

Photoreaction of 2'-chloro-4-R-benzanilide: synthesis of 2-(4-R-phenyl)-1,3-benzoxazole and 9-R-phenanthridin-6(5H)-one (R=H, CH₃, CH₃O)

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Abstract

The UV photolysis of 2'-chloro-4-R-benzanilides in acetonitrile solution under nitrogen atmosphere leads to the formation of intramolecular photocyclization products (9-R-phenanthridin-6(5)-one, 20–30%), along with the minor photoreduction, photo-Fries, and intramolecular photosubstitution products. The photoreaction of 2'-chloro-4-R-benzanilide in acetonitrile solution containing 10% of water or aqueous sodium hydroxide however gives 2-(4-R-phenyl)-1,3-benzoxazole as a major product (~30%) along with the photoreduction, photo-Fries and intramolecular photocyclization products. © 2002 Elsevier Science B.V. All rights reserved.

Keywords: 2'-Chloro-4-R-benzanilides; Intramolecular photocyclization; Intramolecular photosubstitution; Solvent and substituent effect

1. Introduction

The attention paid towards the photochemistry of haloarenes is due to its linkage to the photochemical synthetic methods for ring formation [1–7] and photodegradation of hazardous haloarenes [8–11]. Previously, we have reported about the photoreaction of 2'-halobenzanilide [12] in which we reinvestigated the photochemical behavior of 2'-chloro- and 2'-bromobenzanilide in basic and neutral media. Our results revealed that the bromo-derivative of benzanilide is a better candidate for the intramolecular photosubstitution and photoreduction type products, while the chloro-derivative yields photo-Fries type products as a major photoproduct. Photolysis of aryl halides in solution generally involves radical intermediates through homolytic cleavage of carbon–halogen bond. In aromatic solvents, the reaction of primary photoproduct leads to arylation products, and in hydrogen donor solvents, the reductive dehalogenation [1,13], nucleophilic photosubstitution, and inter- and intramolecular arylation reactions were observed [14]. On the other hand, the studies of the substituent effect and its connection to structure-activity relationship lie in the core of many scientific efforts made towards under-

standing chemical transformation [15]. The transmission of the electronic effect of *para*-substituent [16] through the rich conjugated system of benzanilides will affect the electron density on nitrogen atom; in turn it will alter the internal conjugation in anilides [17] and rotational barrier about C–N bond of amide [18,19]. Electron-donating substituents can therefore alter the amide bond resonance through inductive and $n-\pi$ electron conjugation between the substituent and the ring. As a result, it will affect the reaction mechanism and reaction efficiency dramatically.

This paper presents our study on the effect of *para*-substituent on the photoreaction products of 2'-chloro-4-R-benzanilides, particularly on the intramolecular photosubstitution that leads to the formation of 2-(4-R-phenyl)-1,3-benzoxazole, and on the intramolecular photocyclization that leads to the formation of 9-R-phenanthridin-6(5)-one (Scheme 1).

2. Experimental

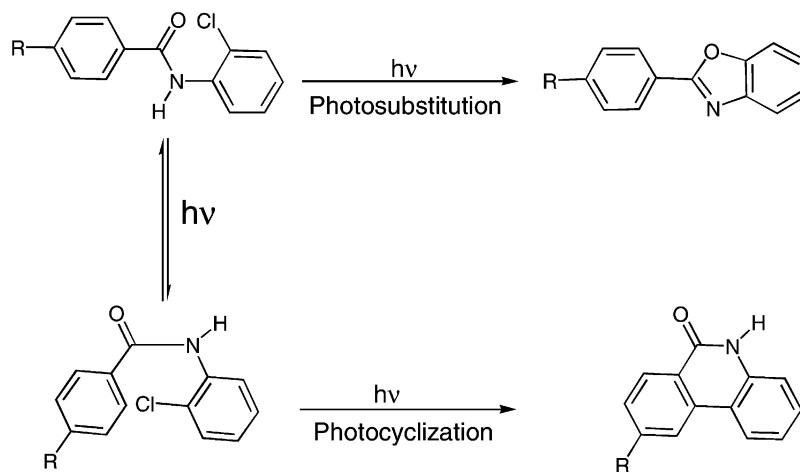
2.1. General

HPLC grade acetonitrile (J.T. Backer) and triple distilled water were used throughout this work. Cyclohexane, ethyl acetate, *n*-hexane, ethanol, methanol (Fisher scientific, HPLC grade) were used. Other chemical reagents such as haloanilines, substituted benzoyl chloride and sodium hydroxide were of analytical grade and used without any further treatment.

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Scheme 1.

The UV absorption change was measured for 2.5 ml aliquots of proper concentrations (absorbance over 1.0) of the haloarene in 1 cm quartz cuvette. The solutions were purged with nitrogen gas prior to irradiation, the irradiation were performed with Xe-lamp. Cut off filter of 1 cm path of alcohol reagent was used to filtrate light shorter than 215 nm.

Preparative photoreactions were performed in quartz immersion wall photolysis reactor, the light source used for irradiation was of medium pressure Hg-lamp (450 W) operated at 110 V. Nitrogen gas was circulated prior and during irradiation, and the reaction temperature was kept at $\sim 4^\circ\text{C}$.

Melting points were measured on a Thomas Hoover capillary melting point apparatus. UV-Vis absorption spectra were recorded on JASCO UV-530 spectrophotometer. Infrared spectra (KBr) were recorded on Mattson Galax series 7020 Nicolet Magna 550 FT-IR spectrophotometer. ^1H and ^{13}C -NMR spectra were recorded on Bruker 400 spectrometer in DMSO- D_6 solvent with TMS as an internal standard. Mass spectra were obtained using a HP 5989A mass spectrometer hyphenated to HP 5890 series II gas chromatography. Elementary analyses were carried on an elemental analysis Carlo Erba CHNS-O E.A. 1180. Dynamex HPLC chromatography, equipped with Microsorb MV C18 (15 cm \times 2 mm i.d.) analytical column was used for the analyses of photoproducts.

