# Photoreaction of 2-morpholinoacrylonitrile with substituted 1-acetonaphthones. Part II<sup>†</sup>

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Photochemical reactions of substituted 1-acetonaphthones in the presence of 2-morpholinoacrylonitrile were investigated. The type of reaction, photocycloaddition vs. photosubstitution, is dependent on the nature of the additional substituent. The location of the additional substituent on the ring also affects the type of addition, [2 + 2] vs. [4 + 2].

In the course of our studies on the photochemical behaviour of acylnaphthalenes,<sup>1-6</sup> especially substituted 1-acetonaphthones **1b**-e,<sup>7</sup> towards captodative alkenes,<sup>8</sup> especially 2morpholinoacrylonitrile, 2, we investigated the photochemical reactions of further substituted 1-acetonaphthones. Our earlier studies showed the occurrence of two types of reactions: photosubstitution and photoaddition, which is dependent on the nature of the additional substituent on the naphthalene ring of 1-acetonaphthone. Our earlier results also indicated that the type of addition, [2 + 2] vs. [4 + 2], is dependent on the location of the additional substituent on the ring.<sup>7</sup> Only in the case of the 4-bromo derivative 1b, has photosubstitution of bromine been observed.<sup>7</sup> In continuation of this work, we prepared 4-chloro-, 4-fluoro-, 4-methyl- and 2methylsubstituted 1-acetonaphthones 1f-i, respectively, and investigated their photochemical behaviour in the presence of 2, to ascertain the effect of an additional substituent on the type of reaction.

# **Results and discussion**

Irradiation ( $\lambda \ge 280$  nm) of equimolar solutions of ketones **1f**-i with **2** resulted in the occurrence of one or both reactions, depending on the type of substituent. Whereas in the cases of

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4-chloro 1f only photosubstitution and 4-fluoro 1g both reactions were observed, irradiation of 4-methyl 1h and 2-methyl 1i derivatives in the presence of 2 resulted in the addition of 2 to the naphthalene skeleton of 1h and 1i. IR, <sup>1</sup>H NMR and UV data gave useful information for the structural assignment of the photoproducts. Characterization of the photosubstitution product 3 in the case of 1f and 1g was achieved by comparison of its physical and spectroscopic data with those of 3 obtained upon irradiation of the 4-bromo derivative **1b** in the presence of **2**.<sup>7</sup> Irradiation of a mixture of **1g** and **1i** with 2 causes the formation of [2 + 2]-cycloadducts 4d and 4e, respectively. <sup>1</sup>H NMR spectra of 4d and 4e showed the resonance of an acetyl group at 2.04 and 1.99 ppm, respectively, which indicates the attachment of this group to the cyclobutane ring.<sup>4,7</sup> This observation is also supported by comparison of the <sup>1</sup>H NMR data of 4d and 4e with those of 4a-c, which are summarized in Table 1. The UV spectra (in chloroform solution) exhibit intense (lg  $\varepsilon = 3.73$  and 3.52) absorptions at 276 nm for 4d and 4e, respectively, consistent with 1,2-adducts with styrene-type conjugation of the benzoid ring and a residual double bond.

The *exo* orientation of the morpholino group was confirmed by exact analysis of the 500 MHz <sup>1</sup>H NMR spectrum of compound 4d. The 1-CH<sub>2</sub> protons form an AX pattern with  $\delta_A = 3.28$  (*endo*-1-H),  $\delta_X = 2.67$  (*exo*-1-H) and a geminal coupling of 12.17 Hz, the high-field portion of which is additionally split by 0.73 Hz due to a long range (W type) interaction with 2a-H ( $\delta = 3.32$ ). On the other side, the anisotropic effect of the



**Table 1** Structurally relevant <sup>1</sup>H NMR chemical shifts ( $\delta$  values) and <sup>1</sup>H, <sup>1</sup>H coupling *J* (Hz) of **4d** and **4e** in comparison with **4a**, **4b** and **4c** 

