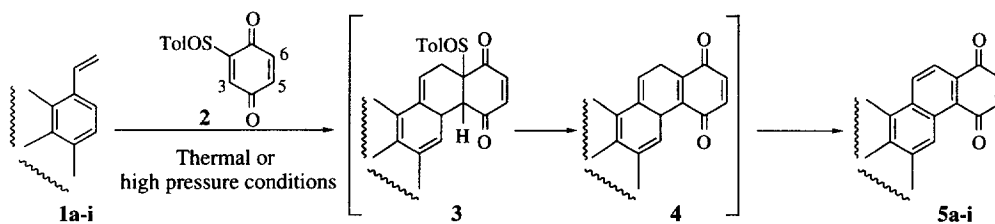
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**Abstract:** A wide range of substituted 1,4-phenanthrenequinones **5a-g** and benz[*c*]- and benz[*a*]-1,4-phenanthrenequinones (**5h**) and (**5i**) were synthesized in one step through Diels-Alder cycloadditions of 2-(*p*-tolylsulfinyl)-1,4-benzoquinone **2** and vinylaromatic derivatives **1a-i** under thermal and high pressure conditions in moderate to good yields (33-80%). © 1997 Elsevier Science Ltd.

The syntheses of polycyclic aromatic compounds<sup>1</sup> and carbocyclic helicoidal molecules<sup>2</sup> are receiving increasing attention due to their exceptional properties. Although photocyclization of adequately substituted stilbenes<sup>3</sup> has been the method of choice to their syntheses, nowadays the strategy based on iterative Diels-Alder reactions of quinones with vinyl or divinylbenzenes and naphthalenes is being applied both to polyaromatic derivatives and polycyclic quinones.<sup>4</sup> This method is still problematic owing to the poor dienic reactivity of vinylaromatic derivatives and the low yields achieved in the aromatization of the initial adducts effected by an excess of quinone acting as an oxidant. Although these Diels-Alder cycloadditions have been extensively studied with several dienophiles,<sup>5</sup> including quinones,<sup>6</sup> few improvements have been achieved up to date.<sup>7</sup> Among them, the addition of oxidants like chloranil,<sup>7a-c,g,h</sup> or catalysts such as trichloroacetic acid<sup>4a,7d,f,h</sup> should be mentioned. The use of Lewis acid catalysts is precluded since quinones react with styrenes in their presence giving rise to benzofuran derivatives resulting from addition reactions.<sup>8</sup> Other improvements included sonication<sup>9</sup> and introduction of strong electron-donating groups on the  $\alpha$ -carbon of the styrene double bond.<sup>10</sup> A recent Diels-Alder approach to helicenebisquinones stemmed from these  $\alpha$ -alkoxystyrenes.<sup>2,4b</sup>

As part of an ongoing programme seeking to exploit the high dienophilic reactivity of sulfinylquinones in asymmetric synthesis,<sup>11</sup> we thought of employing such dienophiles to the synthesis of 1,4-phenanthrenequinones and higher quinones. Several observations allowed us to predict significant improvements with such dienophiles. The Diels-Alder adducts which resulted from sulfinylquinones underwent a facile elimination of the sulfinyl group recovering the quinonic framework.<sup>11b</sup> Moreover, the electron-withdrawing character of the sulfoxide, increasing the oxidation potential of the quinone,<sup>12</sup> should facilitate the subsequent aromatization of the adducts. In order to check these points we undertook a model study of Diels-Alder cycloadditions of 2-(*p*-tolylsulfinyl)-1,4-benzoquinone **2**<sup>13</sup> with several substituted vinylbenzenes and naphthalenes **1a-i**. The results are described herein.

Vinylaromatic derivatives **1a,b,d,f,i** were commercially available, whereas **1c,e,g,h** were prepared from adequately substituted benzaldehydes by applying the general Wittig method of Tagaki et al.<sup>14</sup> All styrene derivatives **1a-g** and vinylnaphthalenes **1h,i** were submitted to reaction with quinone **2** under thermal and high pressure conditions, to afford 1,4-phenanthrenequinones **5a-i**.<sup>15</sup> (Scheme 1 and Table 1).