2.2. General procedure for the synthesis of 2'-halo-4-R-benzanilide

2-Chloroaniline (2.55 g, 0.02 mol) was stirred in 20 ml of pyridine and 1 equiv. of 4-R-benzoyl chloride (0.02 mol) was added slowly drop by drop at 0°C . The mixture was stirred in ice bath for 2 h and in room temperature for 3 h. When 250 ml of water was added, a white solid was precipitated. The resulting solid was isolated typically in $>65\%$ yield.

2.2.1. 2'-Chlorobenzanilide ($\text{C}_{13}\text{H}_{10}\text{ClNO}$) (**1a**)

Yield 66%; m.p. (crystallized from *n*-hexane) $100\text{--}102^\circ\text{C}$ (lit. value 103.5°C) [20]. UV (λ_{max} in acetonitrile) 260 nm ($\epsilon_{260} = 1.2 \times 10^4 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$). IR (KBr) 3225, 3059, 1653 cm^{-1} . ^1H -NMR (DMSO- D_6): δ 10.06 (s, 1H), 8.01 (dt, $J = 6.9, 1.5 \text{ Hz}$, 2H), 7.60–7.54 (m, 5H), 7.40 (td, $J = 6.0, 1.6 \text{ Hz}$, 1H), 7.33 ppm (td, $J = 6.0, 1.5 \text{ Hz}$, 1H). MS m/z (relative intensity): 233 (25, $\text{M}^+ + 2$) 231 (93, M^+), 196 (15, $\text{M}^+ - \text{Cl}$). Analytically calculated for $\text{C}_{13}\text{H}_{10}\text{ClNO}$: C, 67.40%; H, 4.35%; N, 6.05%. Found: C, 67.40%; H, 4.37% and N, 5.97%.

2.2.2. 2'-Chloro-4-methylbenzanilide ($\text{C}_{14}\text{H}_{12}\text{ClNO}$) (**1b**)

Yield: 92%; m.p. (crystallized from *n*-hexane) $93\text{--}95^\circ\text{C}$. UV (λ_{max} in acetonitrile) 261 nm ($\epsilon_{261} = 1.5 \times 10^4 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$), 235 nm ($\epsilon_{235} = 1.5 \times 10^4 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$). IR (KBr) 3286.6, 3034.2, and 1651.2 cm^{-1} . ^1H -NMR (DMSO- D_6): δ 9.95 (s, 1H), 7.92–7.89 (dt, $J = 8.1, 2.1 \text{ Hz}$, 2H), 7.61–7.58 (dd, $J = 7.8, 1.5 \text{ Hz}$, 1H), 7.57–7.54 (dd, $J = 7.8, 1.5 \text{ Hz}$, 1H), 7.41–7.26 (m, 4H) and 2.39 ppm (s, 3H). ^{13}C -NMR (DMSO- D_6) 165.25, 141.92, 135.16, 131.14, 129.54, 129.44, 129.05, 128.41, 127.73, 127.45, 127.38 and 21.04 ppm. MS m/z (relative intensity): 247 (1, $\text{M}^+ + 2$), 246 (0.74, $\text{M}^+ + 2 - 1$), 245 (4, M^+), 244 (1.0, $\text{M}^+ - 1$), 212 (3.2, $\text{M}^+ - \text{Cl}$), 210 (20), 119 (100, $\text{C}_8\text{H}_7\text{O}^+$), 91 (69, $\text{C}_7\text{H}_6\text{N}^+$), 77 (2, C_6H_5^+), 65 (73), 63 (40) and 51 (11). Analytically calculated for $\text{C}_{14}\text{H}_{12}\text{ClNO}$: C, 68.44%; H, 4.92%; N, 5.70%. Found: C, 68.13%; H, 4.94%; N, 5.69%.

2.2.3. 2'-Chloro-4-methoxybenzanilide ($\text{C}_{14}\text{H}_{12}\text{ClNO}_2$) (**1c**)

Yield 85%; m.p. (crystallized from *n*-hexane) $143\text{--}145^\circ\text{C}$ (lit. value $145\text{--}146^\circ\text{C}$) [21]. UV (λ_{max} in acetonitrile) $\lambda_{\text{max}} = 267 \text{ nm}$ ($\epsilon_{267} = 2.0 \times 10^4 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$). IR (KBr): 3285, 3034, 2839 and 1646 cm^{-1} . ^1H -NMR (DMSO- D_6): δ 9.88 (s, 1H), 7.97 (d, $J = 6.4 \text{ Hz}$, 2H),

7.61–7.57 (dd, $J = 8.4, 2.2$ Hz, 1H), 7.57–7.53 (dd, $J = 8.4, 2.2$ Hz, 1H), 7.38 (td, $J = 8.2, 2.1$ Hz, 1H), 7.31–7.25 (td, $J = 8.0, 2.2$ Hz, 1H), 7.07 (d, $J = 6.4$ Hz, 2H) and 3.97 ppm (s, 3H). $^{13}\text{C-NMR}$ (DMSO- D_6) 164.76, 162.09, 135.26, 129.63, 129.50, 129.40, 128.41, 127.42, 127.25, 126.03, 113.72 and 55.46 ppm. MS m/z (relative intensity): 263 (1, $\text{M}^+ + 2$), 261 (3, M^+), 226 (10, $\text{M}^+ - \text{Cl}$), 135 (100, $\text{C}_8\text{H}_7\text{O}_2^+$), 107 (10, $\text{C}_7\text{H}_6\text{O}^+$), 92 (25, $\text{C}_6\text{H}_5\text{N}^+$), 77 (36, C_6H_5^+) and 64 (26). Analytically calculated for $\text{C}_{14}\text{H}_{12}\text{ClNO}_2$: C, 64.25%; H, 4.62%; N, 5.35%. Found C, 64.51%; H, 4.63%; N, 5.27%.