	CH <sub>3</sub> CO	2a-H	3-Н	4-H	$J_{2a-3}$
4a	2.01	3.24	5.67	6.73	5.7
4b	2.00	3.40	6.59	_	6.15
4c	2.00	3.30	4.74	_	6.41
4d	2.04	3.32	5.36	_	6.30
4e	1.99	3.24	5.62		5.61

cyano group *cis* to the *endo*-1-H causes a deshielding effect on this proton, which consequently shows this signal at a lower field in comparison to the *exo*-1-H, which is *cis* to the morpholino group. A four-spin system was also observed for 2a-H, 3-H, 4-F and 1-H<sub>exo</sub>. The resonance for 2a-H shows a vicinal coupling of 6.30 Hz with 3-H, coupling with 4-F (4.73 Hz) and long-range coupling with 1-H<sub>exo</sub> (0.73 Hz). These data indicate that the X part of the AX system at higher field is *cis* to the morpholino group, which displays an *exo* orientation of the morpholino group. Such an orientation has also been observed earlier in the case of **4c** by an X-ray crystal structure analysis as well as by an NOE signal intensity difference determination for **4b**.<sup>7</sup>

The formation of the [4 + 2]-cycloadduct **5c** was observed upon irradiation of a mixture of 1i and 2. Since the structures of 5a and 5b have been unambiguously determined an earlier from X-ray structural analysis<sup>1</sup> and by a NOE signal intensity difference determination experiment,<sup>7</sup> respectively, the assignment for 5c was based on comparison of its <sup>1</sup>H chemical shifts and couplings with those obtained for 5a and 5b (Table 2) and on its UV spectrum. The resonance of the CH<sub>3</sub>CO group at 2.53 ppm, compared with the same resonance for 5a and 5b, and also the AX pattern for 3-H and 4-H with a vicinal coupling of 6.32 Hz indicate 1,4-addition of 2 to 1i. The UV spectrum (in chloroform solution) exhibits absorption, lg  $\varepsilon = 2.86$ and 3.27, at 273 and 242 nm, respectively, indicative of a nonconjugated benzoid ring and residual double bond and formation of the 1,4-ethanonaphthalene skeleton. Most of the cycloadducts are thermally unstable and undergo retrocleavage to the starting material on heating. Our new results on cycloaddition support the formation of an exciplex intermediate, which we proposed earlier.7

Product **5b** was hydrolyzed to give the 1,4-diketone **6** following a published procedure.<sup>9</sup> The IR spectrum of **6** showed a broad band for both CO groups at 1714 cm<sup>-1</sup> and the loss of the CN group. The <sup>1</sup>H NMR spectrum also supports the hydrolysis of **5b** and formation of **6**.



An interesting result was obtained upon irradiation of **5b** at 253.8 nm. Whereas upon irradiation photoisomerization of **5a** into a dihydrobenzosemibullvalene product<sup>4</sup> by a di- $\pi$ -methane rearrangement<sup>10,11</sup> has been reported, a retro photo-Diels-Alder reaction was observed on irradiation of **5b**. The

**Table 2** Structurally relevant <sup>1</sup>H NMR chemical shifts ( $\delta$  values) and <sup>1</sup>H, <sup>1</sup>H coupling J (Hz) of 5c in comparison with 5a and 5b

	CH <sub>3</sub> CO	2-Н	3-Н	4-H	$J_{3,4}$
5a	2.53	6.93	6.77	4.45	7.8
5b	2.53		5.32	4.31	7.16
5c	2.53		а	4.41	6.32

<sup>1</sup>H NMR spectrum of a crude reaction mixture after 12 h irradiation showed only peaks characteristic of both compounds 1e and 2.

# Experimental

All melting points were determined with a Stuart Scientific SMP2 and are uncorrected. IR spectra were obtained on a Shimadzu IR-435 and Perkin–Elmer 983 spectrometers. UV spectra were recorded on a Shimadzu UV-160. <sup>1</sup>H NMR spectra were collected on Bruker AW 80 (80 MHz), Bruker WM 300 (300 MHz), and Bruker drx 500 (500 MHz) apparatus. <sup>13</sup>C NMR spectra were recorded on a Bruker drx 500 (500 MHz) spectrometer; the DEPT technique was employed for compound 4d. MS (EI and FD mode) spectra were obtained on an AMD 604. Elemental analyses were run on Heraeus CHN-O-RAPID and Carlo Erba 1106 CHN analyzers. Preparative layer chromatography (PLC) was carried out on  $20 \times 20$  cm<sup>2</sup> plates, coated with a 1 mm layer of Merck silica gel PF<sub>254</sub>, prepared by applying the silica as a slurry and drying in air.

All irradiations were carried out in a pyrex cell ( $\lambda > 280$  nm) using a 400 W high pressure Hg vapour lamp from NARVA (with a 150 W high pressure mercury burner from Philips in the case of **1g**) through a water-cooled immersion well made of Duran glass. A solution of 1 mmol of each of the ketones **1f**, **h**, **i** and **2** was irradiated in 15 mL dry benzene (c = 0.067 M) and in the case of **1g** in 20 mL acetonitrile (c = 0.05 M) and continuously purged with a stream of argon for the times given below.