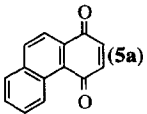


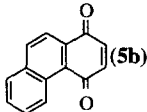

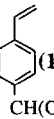
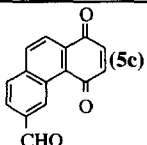
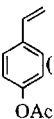
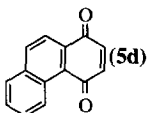

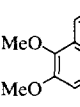
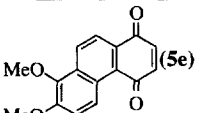

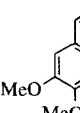
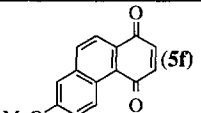

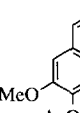
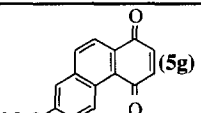

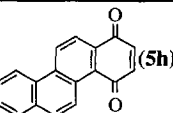



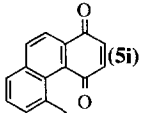

Thermal cycloadditions were carried out in refluxing toluene or acetonitrile. Only in the case of vinylnaphthalene **1h**, acetic acid was proved to be the best solvent, giving rise to quinone **5b** in 75% yield (entry 13). Most reactions were performed in a 6 (for vinylbenzenes **1a-g**) or 3 fold excess (for vinylnaphthalenes **1h,i**) of sulfinylquinone **2**, to favour the oxydation of dihydroaromatic compounds **4** which resulted from pyrolytic elimination of the sulfoxide in the adducts initially formed **3**. In the case of the less reactive styrenes **1a,b** and **1d**, lacking strong electron donating substituents on the aromatic ring, thermal reactions worked better with a 6 fold excess of vinylbenzene (entries 1, 3 and 6).<sup>16</sup> All dienes **1a-h**, but **1f**, reacted exclusively on the C<sub>2</sub>-C<sub>3</sub> quinonic double bond supporting the sulfoxide group. In thermal conditions (entry 10), the electron-rich styrene **1f** gave a 65:35 mixture of **5f** and the regioisomeric 2- and 3-sulfinyl-1,4-phenanthrenequinones resulting from Diels-Alder reactions on the C<sub>5</sub>-C<sub>6</sub> unsubstituted dienophilic double bond. From this mixture, quinone **5f** could be isolated by flash chromatography, in a yield significantly better (60%) than that previously described from the same styrene **1f** and the parent *p*-benzoquinone (31%).<sup>7a</sup> The obtention of **5a** and **5h** was achieved in similar yields to those described (entries 1 and 13), whereas in the case of **5e** and **5j** the yield was lower (entries 8 and 16). Styrenes **1c** and **1g** did not afford the desired 1,4-phenanthrenequinones **5c** and **5g** giving rise to complex reaction mixtures. In the cycloaddition of styrene **1e**, we could improve the formation of **5e** by adding trichloroacetic acid to the reaction medium (entry 8). When cycloaddition of vinylnaphthalene **1i** was conducted in CH<sub>3</sub>CN (entry 16) we observed addition byproducts which decreased the yield of the corresponding phenanthrenequinone **5i**.

In view of this low reactivity, we decided to carry out the cycloadditions under high pressures. In all cases but one, yields of 1,4-phenanthrenequinones **5a-g** and benz[*c*]- and benz[*a*]1,4-phenanthrenequinones, (**5h**) and (**5i**), were much better under these conditions (10-13 Kbars). The only exception was quinone **5f** which was obtained with a higher yield under thermal conditions (compare entries 10 and 11). Styrenes **1g** and **1c** only reacted under high pressure conditions affording respectively quinones **5g** (entry 12) and 6-formyl-1,4-phenanthrenequinone (**5c**), after hydrolysis of the diethoxyacetal functionality under the experimental conditions (entry 5). When cycloadditions of styrenes **1e,f** were conducted in CH<sub>3</sub>CN (entries 9 and 11) we observed again addition byproducts. From all the crude reaction mixtures, 2-(*p*-tolylsulfinyl)-1,4-hydroquinone resulting in the reduction of quinone **2** could be recovered to be recycled and reutilized.

In conclusion, the Diels-Alder cycloadditions of sulfinylquinone **2** and vinylaromatic derivatives **1a-i** under high pressure conditions allowed the obtention of differently substituted 1,4-phenanthrenequinones in better yields than those described. Quinones **5b-d** and **5g**, not accessible till now, were easily available in moderate to good yields. Application of this methodology to the synthesis of higher quinones is in course.