2.3. Preparative photoreaction

2.3.1. Photoreaction of 2'-chloro-4-methylbenzanilide

To a large quartz immersion wall photolysis unit with provision for circulation of nitrogen was added 500 ml of acetonitrile (in another experiment 400 ml acetonitrile:100 ml H_2O or 400 ml acetonitrile:100 ml of 1 M aqueous NaOH) and 0.7 mmol of 2'-chloro-4-methylbenzanilide (**1b**). With nitrogen circulation, the solution was irradiated with a 450 W mercury lamp (medium pressure, 110 V) at 4 °C for 3 h. After evaporation of the solvent, preparative TLC developed by *n*-hexane/ethyl acetate (3:1) gave six components. They were identified as 9-methylphenanthridin-6(5)-one (**4b**), 4-methylbenzanilide (**2b**), 4'-amino-3'-chloro-4-methylbenzophenone (yellow color) (**6b**), 2'-chloro-4-methylbenzanilide (recovered) (**1b**), 2'-amino-3'-chloro-4-methylbenzophenone (yellow color) (**5b**) and 2-(4-methylphenyl)-1,3-benzoxazole, respectively (**3b**).

2.3.1.1. 4-Methylbenzanilide ($\text{C}_{14}\text{H}_{13}\text{NO}$) (**2b**). Yield 3.5% (CH_3CN), 8.4% ($\text{CH}_3\text{CN}:\text{NaOH}$); m.p. (crystallized from *n*-hexane) 134 °C. UV (λ_{max} in acetonitrile) 265 nm ($\epsilon_{265} = 1.6 \times 10^4 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$), 237 nm ($\epsilon_{237} = 1.3 \times 10^3 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$). IR (KBr): 3352, 3057, 2916 and 1649 cm^{-1} . $^1\text{H-NMR}$ (DMSO- D_6): δ 10.25 (s, 1H), 7.87 (d, $J = 8.0$ Hz, 2H), 7.77 (d, $J = 8.0$ Hz, 2H), 7.34 (t, $J = 8.0$ Hz, 4H), 7.09 (t, $J = 7.3$ Hz, 1 H), 2.38 ppm (s, 3H). $^{13}\text{C-NMR}$ (DMSO- D_6) 163.52, 163.44, 139.71, 137.42, 137.32, 130.27, 130.23, 127.07, 126.74, 125.86, 121.71, 118.54, 118.43, 19.18 ppm. MS m/z (relative intensity): 212 (6, MH^+), 211 (38, M^+), 119 (80, $\text{C}_8\text{H}_7\text{O}^+$), 91 (78, $\text{C}_6\text{H}_5\text{N}^+$), 77 (5, C_6H_5^+), 65 (100) and 51 (24). Analytically calculated for $\text{C}_{14}\text{H}_{13}\text{NO}$: C, 79.59%; H, 6.20%; N, 6.63%. Found C, 79.79%; H, 6.16%; N, 6.62%.

2.3.1.2. 2-(4-Methylphenyl)-1,3-benzoxazole ($\text{C}_{14}\text{H}_{11}\text{NO}$) (**3b**). Yield 6% (CH_3CN), 33% ($\text{CH}_3\text{CN}:\text{NaOH}$); m.p. (crystallized from ethanol) 112–114 °C (lit. 113–114 °C) [22]. UV (λ_{max} in cyclohexane) 314 ($\epsilon_{314} = 1.13 \times 10^4 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$), 301 nm ($\epsilon_{301} = 2.2 \times 10^4 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$), 294 nm ($\epsilon_{294} = 2.1 \times 10^4 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$). IR (KBr): 3055, 2918 and 1620 cm^{-1} . $^1\text{H-NMR}$ (400 MHz): δ 8.09, 8.07 (d, $J = 8.0$ Hz, 2H), 7.77 (t, $J = 8.0$ Hz,

2H), 7.42–7.38 (m, 4H) and 2.40 ppm (s, 3H). $^{13}\text{C-NMR}$ (DMSO- D_6): δ 168.02, 155.72, 147.73, 147.15, 135.54, 135.41, 132.82, 130.33, 129.29, 125.29, 116.46 and 26.74 ppm. MS m/z (relative intensity): 210 (11), 209 (100, M^+), 180 (4), 116 (5, $\text{C}_7\text{H}_5\text{NO}^+$), 105 (9, $\text{C}_5\text{H}_4\text{NO}^+$), 91 (36, C_7H_7^+), 77 (11), 64 (45), 63 (93) and 51 (25). Analytically calculated for $\text{C}_{14}\text{H}_{11}\text{NO}$: C, 80.36%; H, 5.30%; N, 6.69%. Found C, 80.10%; H, 5.46%; N, 6.50%.

2.3.1.3. 9-Methylphenanthridin-6(5)-one ($\text{C}_{14}\text{H}_{11}\text{NO}$) (**4b**).

Yield 34% (CH_3CN), 7% ($\text{CH}_3\text{CN}:\text{NaOH}$); m.p. (crystallized from *n*-hexane) 267–269 °C. UV (λ_{max} in acetonitrile) 334 nm ($\epsilon_{334} = 8.8 \times 10^3 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$), 320 nm ($\epsilon_{320} = 9.8 \times 10^3 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$), 308 nm ($\epsilon_{308} = 7.5 \times 10^3 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$), 270 nm ($\epsilon_{270} = 1.3 \times 10^4 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$), 261 nm ($\epsilon_{261} = 2.0 \times 10^4 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$), 252 nm ($\epsilon_{252} = 1.9 \times 10^4 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$), 239 nm ($\epsilon_{239} = 6.5 \times 10^4 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$), 233 nm ($\epsilon_{233} = 6.0 \times 10^4 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$). IR (KBr): 3441, 3007, 2884 and 1670 cm^{-1} . $^1\text{H-NMR}$ (DMSO- D_6): δ 11.56 (s, 1H), 8.29–8.16 (m, 3H), 7.41–7.32 (m, 4H), 2.49 ppm (s, 3H). $^{13}\text{C-NMR}$ (DMSO- D_6) 160.83, 143.01, 136.72, 134.24, 129.44, 129.16, 127.47, 123.30, 123.19, 122.50, 122.14, 117.52, 116.06, 21.54 ppm. MS m/z (relative intensity): 210 (13), 209 (100, M^+), 181 (3, $\text{M}^+ - \text{CO}$), 180 (16), 152 (4), 105 (6), 91 (5), 90 (20), 76 (25), 63 (28) and 51 (15). Analytically calculated for $\text{C}_{14}\text{H}_{11}\text{NO}$: C, 80.36%; H, 5.30%; N, 6.69%. Found C, 80.22%; H, 5.28%; N, 6.68%.