# Irradiation of 4-chloro-1-acetonaphthone 1f in the presence of 2-morpholinoacrylonitrile 2

The solution was irradiated for 8 h. The solvent was evaporated and PLC of the residue (toluene–ethyl acetate, 7:1) gave zone 1 ( $R_f = 0.45$ , 170 mg of **1f**), zone 2 ( $R_f = 0.42$ , 120 mg of **2**) and zone 3 ( $R_f = 0.36$ , 39 mg of **3**; 13% based on **1f** used, 74% based on **1f** consumed). The latter was recrystallized from *n*-hexane–ethyl acetate (10:1), m.p. 186–187 °C (lit. m.p.,<sup>7</sup> 186–187 °C).

## Irradiation of 4-fluoro-1-acetonaphthone 1g in the presence of 2

The solution was irradiated for 15 h. The solvent was evaporated and PLC of the residue (toluene-ethyl acetate, 10:1) gave zone 1 ( $R_f = 0.67$ , 125 mg of 1g), zone 2 ( $R_f = 0.49$ , 12 mg of 2) and zone 3 ( $R_f = 0.36$ , 28 mg of 3), which was recrystallized from *n*-hexane-ethyl acetate (10:1), m.p. 186–187 °C (18% based on 1g used) and zone 4 ( $R_f = 0.12$ , 44 mg of 4d), which was recrystallized from *n*-hexane-ethyl acetate (5:1), m.p. 189–190 °C (27% based on 1g used).

*rel-*(2*R*,2a*S*,8b*S*)-8b-Acetyl-4-fluoro-1,2,2a,8b-tetrahydro-2-morpholinocyclobuta [*a*] naphthalene-2-carbonitrile, 4d. IR (KBr): *v* 2220 (CN), 1705 (CO) cm<sup>-1</sup>. <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>):  $\delta$  2.04 (s, 3H, CH<sub>3</sub>), 2.38 (m<sub>c</sub>, 2H, CH<sub>ax</sub>N), 2.50 (m<sub>c</sub>, 2H, CH<sub>eq</sub>N), 2.67 (dd,  $|^2J| = 12.17$ ,  ${}^4J_{1, 2a} = 0.72$ , 1-*exo*-H), 3.28 (d,  $|^2J| = 12.17$ , 1-*endo*-H), 3.32 (ddd,  ${}^3J_{2a, 3} = 6.30$ ,  ${}^4J_{2a, F} = 4.73$ ,  ${}^4J_{2a, 1-exo-H} = 0.72$ , 2a-H), 3.72 [m<sub>c</sub>, 4H, (CH<sub>2</sub>)<sub>2</sub>O], 5.36 (dd,  ${}^3J_{3, F} = 12.81$ ,  ${}^3J_{3, 2a} = 6.30$  Hz, 3-H), 6.98 (m<sub>c</sub>, 1H, 8H), 7.34 (m<sub>c</sub>, 2H, 6- and 7-H), 7.56 (m<sub>c</sub>, 1H, 5-H).  ${}^{13}$ C NMR (CDCl<sub>3</sub>):  $\delta$  25.13 (CH<sub>3</sub>), 42.40 (C-1), 45.51 and 45.58 ( $|{}^3J_{C, F}| = 9.47$ , C-2a), 47.19 [(CH<sub>2</sub>)<sub>2</sub>N],48.17 (C-8b), 63.45 and 63.48 ( $|{}^4J_{C, F}| = 3.98$ , C-2), 66.57 [(CH<sub>2</sub>)<sub>2</sub>O], 97.50 and 97.66 ( $|{}^2J_{C, F}| = 20.43$ , C-3), 116.33 (CN), 122.84 and 122.90 ( $|{}^3J_{C, F}| = 4.49$ , C-6), 128.92 and 130.84 (C-7, C-8), 135.32 and 135.37 ( $|{}^2J_{C, F}| = 6.49$ , C-4a), 158.50 and 160.54 ( $|{}^1J_{C, F}| = 257.43$  Hz, C-4), 204.56 (CO). EI-MS (70 eV,

150 °C): m/z (%) 325 [M<sup>+</sup> - 1, (0.05), 299 [M<sup>+</sup> - HCN] (0.8), 283 [M<sup>+</sup> - COCH<sub>3</sub>] (8), 196 [M<sup>+</sup> - morpholine - COCH<sub>3</sub>] (9), 188 [M<sup>+</sup> - 2] (22), 173 [M<sup>+</sup> - 2 - CH<sub>3</sub>] (81), 145 [M<sup>+</sup> - 2 - COCH<sub>3</sub>] (25), 138 [M<sup>+</sup> - 1g] (100). UV (CHCl<sub>3</sub>):  $\lambda_{max}$ (lg ε) 276 (3.73), 268 nm (3.74). Anal. calc. for C<sub>19</sub>H<sub>19</sub>N<sub>2</sub>O<sub>2</sub>F (326.368): C, 69.92; H, 5.87; N, 8.58%. Found: C, 69.72; H, 5.92; N, 8.61%.