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**Table 1. Diels-Alder reactions between vinylaromatic derivatives 1a-i and sulfinylquinone 2.**

entry	diene	ratio 1 / 2	solvent	T (°C)	pressure (Kbar)	time (h)	1,4-phenanthrenequinone	yield (%)	lit. yield (%)
1		6 / 1	toluene	110	---	24		34	31 <sup>a</sup>
2		1 / 6	CH <sub>2</sub> Cl <sub>2</sub>	20	12.5	96		55	
3		6 / 1	CH <sub>3</sub> CN	80	---	96		24	53
4		1 / 6	CH <sub>2</sub> Cl <sub>2</sub>	20	13	48			
5		1 / 6	toluene	20	13.5	72		33	
6		6 / 1	CH <sub>3</sub> CN	80	---	96		19	49
7		1 / 6	CH <sub>2</sub> Cl <sub>2</sub>	20	13	24			
8		1 / 6	toluene <sup>b</sup>	110	---	24		30	63 <sup>a</sup>
9		1 / 6	toluene <sup>c</sup>	20	10	60		65	
10		1 / 6	toluene	110	---	24		60 <sup>d</sup>	31 <sup>a</sup>
11		1 / 6	toluene <sup>c</sup>	20	13	48		25 <sup>e</sup>	
12		1 / 6	CH <sub>3</sub> CN	20	13	48		65	
13		1 / 6	AcOH	120	---	4		75	77 <sup>f</sup>
14		1 / 3	CH <sub>3</sub> CN	80	---	96		50	
15		1 / 3	CH <sub>2</sub> Cl <sub>2</sub>	20	12	18		80	
16		1 / 3	toluene <sup>c</sup>	110	---	24		27	37 <sup>f</sup>
17		1 / 3	toluene	20	12	24		48	

<sup>a</sup> Reference 7f. <sup>b</sup> 10 mol% of Cl<sub>3</sub>CCO<sub>2</sub>H as catalyst. <sup>c</sup> In CH<sub>3</sub>CN, the yields of phenanthrenequinones decreased due to the formation of addition byproducts. <sup>d</sup> Obtained as a 65:35 mixture of **3f** and 2- and 3-*p*-tolylsulfinyl-1,4-phenanthrenequinones. <sup>e</sup> Obtained as a 35:65 mixture of **3f** and 2- and 3-*p*-tolylsulfinyl-1,4-phenanthrenequinones. <sup>f</sup> Reference 6b.

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15. All new compounds were characterized on the basis of their IR, <sup>1</sup>H-NMR (200 MHz, CDCl<sub>3</sub>) and <sup>13</sup>C-NMR (50 MHz, CDCl<sub>3</sub>) spectral data and elemental analysis. **5b**: mp 179-180 °C (MeOH); <sup>1</sup>H-NMR δ 9.79 (1H, m), 8.18 (1H, d, *J* = 8.6 Hz), 8.13 (1H, dd, *J* = 0.6 and 8.6 Hz), 7.78 (1H, dd, *J* = 1.1 and 8.8 Hz), 7.73 (1H, dd, *J* = 1.7 and 8.8 Hz), 7.01 and 6.96 (2H, AB system, *J* = 10.2 Hz). **5c**: mp 154 °C (MeOH); <sup>1</sup>H-NMR δ 10.25 (1H, s), 10.08 (1H, broad s), 8.32 and 8.24 (2H, AB system, *J* = 8.6 Hz), 8.13 (1H, dd, *J* = 1.3 and 8.5 Hz), 7.99 (1H, d, *J* = 8.5 Hz), 7.05 and 7.00 (2H, AB system, *J* = 10.2 Hz). **5d**: mp 140-141 °C (MeOH); <sup>1</sup>H-NMR δ 9.32 (1H, d, *J* = 2.5 Hz), 8.19 and 8.14 (2H, AB system, *J* = 8.5 Hz), 7.92 (1H, d, *J* = 8.8 Hz), 7.44 (1H, dd, *J* = 2.3 and 8.8 Hz), 7.00 and 6.94 (2H, AB system, *J* = 10.3 Hz), 2.40 (3H, s). **5g**: mp 218 °C (MeOH); <sup>1</sup>H-NMR δ 9.28 (1H, s), 8.10 and 8.02 (2H, AB system, *J* = 10.2 Hz), 7.22 (1H, s), 6.92 (2H, s), 3.98 (3H, s), 2.40 (3H, s).
16. When long reaction times (entries 3 and 6) or high temperatures (entry 1) are required, polymerization of the vinylaromatic derivative decreased the yield of cycloaddition.