Effect of *para*-Substituents on the Photochemical Ring-opening Reactivity of 1-(*p*-Substituted-benzoyl)aziridines in Methanol

Sei-ichi Nishimoto, Tsukuru Izukawa, Yasushi Haruta, and Tsutomu Kagiya[•] Department of Hydrocarbon Chemistry, Faculty of Engineering, Kyoto University, Kyoto 606, Japan

Photolysis of 1-(p-substituted-benzoyl) aziridines (1a-e) in Ar-purged methanol led to N-(2-methoxyethyl) benzamides (3b-e) as the methanolysis products and/or N-ethylbenzamides (2a and b). Penta-1,3-diene quenched the formation of (2a and b) but not (3b-e).

Photosolvolytic reactions¹ including the photoalcoholysis of three-membered ring compounds² have attracted mechanistic interest. We reported previously³ that 1-(2-naphthoyl)aziridine undergoes photochemical ring opening at the aziridinyl moiety to produce a methanolysis product, *N*-(2-methoxyethyl)-naphthalene-2-carboxamide, in methanol, and *N*-ethyl-naphthalene-2-carboxamide via homolysis in propan-2-ol. More recently, the reactivities of excited singlet and triplet states [^{1.3}(π,π^{*})] of 1-(2-naphthoyl)aziridine in a series of alcohols have been characterized in further detail.⁴ This paper describes a study of substituent effects on the photochemical ring-opening mode, whether heterolysis or homolysis, of *para*substituted 1-benzoylaziridines (1a-e) in methanol under Ar.

Results and Discussion

Irradiation (λ_{ex} > 290 nm) of an Ar-purged methanol solution of 1-benzoylaziridine (1a) (29mm) led to N-ethylbenzamide (2a) (23%) along with the ring-opened oligomer of (1a) (Table). This is analogous to the photolysis of the 2-naphthoyl analogue in propan-2-ol which produces N-ethylnaphthalene-2-carboxamide³ Thus, the ring opening of (1a) by a radical mechanism accounts for the formation of (2a).^{3,4} In contrast, photolyses of a series of para-substituted 1-benzoylaziridines (1b-e) (25-33mm) gave rise to the corresponding N-(2-methoxyethyl) derivatives (3b-e) (5-100%) as the methanolysis products. Although photomethanolysis occurred selectively for (1c and d), a homolysis product (2b) was also produced in the photoreaction of (1b). The products were identified by comparison with authentic specimens. These reaction characteristics show a trend that the introduction of para-substituents into (1a) favours photomethanolysis of the aziridine-ring moiety, which possibly proceeds by an ionic mechanism.^{3.4}

It is also noteworthy that the nitro substituent of (1e) undergoes photoreduction to the amino group under mild conditions. Thus, upon irradiation of (1e) for 5 h the product mixture included N-(2-methoxyethyl)-p-aminobenzamide (4) (10%) along with N-(2-methoxyethyl)-p-nitrobenzamide (3e) (18%) and larger amounts of several unidentified products (52%)from the material balance) (Table). Prolonged irradiation up to 70 h under the same conditions, however, led to (4) almost quantitatively. In a control experiment, (3e) (21mm) was found to be reduced to (4) (22%) when irradiated for 11 h in Ar-purged methanol. As for the photoreaction of (1e) as above, a mixture of intermediate products (47% from the material balance) was formed simultaneously. Furthermore, the time-course experiments revealed that the intermediate products undergo photoreduction successively to produce the final product $(\bar{4})$.⁵ These results provide the possibility that (1e) is first converted into (3e) by photomethanolysis which is subsequently photoreduced to (4). In the light of the quenching experiment described below, an alternative pathway of initial reduction of the nitro substituent of (1e) followed by methanolysis of the aziridinering moiety is also quite likely for the formation of (4).

The quenching of the photoreactions of (1a-e) with penta-1,3-diene was also determined. As shown in the Table, the formation of (2a) was completely quenched but the

$$x - \underbrace{(1)}_{(1)} \overset{0}{\underset{CH_{3} \text{ OH}}{(1)}} x = Br \qquad (2) \ Y = H \\ b; \ x = CH_{3} \ e; \ X = NO_{2} \qquad (3) \ Y = OCH_{3} \\ c; \ x = CH_{3}O \qquad (4) \ x = NH_{2}, \ Y = OCH_{3}$$

Photolysis of 1-(p-substituted-benzoyl)aziridines (1a-e) in the absence and presence of penta-1,3-diene in Ar-purged methanol^a

Compound	[(1)]/ mм	[Penta-1,3-diene]/ тм	Irradiation time (h)	Conversion of (1) (%)	Yield ^b (%)			
					(2)	(3)	(4)	Others
(12)	29	0	5.8	45	23	0		22°
	29	73	5.0	19	0	0		19°
(1b)	33	0	5.3	25	11	14		0
	30	39	5.0	14	1	13		0
(1c)	25	0	5.1	5	0	5		0
	21	46	5.0	6	0	6		0
(1d)	26	0	5.0	100	0	100		0
	21	50	5.0	100	0	100		0
(1e)	26	0	5.0	80	0	18	10	52ª
	26	30	5.0	63	0	16	5	42 <i>ª</i>