# Irradiation of 4-methyl-1-acetonaphthone 1h in the presence of 2

The solution was irradiated for 8 h. The solvent was evaporated and PLC of the residue (toluene–ethyl acetate, 3:1) gave zone 1 ( $R_f = 0.73$ , 168 mg of **1h**), zone 2 ( $R_f = 0.6$ , 110 mg of **2**), and zone 3 ( $R_f = 0.49$ , 35 mg of **4e**; 11% based on **1h** used, 80% based on **1h** consumed). The latter was recrystallized from *n*-hexane–ethyl acetate (10:1), m.p. 138–139 °C (decomp.).

rel-(2R,2aS,8bS)-8b-Acetyl-4-methyl-1,2,2a,8b-tetrahydro-2morpholinocyclobuta [a] naphthalene-2-carbonitrile, 4e. IR (KBr): v 2220 (CN), 1710 (CO) cm<sup>-1</sup>. <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>):  $\delta$  1.99 (s, 3H, COCH<sub>3</sub>); 2.22 (s, 3H, CH<sub>3</sub>); 2.41–2.54 [m, 4H, (CH<sub>2</sub>)<sub>2</sub>N]; AX ( $\delta_A = 2.64, \ \delta_X = 3.29, \ |^2 J_{AX}| = 12.07,$ 1-CH<sub>2</sub>), 3.73–3.75 [m, 4H, (CH<sub>2</sub>)<sub>2</sub>O]; AX ( $\delta_{A} = 3.24$ ,  $\delta_{X} = 5.62$ ,  ${}^{3}J_{AX} = 5.61$  Hz; 2a-H, 3-H); 6.95–7.41 (m, 4H, aromatics). EI-MS (70 eV, 125 °C): m/z (%) 295 [M<sup>+</sup> – HCN] (0.35), 279  $[M^+ - COCH_3]$  (2.25), 264  $[M^+ - COCH_3]$  $-CH_3$ ] (0.45), 236 [M<sup>+</sup> – morpholine] (0.1), 221 [M<sup>+</sup> - morpholine - CH<sub>3</sub>] (0.31), 209 [M<sup>+</sup> - morpholine - HCN] (0.71), 184 [M<sup>+</sup> - 2] (73), 169 [1h - CH<sub>3</sub>] or  $[M^+ - 2 - CH_3]$  (100), 141  $[1h - COCH_3]$  or  $[M^+]$ - COCH<sub>3</sub>] (19), 138  $[M^+ - 1c]$  (16). UV (CHCl<sub>3</sub>):  $\lambda_{max}$ (lg  $\epsilon$ ) 276 (3.52), 246 nm (3.59). Anal. calc. for  $C_{20}H_{22}N_2O_2$ (322.395): C, 74.51; H, 6.87; N, 8.69%. Found: C, 73.97; H, 6.94; N, 8.74%.

#### Irradiation of 2-methyl-1-acetonaphthone 1i in the presence of 2

The solution was irradiated for 12 h. The solvent was evaporated and PLC of the residue (toluene-ethyl acetate, 3:1) gave zone 1 ( $R_{\rm f} = 0.76$ , 165 mg of 1i), zone 2 ( $R_{\rm f} = 0.61$ , 120 mg of 2), and zone 3 ( $R_{\rm f} = 0.47$ , 25 mg of 5c; 8% based on 1i used, 72% based on 1i consumed). The latter was recrystallized from *n*-hexane-ethyl acetate 10:1), m.p. 140–141 °C (decomp.).