2.3.1.4. 2'-Amino-3'-chloro-4-methylbenzophenone ($\text{C}_{14}\text{H}_{12}\text{ClNO}$) (**5b**).

Yield 1% (CH_3CN), 7% ($\text{CH}_3\text{CN}:\text{NaOH}$); m.p. (crystallized from *n*-hexane) 68 °C. UV (λ_{max} in CH_3CN) 370 nm ($\epsilon_{370} = 3.2 \times 10^3 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$), 262 nm ($\epsilon_{262} = 7.1 \times 10^3 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$) and 233 nm ($\epsilon_{233} = 1.1 \times 10^4 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$). IR (KBr): 3422, 3318, 2926, 2855 and 1728 cm^{-1} . $^1\text{H-NMR}$ (DMSO- D_6): δ 7.48 (m, 3H), 7.26 (m, 3H), 6.87 (s, 2H), 6.56 (m, 1H), 2.24 ppm (s, 3H). MS m/z (relative intensity): 247 (10, $\text{M}^+ + 2$), 246 (18, $\text{M}^+ + 1$), 245 (33, M^+), 244 (43, $\text{M}^+ + 1$), 232 (11, $\text{M}^+ + 2 - \text{CH}_3$), 230 (24, $\text{M}^+ - \text{CH}_3$), 153 (9), 119 (22, $\text{C}_8\text{H}_7\text{O}^+$), 91 (62, C_7H_7^+), 65 (100). Analytically calculated for $\text{C}_{14}\text{H}_{12}\text{ClNO}$: C, 68.44%; H, 4.92%; N, 5.70%. Found C, 68.89%; H, 5.13%; N, 5.46%.

2.3.1.5. 4'-Amino-3'-chloro-4-methylbenzophenone ($\text{C}_{14}\text{H}_{12}\text{ClNO}$) (**6b**).

Yield 3% (CH_3CN), 7% ($\text{CH}_3\text{CN}:\text{NaOH}$). UV (λ_{max} in acetonitrile) 317 nm ($\epsilon_{317} = 4.3 \times 10^3 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$), 240 nm ($\epsilon_{240} = 7.3 \times 10^3 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$) and 205 nm ($\epsilon_{205} = 1.4 \times 10^4 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$). $^1\text{H-NMR}$ (400 MHz): δ 7.37, 7.36 (d, $J = 2.0$ Hz, 1H), 7.32, 7.29 (d, $J = 8.0$ Hz, 2H), 7.26, 7.24 (d, $J = 8.5$ Hz, 1H), 7.10, 7.08 (d, $J = 8$ Hz, 2H), 6.62, 6.60 (d, $J = 8.52$ Hz, 1H), 6.12 (s, 2H) and 3.10 ppm (s, 3H). MS m/z (relative intensity): 247 (13, $\text{M}^+ + 2$), 245 (31, M^+), 232 (3, $\text{M}^+ + 2 - \text{CH}_3$), 230 (7, $\text{M}^+ - \text{CH}_3$), 210 (7, $\text{M}^+ - \text{Cl}$), 180 (1), 154 (32), 119 (23, $\text{C}_8\text{H}_7\text{O}^+$), 91 (100, C_7H_7^+), 65 (70).

2.3.2. Photoreaction of 2'-chloro-4-methoxybenzanilide

To a large (500 ml) quartz immersion wall photolysis unit with provision for circulation of nitrogen was added 500 ml of acetonitrile (in another experiment 400 ml acetonitrile and 100 ml 1 M aqueous NaOH) and 0.7 mmol of 2'-chloro-4-methoxybenzanilide (**1c**). With nitrogen circulation, the solution was irradiated with 450 W mercury lamp (medium pressure, 110 V) at 4 °C for 3 h. After evaporation of the solvent, preparative TLC developed by *n*-hexane/ethyl acetate (3:1) gave six components. They were identified as 9-methoxyphenanthridin-6(5)-one (**4c**), 4-methoxybenzanilide (**2c**), 4'-amino-3'-chloro-4-methoxybenzophenone (traces <1% identified by its yellow color and its UV-spectrum) (**6c**), 2'-chloro-4-methoxybenzanilide (recovered) (**1c**), 2'-amino-3'-chloro-4-methoxybenzophenone (yellow color) (**5c**) and 2-(4-methoxyphenyl)-1,3-benzoxazole, respectively (**3c**).

2.3.2.1. 4-Methoxybenzanilide (C₁₄H₁₃NO₂) (2c). Yield 30% (CH₃CN), 11% (CH₃CN:NaOH); m.p. (crystallized from cyclohexane:ethyl acetate) 154–156 °C. UV (λ_{\max} in CH₃CN) 272 nm ($\epsilon_{272} = 2.0 \times 10^4 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$). IR (KBr) 3343, 3051, 2959, 1657 cm⁻¹. ¹H-NMR (DMSO-D₆): δ 10.08 (s, 1H), 7.97, 7.95 (d, *J* = 8.8 Hz, 2H), 7.77, 7.75 (d, *J* = 7.7 Hz, 2H), 7.34 (t, *J* = 7.7, 8.0 Hz, 2H), 7.08 (m, 3H), 3.97 ppm (s, 3H). ¹³C-NMR (DMSO-D₆) 165.25, 162.22, 139.66, 129.92, 128.89, 127.30, 123.77, 120.68, 113.94, 55.77 ppm. MS *m/z* (relative intensity): 228 (2), 227 (14, M⁺), 135 (100, C₈H₇O₂⁺), 107 (11, C₇H₆O⁺), 92 (16, C₆H₅N⁺), 77 (34, C₆H₅⁺), 65 (13) and 51 (5). Analytically calculated for C₁₄H₁₃NO₂: C, 73.99%; H, 5.77%; N, 6.16%. Found C, 74.02%; H, 5.77%; N, 6.20%.

