

## Isolation of Cyclohexadienone Intermediates in the Photo-Fries Rearrangement of 2,4-Dimethylnaphth-1-yl and 1,4-Dimethylnaphth-2-yl 2,4,6-Trimethylbenzoates

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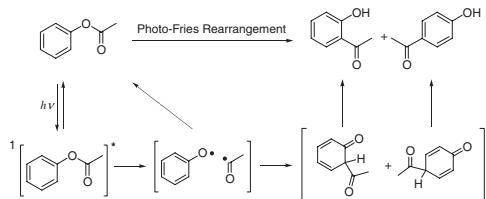
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Labile cyclohexadienones were isolated for the first time in good yields in the photo-Fries rearrangement of partially blocked naphthyl esters. Upon direct excitation at 313 nm, 1,4-dimethylnaphth-2-yl and 1,4-dimethylnaphth-1-yl 2,4,6-trimethylbenzoates afforded 1-acyl-2-naphthalenone and 2- and 4-acyl-1-naphthalenones, respectively. This isolation is of particular importance as a direct mechanistic proof and also as a convenient route to these thermally less-accessible compounds.

The photo-Fries rearrangement of aryl esters has been studied extensively and reviewed frequently with an emphasis on its synthetic advantage of the unique positional selectivity of the rearrangement.<sup>1</sup> The mechanism of the photo-Fries rearrangement has also been investigated in considerable detail, in contrast to the thermal Fries-rearrangement, in which ionic intermediates are involved. CIDNP experiments revealed that the photoreaction occurs in the singlet manifold to give the acyl-aryloxy radical pair;<sup>2</sup> this radical pair recombines to cyclohexadienone intermediate(s), which eventually tautomerize to the corresponding acylphenol derivatives, as shown in Scheme 1. A recent flash photolysis study on the photo-Fries rearrangement of phenyl acetate revealed the intervention of two different transient species, the decay profiles of which are nicely correlated with the formations of *o*- and *p*-acetylphenols, thus supporting the assignment of these intermediates to the *ortho*- and *para*-cyclohexadienones (Scheme 1).<sup>3</sup>

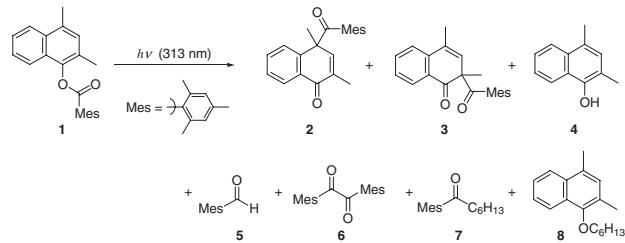


Scheme 1.

We have recently investigated the photochemistry of partially and fully blocked aryl esters.<sup>4</sup> Irradiation of these aryl esters in neutral solutions predominantly affords the photodecarboxylation and photo-Fries rearrangement products, while the addition of alcohol and a catalytic amount of acid to the solution switched the photoreactivity to transesterification, which is well understood in the framework of the photo-Fries reaction mechanism, involving the initial CO–O bond cleavage and subsequent rearrangement to the *ortho* and *para* positions to give the corresponding cyclohexadienones. However, all attempts to isolate or detect such intermediates were unsuccessful at least with mesityl and related substituted phenyl esters, probably owing to the thermal and/or photochemical instability of the intermediates.

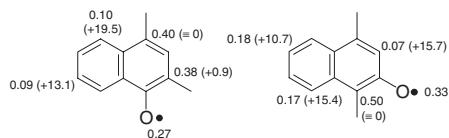
Here, we report the first successful isolation of such cyclohexadienoid intermediates obtained in the photolysis of blocked naphthyl esters, which unambiguously reveals its intervention in the photo-Fries rearrangement.