rel-(1S,4R,9R)-1-Acetyl-1,4-dihydro-2-methyl-9-morpholino-1,4-ethanonaphthalene-9-carbonitrile, 5c. IR (KBr): v 2210 (CN), 1705 (CO) cm<sup>-1</sup>. <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>):  $\delta$  AB  $(\delta_{\rm A} = 1.90, \ \delta_{\rm B} = 2.20, \ |^2 J_{\rm AB}| = 12.52, \ 2H, \ 10\text{-}{\rm CH}_2); \ 2.33 \ (s, h)$ 3H, CH<sub>3</sub>); 2.53 (s, 3H, COCH<sub>3</sub>); 2.55 (m<sub>c</sub>, 2H, CH<sub>ax</sub>N); 2.74  $(m_{c}, 2H, CH_{eq}N); 3.50 (m_{c}, 2H, CH_{ax}O); 3.59 (m_{c}, 2H,$  $CH_{eq}O$ ; AX ( $\delta_A = 4.41$ ,  $\delta_X = overlapped$  with aromatic Hs,  ${}^{3}J_{AX} = 6.32$  Hz); 6.72–7.20 (m, 5H, aromatic H and 3-H) EI-MS (70 eV, 100 °C); m/z (%) 322 [M<sup>+</sup>] (0.17), 307 [M<sup>+</sup>  $- CH_3$  (0.8), 295 [M<sup>+</sup> – HCN] (0.28), 279 [M<sup>+</sup> – COCH<sub>3</sub>] (0.55), 226  $[M^+ - COCH_3 - CN]$  (1.58), 211  $[M^+ - COCH_3]$  $- \text{CN} - \text{CH}_3$ ] (0.71), 198 (1.89), 184  $[\text{M}^+ - 2]$  (55), 169  $[\text{M}^+$  $-2 - CH_3$ ] 100), 155 (22), 141 [M<sup>+</sup> - 2 - COCH<sub>3</sub>] (36), 138  $[M^+ - 1i]$  (4), 115  $[M^+ - 2 - COCH_3 - CN]$  (26). FD-MS (0.005 V): *m*/*z* (%) 322 [M<sup>+</sup>] (100), 226 (33), 184 (52), 138 (14). UV (CHCl<sub>3</sub>):  $\lambda_{max}$  (lg  $\varepsilon$ ) 273 (2.86), 242 nm (3.27).

Anal. calc. for  $C_{20}H_{22}N_2O_2$  (322.395): C, 74.51; H, 6.87; N, 8.69%. Found. C, 73.77; H, 6.78; N, 8.34%.

### **Irradiation of 5b**

A solution of 50 mg (0.15 mmol) of **5b** in 3 mL of acetonitrile (c = 0.05) contained in a quartz cell was irradiated in a Rayonet reactor at 253.8 nm for 12 h. The reaction was followed by TLC. TLC showed the retro-Diels-Alder reaction of **5b** and formation of **1e** and **2**. Solvent was evaporated. <sup>1</sup>H NMR of the residue showed characteristic peaks of **1e** and **2**.

#### Hydrolysis of 5b

In adaptation of a published procedure, a suspension of 60 mg (0.23 mmol) of  $CuSO_4 \cdot 5H_2O$  and 16 mg (0.005 mmol) of  $Na_2HPO_4 \cdot 12H_2O$  in 1 mL of water, 1.5 mL of methanol and 1.5 mL of acetone was stirred for 10 min, then 50 mg (0.15 mmol) of **5b** was added, the mixture stirred for 6 h, and a further 11 mg (0.003 mmol) of  $Na_2HPO_4 \cdot 12H_2O$  was added. After stirring for 72 h at room temperature, the organic material was extracted with 5 mL of chloroform, the extract was dried with MgSO<sub>4</sub> and concentrated to give 40 mg of **6**. PLC, toluene–ethyl acetate, (7:1),  $R_f = 0.36$ , gave 32 mg (90%) of **6** as a viscose oil.

#### rel-(1R,4R)-1-Acetyl-1,4-dihydro-2-methoxy-1,4-ethano-

**naphthalene-9-one, 6.** IR (film): v 1714 cm<sup>-1</sup> (CO, br). <sup>1</sup>H NMR (80 MHz, CDCl<sub>3</sub>):  $\delta$  AB ( $\delta_{A} = 2.15$ ,  $\delta_{B} = 2.60$ , |<sup>2</sup> $J_{AB}$ | = 18, 2H, CH<sub>2</sub>); 2.51 (s, 3H, COCH<sub>3</sub>); 3.60 (s, 3H, OCH<sub>3</sub>); AX ( $\delta_{A} = 4.21$ ,  $\delta_{X} = 5.32$ , <sup>3</sup> $J_{AX} = 6.4$  Hz, 3-H, 4-H), 7.01–7.30 (m, 4H, aromatic H).

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