2.3.2.2. 2-(4-Methoxyphenyl)-1,3-benzoxazole (C₁₄H₁₁NO₂) (3c). Yield 9.2% (CH₃CN), 32% (CH₃CN:NaOH); m.p. 90 °C (lit. 95 °C) [22,23].² UV (λ_{\max} in cyclohexane) 321 nm ($\epsilon_{321} = 1.8 \times 10^4 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$), 306 nm ($\epsilon_{306} = 3.4 \times 10^4 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$), 299 nm ($\epsilon_{299} = 3.2 \times 10^4 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$), 294 nm ($\epsilon_{294} = 3.2 \times 10^4 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$). IR (KBr): 3049, 2982 and 1616 cm⁻¹. ¹H-NMR (400 MHz): δ 8.15, 8.12 (d, *J* = 9 Hz, 2H), 7.76–7.72 (m, 2H), 7.38–7.36 (m, 2H), 7.16, 7.13 (d, *J* = 9 Hz, 2H), and 3.85 ppm (s, 3H). ¹³C-NMR (DMSO-D₆): δ 162.37, 162.17, 150.10, 141.68, 129.12, 124.96, 124.70, 119.41, 118.74, 114.78, 110.69 and 55.51 ppm. MS *m/z* (relative intensity): 225 (63, M⁺), 210 (24) 182 (33), 64 (37), 58 (51) and 44 (100). Analytically calculated for C₁₄H₁₁NO₂: C, 74.65%; H, 4.92%; N, 6.22%. Found C, 74.51%; H, 4.92%; N, 6.25%.

2.3.2.3. 9-Methoxyphenanthridin-6(5)-one (C₁₄H₁₁NO₂) (4c). Yield 31% (CH₃CN), 17% (CH₃CN:NaOH); m.p. (crystallized from *n*-hexane) 238–240 °C. UV (λ_{\max}

in CH₃CN) 332 nm ($\epsilon_{332} = 4.0 \times 10^3 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$), 320 nm ($\epsilon_{320} = 3.9 \times 10^3 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$), 280 nm ($\epsilon_{280} = 3.6 \times 10^3 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$), 262 nm (sh, $\epsilon_{262} = 1.3 \times 10^4 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$), 246 nm ($\epsilon_{246} = 2.8 \times 10^4 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$). IR (KBr): 3470 (weak), 3002, 2833, 1656 cm⁻¹. ¹H-NMR (DMSO-D₆): δ 11.50 (s, 1H), 8.42, 8.39 (d, *J* = 7.8 Hz, 1H), 8.24, 8.21 (d, *J* = 8.7 Hz, 1H), 7.88, 7.87 (d, *J* = 2.4 Hz, 1H), 7.47 (t, *J* = 8.1 Hz, 1H), 7.35, 7.33 (d, *J* = 8.1 Hz, 1H), 7.27–7.19 (m, 2H) and 3.97 ppm (s, 3H). MS *m/z* (relative intensity): 226 (7), 225 (44, M⁺), 196 (3, M⁺–CO), 182 (8, M⁺–CONH), 167 (3), 154 (11), 105 (4), 98 (3), 77 (10), 58 (100), 44 (58). Analytically calculated for C₁₄H₁₁NO₂: C, 74.65%; H, 4.92%; N, 6.22%. Found C, 74.33%; H, 4.94%, N, 6.19%.

2.3.2.4. 2'-Amino-3'-chloro-4-methoxybenzophenone (C₁₄H₁₂ClNO₂) (5c). Yield 4.1% (CH₃CN), 2.43 (CH₃CN:NaOH); m.p. (crystallized from ethanol) 120–122 °C. UV (λ_{\max} in CH₃CN) 367 nm ($\epsilon_{367} = 8.1 \times 10^3 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$), 284 nm ($\epsilon_{284} = 1.6 \times 10^4 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$) and 231 nm ($\epsilon_{231} = 3.3 \times 10^4 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$). ¹H-NMR (DMSO-D₆): δ 7.62, 7.59 (d, *J* = 12 Hz, 2H), 7.53–7.49 (dd, *J* = 10.4, 2.0 Hz, 1H), 7.31–7.28 (dd, *J* = 10.4, 2.0 Hz, 1H), 7.07, 7.04 (d, *J* = 12 Hz, 2H), 6.70 (s, 2H), 6.61 (t, *J* = 10.4 Hz, 1H), 3.84 ppm (s, 3H). MS *m/z* (relative intensity): 262 (13, M⁺ + 2), 261 (28, M⁺ + 1), 260 (37, M⁺), 246 (13), 154 (12), 135 (20, C₈H₇O₂⁺), 92 (14), 90 (15, C₆H₅⁺), 77 (14, C₆H₅⁺) and 63 (20). Analytically calculated for C₁₄H₁₂NO₂: C, 64.25%; H, 4.62%; N, 5.35%. Found C, 64.28%; H, 4.60%, N, 5.35%.