Since unblocked 1-naphthyl arencarboxylates are known to undergo photo-Fries rearrangements to give the corresponding 2- and 4-arylnaphthols,<sup>5</sup> we first chose 2,4-dimethylnaphth-1-yl 2,4,6-trimethylbenzoate (**1**) as substrate, which was synthesized from 2,4-dimethylnaphth-1-ol.<sup>6</sup> A hexane solution of **1** (2.5 mM), placed in a donut-shaped Pyrex vessel, was irradiated at  $-40^{\circ}\text{C}$  under Ar with a 300-W medium-pressure Hg lamp ( $\lambda > 280\text{ nm}$ ). After irradiation for 2 h, the photolysate was concentrated, and the residue was purified by column chromatography over alumina with hexane eluent to yield 4-cyclohexadienone (**2**)<sup>7</sup> in 22% isolated yield (Scheme 2). Cage-escape product, 2,4-dimethylnaphthol (**4**), was also obtained, along with trace amounts of radical escape products **5**–**8**. In contrast, no *ortho*-isomer **3** or decarboxylation product was isolated by the above photolysis/work-up procedures. In a similar photolysis in acetonitrile, **2** was isolated in 15% yield. The lack of **3** is a little puzzling, since the spin density of 2,4-dimethylnaphthoxy radical (calculated at the B3LYP/EPRII level) is similarly large at the 2- and 4-positions (Figure 1), suggesting the facile formation of both isomers. However, the formation of a small amount of **3** was detected at low conversions by HPLC analysis, but **3** was photochemically labile under the irradiation conditions particularly upon prolonged irradiations ( $\lambda > 280\text{ nm}$ ), probably owing to the longer  $\lambda_{\text{max}}$  of **3** ( $\approx 320\text{ nm}$ ) than that of **2** ( $\approx 260\text{ nm}$ ).



Scheme 2.

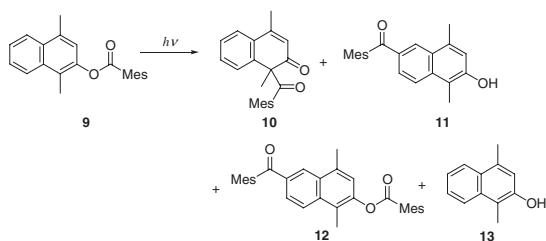
In order to minimize the secondary photodecomposition of **3** (and presumably of **2** as well), we irradiated the sample solution at 313 nm with a medium-pressure Hg lamp fitted with an aqueous  $\text{K}_2\text{CrO}_4$  filter. Upon irradiation at 313 nm for 1 h, ester **1** gave the isomeric cyclohexadienones (**2** and **3**)<sup>8</sup> and naphthol **4** in 26, 22, and 15% yields based on consumption of substrate, respectively, at 15% conversion as determined by the HPLC analysis. The *ortho*-rearranged cyclohexadienone **3**, which eluted slightly later than **2**, was isolated by preparative HPLC on a Kanto ODS column (150 mm  $\times$  4.6 mm,  $\Phi = 5\text{ }\mu\text{m}$ ) with aque-



**Figure 1.** Calculated spin densities of relevant radical species. Vaules in the parentheses are the heats of formation (in kcal/mol) of relevant 2,4,6-trimethylbenzoyl dimethylbeozocyclohexadienones derived from each radical species.<sup>9</sup>

ous acetonitrile as eluent. Prolonged irradiations led to increased yields of **2** and the complete loss of **3**.

We further performed the photolysis of 1,4-dimethylnaphth-2-yl 2,4,6-trimethylbenzoate (**9**).<sup>10</sup> Irradiation ( $\lambda > 280$  nm; 2 h) at  $-40^{\circ}\text{C}$  gave 1-acylcyclohexadienone **10**<sup>11</sup> in 22% isolated yield, along with 6-acylnaphthol **11** in 13% and naphthol **13** in 13% (Scheme 3). A small amount of **12** was also detected. The absence of 8-acylnaphthol may be due to the larger heat of formation for this rearrangement (Figure 1).



**Scheme 3.**

4-Benzoyl-4-methyl-2,5-cyclohexadienone and its derivatives have already been prepared but requires wearisome multi-step syntheses.<sup>12</sup> To the best of our knowledge, no 2-acylcyclohexadienone derivative has been isolated so far. In contrast, the present photorearrangement allows us to conveniently prepare and isolate such benzocyclohexadienones in appreciable yields as *ortho*- and *para*-rearranged products.

In summary, we have shown for the first time that acylcyclohexadienone intermediates are involved in the photo-Fries rearrangement, by employing naphthyl esters that carry methyl groups at the photo-Fries rearrangement-susceptible positions.<sup>13</sup> Studies on thermal and photochemical behavior of these chemically intriguing species are in progress.