3. Results and discussion

The electronic spectra of 2'-chloro-4-R-benzanilides (**1a** (R=H), **1b** (R=CH₃), **1c** (R=CH₃O)) in acetonitrile are presented in Fig. 1. The maximal absorptions (λ_{\max}) were 260 nm for **1a** ($\epsilon_{260} = 1.2 \times 10^4 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$), 235 and 261 nm ($\epsilon_{235} = 1.5 \times 10^4 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$ and $\epsilon_{261} = 1.5 \times 10^4 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$, respectively) for **1b**, and 267 nm ($\epsilon_{267} = 2.0 \times 10^4 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$) for **1c**, respectively. Upon irradiation with Xe-lamp (cut-off filter of alcohol reagent to eliminate light shorter than 215 nm), the spectrum of **1a** showed sharp isosbestic points at $\lambda = 227$, 250 and 277 nm. The spectrum of **1b** showed sharp isosbestic points at $\lambda = 218$, 245 and 286 nm. The isosbestic points in the spectrum of **1c** appeared at $\lambda = 217$, 253 and 289 nm. The clear appearance of isosbestic points can be considered as a good indication for the conversion of **1** to a single new product [2,25,26], while the case is not always as that [12,27,28]. The chemical yield of the products and their extinction coefficients play a major role in representing these isosbestic points. For example, the ϵ (benzoxazole) is in the order of 10⁴ at ~300 nm; this value is more than fivefold higher than the extinction coefficients of the rest of photoproducts at this region of the spectrum, whereas the

² The literature values for the melting point of 2-(4'-methoxyphenyl)-1,3-benzoxazole is varied from 95 °C in Ref. [21] to 101 °C in Ref. [20] to 105 °C. See Ref. [24].

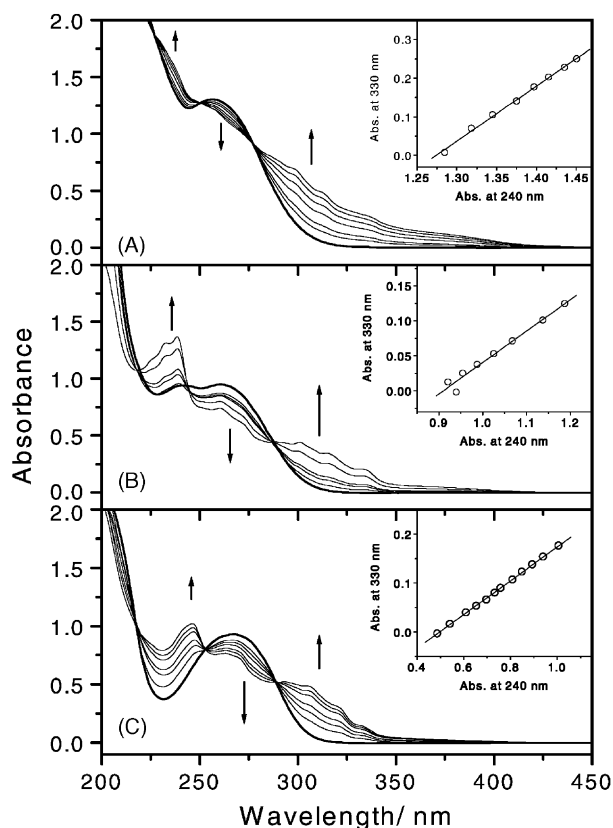


Fig. 1. UV absorption spectral change upon irradiation with filtered light from Xe-lamp (cut off filter of alcohol reagent) in pure acetonitrile degassed with nitrogen gas prior to irradiation: (A) $1.10 \times 10^{-4} \text{ mol dm}^{-3}$ 2'-chlorobenzanilide in acetonitrile solution (irradiation time: 0, 1.5, 2.5, 4.5, 6.5, 8.5 and 10 min); (B) $6.18 \times 10^{-5} \text{ mol dm}^{-3}$ 2'-chloro-4-methylbenzanilide (irradiation time: 0, 0.33, 0.75, 1.0, 1.5, 2.5 and 5 min); (C) $4.65 \times 10^{-5} \text{ mol dm}^{-3}$ 2'-chloro-4-methoxybenzanilide (irradiation time: 0, 0.33, 0.67, 1.0, 2.0, 3.0 and 4.0 min). The tick lines in the figure show the spectra of non-irradiated sample. Insets show the plotting of the signal intensity at 330 nm against signal intensity at 240 nm.

$\epsilon(\text{phenanthridone})$ is in order of 10^4 at $\sim 240 \text{ nm}$, being also one order higher than the extinction coefficients of the other photoproducts at this particular wavelength. This suggests that the absorption of the small yield of product **3** around 300 nm is higher than (or comparable to) the absorption of the relatively high yield of product **4** at this wavelength. It seems that the isosbestic point at longer wavelength is governed by the formation of photoproduct **3**, and that at shorter wavelength is governed by the formation of photoproduct **4** (see Fig. 2). The photo-Fries type products have no much effect due to their low yield and relatively low extinction coefficients. 9-R-Phenanthridin-6(5)-ones absorb approximately at 240 nm ($\epsilon_{240} \cong 3\text{--}7 \times 10^4 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$) and at 330 nm ($\epsilon_{330} \cong 4\text{--}9 \times 10^3 \text{ dm}^3 \text{ mol}^{-1} \text{ cm}^{-1}$), respectively, plotting the absorption at $\lambda = 330 \text{ nm}$ against the absorption at $\lambda = 240 \text{ nm}$ of Fig. 1 results in a good linear relationship for **4a–c** (inset of Fig. 1A–C).

The absorption spectrum of irradiated solution of **1c** in acetonitrile, along with its spectrum in acetonitrile:aqueous sodium hydroxide is presented in Fig. 3 for comparison.

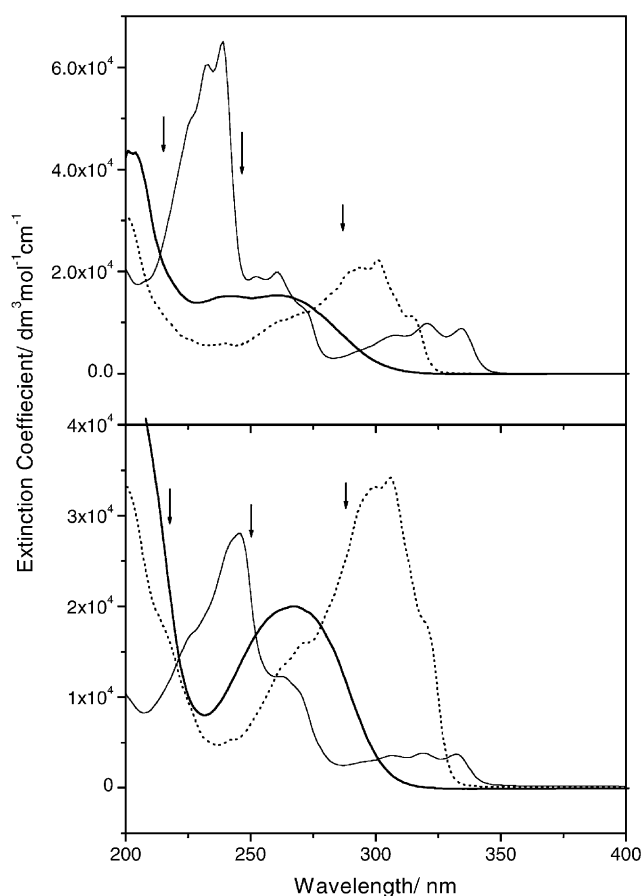


Fig. 2. The UV absorption spectra of 2'-chloro-4-R-benzanilide (thick solid line), 9-R-phenanthridone (solid line) and 2-(4-R-phenyl)-1,3-benzoxazole (dotted line). Top R = CH₃ and bottom R = CH₃O (the arrows indicate the location of the isosbestic points appeared in Fig. 1).

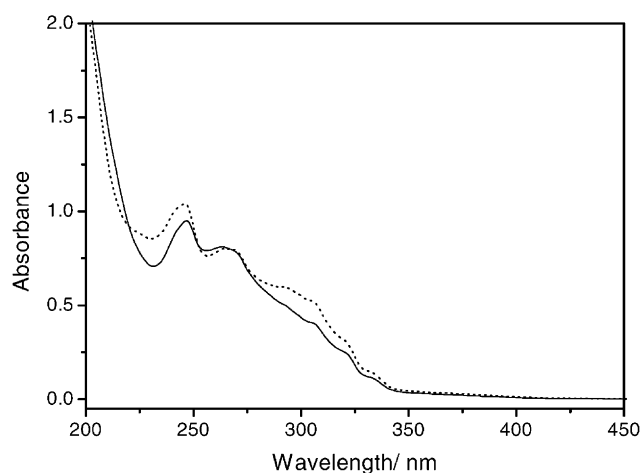


Fig. 3. Absorption spectra of the irradiated solution of 2'-chloro-4-methoxybenzanilide ($4.65 \times 10^{-5} \text{ mol dm}^{-3}$) in degassed solution of pure acetonitrile (solid line) and in acetonitrile:aqueous sodium hydroxide solution (dotted line). The samples were irradiated for 2 min with Xe-lamp ($\lambda > 215 \text{ nm}$).

It is obvious from Fig. 3 that the intensity at $\lambda \cong 300$ nm ($\sim\lambda_{\max}$ of **3c**) is higher in basic medium than in neutral aprotic medium. This reflects the fact of the medium influence on the formation of photosubstitution product **3c**. The same trend was observed from the irradiation of 2'-bromobenzanilide [12], 2'-chlorobenzanilide and 2'-chloro-4-methylbenzanilide.

When the reaction was carried in Pyrex immersion wall photolysis apparatus with circulating nitrogen gas, the isolated photoproducts (Schemes 2 and 3) were the reduction photoproduct 4-R-benzanilide (**2**), the intramolecular photosubstitution product 2-(4-R-phenyl)-1,3-benzoxazole (**3**), the intramolecular photocyclization product 9-R-phenanthridin-6(5)-one (**4**), the *ortho*-photo-Fries type product, 2'-amino-3'-chloro-4-R-benzophenone (**5**), and the *para*-photo-Fries type product, 4'-amino-3'-chloro-4-R-benzophenone (**6**). The chemical yields of these photoproducts in acetonitrile medium are shown in Scheme 2, and in acetonitrile–aqueous NaOH are shown in Scheme 3.

The chemical yield reveals that the photocyclization is the major product in neutral aprotic medium, while the photosubstitution is the major product in protic and basic media (Table 1). This is probably due to the conformational and tautomeric changes [1,2,18] of the reactant in different media upon photolysis, in which in protic (or basic) medium, the mesomeric imidol-form **II** with a rigid double bond between amide nitrogen and carbon of carbonyl group (Chart 1) will prefer the *trans*-form [18]. The *trans*-form allows for intramolecular photosubstitution reaction, i.e. it increases the yield of benzoxazole as evidenced from Table 1 (as well as from Schemes 2 and 3). While in neutral aprotic medium,

Table 1

The yield of 2-(4-methylphenyl)-1,3-benzoxazole (**3b**) and 9-methylphenanthridin-6(5)-one (**4b**) from the photoreaction of 2'-chloro-4-methylbenzanilide in different media

Medium	Photoproduct yield (%)	
	3b	4b
CH ₃ CN	6	34
10% H ₂ O:CH ₃ CN	33	7
10% aqueous NaOH:CH ₃ CN	32	7

the single amide bond of mesomeric structure **Ia** will allow for the rotation of benzoyl group, and hence conformational change to mesomeric *cis*-form **Ib** that assist the photocyclization reaction [2,6], the result is an increase in the yield of phenanthridone. These results agree well with the solvent induced ¹⁵N-NMR shift [18], which interpreted as due to the increase in the contribution of the polar mesomeric structure **II** with increasing solvent polarity. The electron-donating substituent at *para* position play another role (Chart 1), the transmission of the resonance will lead to the formation of an enol-form **IIIa**. The two mesomeric forms **II** and **IIIa** are in competition, but in presence of electron-donating group, the mesomeric **IIIa** becomes more important. The enhancement of the negative charge on oxygen atom in structure **IIIa** relative to structure **II** due to the increase of the electron donation of the substituent will lead to increase the nucleophilicity of the oxygen atom, and hence increases the yield of photosubstitution [18,29,30] product **3** as evidenced from Schemes 2 and 3. Mesomeric form **IIIa** still can change its conformation to **IIIb** and enhances the formation of phenanthridone relative to non-substituted 2'-chlorobenzanilide.