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- 2,4-Dimethyl-4-(2,4,6-trimethylbenzoyl)-4H-naphthalen-1-one (**2**). mp 75–77 °C; IR (KBr)  $\nu_{\text{max}}$  3067, 2997, 2970, 2926, 1701, 1659 cm<sup>-1</sup>; <sup>1</sup>H NMR (400 MHz, CD<sub>3</sub>CN)  $\delta$  1.35 (br s, 3H), 1.80 (d, 3H,  $J = 1.5$  Hz), 1.85 (s, 3H), 2.10 (br s, 3H), 2.18 (s, 3H), 6.70 (br s, 1H), 6.79 (br s, 1H), 6.92 (q, 1H,  $J = 1.5$  Hz), 7.45–7.51 (m, 1H), 7.58–7.64 (m, 1H), 7.82 (m, 1H), 8.07 (m, 1H); <sup>13</sup>C NMR (100 MHz, CD<sub>3</sub>CN)  $\delta$  16.29, 19.32, 20.46, 20.99, 27.75, 55.96, 127.23, 128.94, 129.13, 129.38, 132.56, 133.35, 135.43, 139.42, 139.66, 143.50, 146.82, 185.21, 209.88; HRMS: calcd for C<sub>22</sub>H<sub>22</sub>O<sub>2</sub>: C, 82.99; H, 6.96%. Found: C, 82.52; H, 6.90%. Rearrangement position was confirmed by difference NOE spectrum with presaturation at 1.85 ppm (2-Me) and 1.80 ppm (4-Me). The former showed only H3 signal, while the latter showed both H3 and H5 enhancements.
- Dimethyl-1-(2,4,6-trimethylbenzoyl)-2H-naphthalen-1-one (**3**). <sup>1</sup>H NMR (400 MHz, CD<sub>3</sub>CN)  $\delta$  1.62 (s, 3H), 1.96 (s, 3H), 2.13 (d, 3H,  $J = 1.5$  Hz), 2.16 (s, 3H), 6.06 (q, 1H,  $J = 1.5$  Hz), 6.70 (s, 2H), 7.35–7.40 (m,  $J = 1.1$  Hz, 7.7 Hz, 1H), 7.45 (d,  $J = 7.7$  Hz, 1H), 7.63–7.68 (m,  $J = 1.1$  Hz, 7.7 Hz, 1H), 7.80 (dd,  $J = 1.1$  Hz, 7.7 Hz, 1H). The spectrum was obtained by subtraction from the spectrum of isomeric mixture (2 and 3).
- B3LYP/6-311+g(2d,p)/B3LYP/6-31g(d) calculated heats of formation of possible cyclohexadienoid intermediates (**2**, **3**, **10**, and **14–18**).
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- Spectral data: 1,4-dimethyl-1-(2,4,6-trimethylbenzoyl)-1H-naphthalen-2-one (**10**). mp 83–84 °C; IR (KBr)  $\nu_{\text{max}}$  3064, 2978, 2921, 2861, 1700, 1654 cm<sup>-1</sup>; <sup>1</sup>H NMR (400 MHz, CD<sub>3</sub>CN)  $\delta$  1.75 (s, 6H), 1.85 (s, 3H), 2.19 (s, 3H), 2.30 (d, 3H,  $J_{\text{allyl}} = 1.1$  Hz), 5.91 (q, 1H,  $J_{\text{allyl}} = 1.1$  Hz), 6.72 (s, 2H), 7.39–7.54 (AA'XX', 2H), 7.63–7.67 (AA'XX', 1H,  $J_{5-6} = 7.7$  Hz,  $J_{5-7} = 1.5$  Hz), 7.72–7.76 (AA'XX', 1H,  $J_{7-8} = 7.9$  Hz,  $J_{6-8} = 1.3$  Hz); <sup>13</sup>C NMR (100 MHz, CD<sub>3</sub>CN)  $\delta$  20.03, 20.50, 20.92, 26.50, 66.74, 125.53, 126.98, 128.84, 128.97, 129.08, 131.08, 132.21, 134.06, 139.32, 140.00, 141.26, 154.22, 198.66, 207.38; EI-MS *m/z* (relative intensity) 318 (M<sup>+</sup>, 14), 172 (8), 147 (100), 119 (15), 91 (4), 57 (4); Anal. Calcd for C<sub>22</sub>H<sub>22</sub>O<sub>2</sub>: C, 82.99; H, 6.96%. Found: C, 82.76; H, 7.02%. Rearranged position was confirmed by difference NOE spectrum with presaturation at 2.34 ppm (4-Me), showing both H3 and H5 enhancements.
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