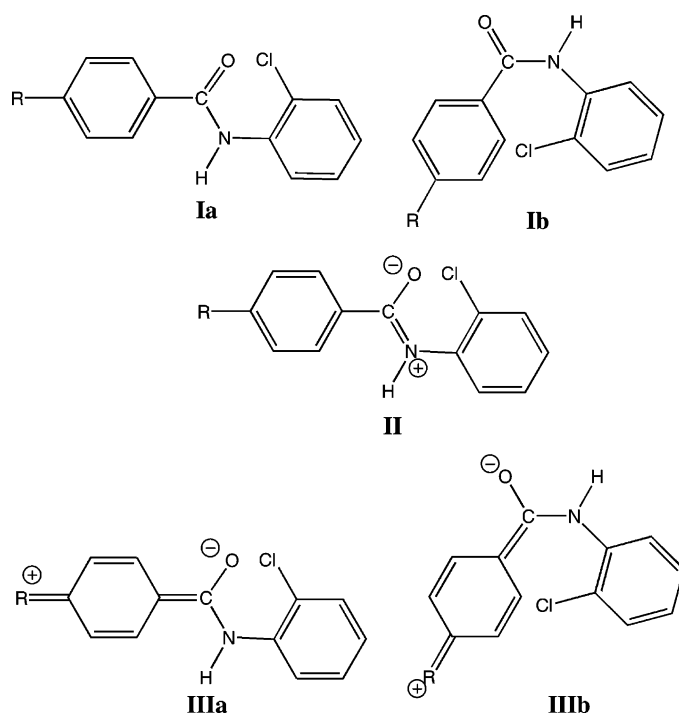
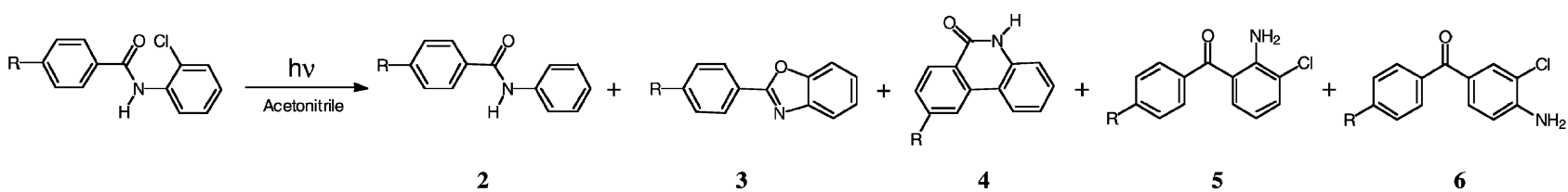
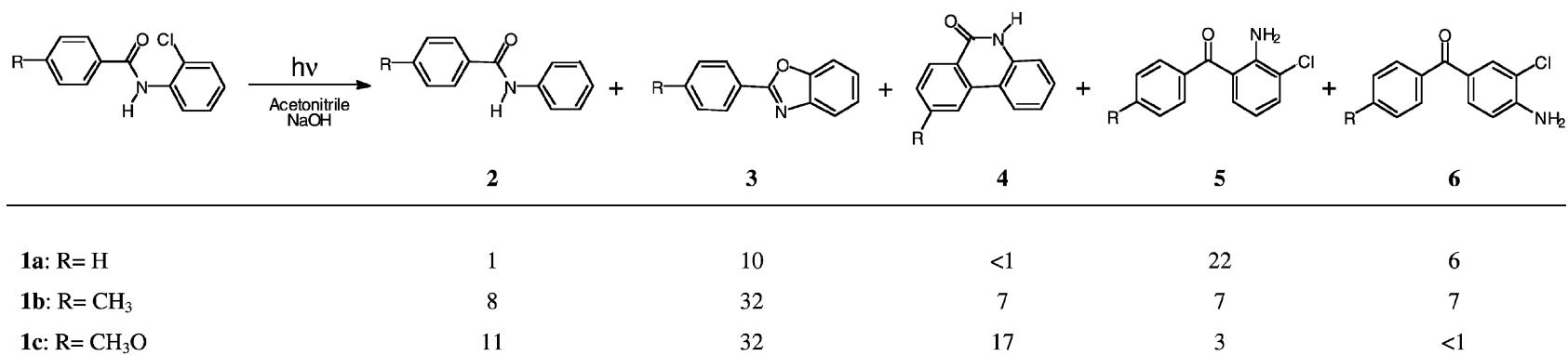


Chart 1.



	2	3	4	5	6
1a: R= H	5	3	19	4	3
1b: R= CH ₃	4	6	34	1	3
1c: R= CH ₃ O	30	9	31	4	2

Scheme 2.



Scheme 3.

As a conclusion, we showed that the intramolecular photostitution and photocyclization reactions of benzanilides could be greatly accelerated by introducing a suitable substituent and choosing a reasonable solvent. We have shown that the nucleophilicity of the oxygen and the conformational structure of the reactant are the major factors in controlling the photoproducts yield of benzoxazole and phenanthridone. These two factors, in addition to the leaving group [12], can be tuned through substituent and solvent. The chemistry observed here, concerning both, the solvent and the substituent effect on the photoreaction of benzanilides agree well with literature [16–19] observation of the solvent and substituent effect on the NMR chemical shift of substituted benzanilides. Further studies on the reaction mechanisms will be published separately.

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