^a Irradiated ($\lambda_{ex.} > 290 \text{ nm}$) with 400 W high-pressure mercury arc at room temperature. ^b Yields were determined by means of ¹H n.m.r. and h.p.l.c. analyses and are based on the starting aziridines. ^c Ring-opened oligomer of (1a). ^d Mixture of unidentified products and the yield was derived from the material balance.

accompanied oligomer formation was barely affected by penta-1,3-diene (73mm). In contrast, the yields of (3c and d) were not reduced by the addition of the diene up to 50mm. Similarly, the yield of (2b) was reduced by 91% in the presence of the diene (39mm), whereas that of (3b) was virtually invariant. In the case of the photoreaction of (1e), the diene (30mm) quenched the reduction of the nitro group leading to (4) and intermediate products but hardly decreased the yield of (3e). These quenching data are consistent with the mechanism⁴ that the photomethanolysis reaction occurs from the excited singlet states (π,π^*) of the *p*-substituted-benzovl moieties of aziridines. while the homolysis products result from their lowest triplet states³ (π,π^*) . In addition, the photoreduction of (1e) to (4) must be a triplet reaction as is commonly the case for aromatic nitro compounds. It is evident from the Table that the quenching of these triplet reactions accounts for decreased conversions of (1a, b, and e) in the presence of penta-1,3-diene. This in turn implies that the triplet state of (1e) can be reduced at the nitro group while preserving the aziridine ring. In association with the above mechanism, the quantitative conversion of (1d) into (3d) is also noteworthy. Thus, it is suggested that the excited singlet state of (1d) undergoes methanolysis more rapidly than if pronounced intersystem crossing takes place, as a result of the internal heavy-atom effect ⁶ of the bromo substituent, to the triplet state. The origin of the dual reactivity of (1b) to produce both (2b) and (3b) is now being explored.

For comparison, Ar-purged solutions of (1c and d) (24mM) in propan-2-ol were also irradiated for 5 h. In contrast to the heterolytic ring-opening reaction in methanol, the formation of *N*-ethyl derivatives (2c) (61%) and (2d) (100%) under these conditions was observed by ¹H n.m.r. This indicates that propan-2-ol can be a less reactive nucleophile compared with methanol, but a better hydrogen donor for the aziridine rings of (1c and d) in their excited states.

In summary we have shown that the photochemical ringopening mode of 1-(*p*-substituted-benzoyl)aziridines depends significantly on the *para*-substituents as well as the alcohol solvents employed.

Experimental

Materials—Methanol and propan-2-ol were of spectroscopic grade and used without further purification. Penta-1,3-diene (*cis-trans* mixture) was distilled before use.

Preparation of (1a-e).-The 1-(p-bromobenzoyl)aziridine (1d) was prepared by the reaction of aziridine (1.6 g, 37 mmol) with *p*-bromobenzoyl chloride (7.8 g, 36 mmol) in the presence of triethylamine (3.6 g, 35 mmol) in acetone (320 ml), in a manner analogous to the preparation of 1-(2-naphthoyl)aziridine.³ The crude reaction mixture was chromatographed on a silica gel column and (1d) (3.3 g, 41%) was eluted with CH₂Cl₂, δ_H(CDCl₃) 2.38 (4 H, s), 7.58 (2 H, d, J 8.0 Hz), and 7.95 (2 H, d, J 8.0 Hz) (Found: C, 47.9; H, 3.5; N, 6.3; O, 6.8; Br, 35.4. C₉H₈BrNO requires C, 47.8; H, 3.6; N, 6.2; O, 7.1; Br, 35.3%). The aziridines (1a-c) were prepared following the reported procedures 7 and purified by vacuum distillation, column chromatography on silica gel with CH_2Cl_2 , and repeated recrystallization from diethyl ether. 1-(p-Nitrobenzoyl)aziridine (1e) was prepared by the method reported ⁸ and purified by repeated recrystallization from light petroleum. All compounds (1a-e) gave satisfactory spectroscopic and elemental analysis data.

Spectroscopic Measurements.—I.r. spectra were measured with a JASCO A-302 spectrophotometer. ¹H N.m.r. spectra were recorded on a JEOL PMX-60 spectrometer with tetramethylsilane as internal standard.

Photolyses and Analyses.—Solutions of (1a—e) (25—33mm) in methanol or propan-2-ol (20 ml) were placed in a Pyrex glass tube (17 mm in diameter), purged for 30 min with Ar under cooling, and then sealed off before irradiation. Irradiation was performed at room temperature using a merry-go-round apparatus equipped with a 400 W high-pressure mercury arc (Eiko-sha 400). After removal of the solvent, the residual mixture was subjected to spectroscopic measurements and h.p.l.c. analysis with a TOYO SODA HLC-802UR highperformance liquid chromatograph under the conditions reported.³ Conversions of the aziridines and the product yields were determined by the simultaneous use of ${}^{1}H$ n.m.r. (CDCl₃) and h.p.l.c. (eluted with tetrahydrofuran). Benzene was used as internal standard for h.p.l.c. In the ¹H n.m.r. analysis, the decrement in the aziridinyl protons of (1a-e) and the increment in the methyl protons of (2a and b) or the methoxy protons of (3b-e) were measured by reference to the total amount of the benzoyl protons of all components. The relative errors were estimated as $<\pm 7\%$ except for the yield of (3c) which is $\pm 18\%$.

In the quenching experiments, Ar-purged solutions of (1a - e)(21-30mM) in methanol containing penta-1,3-diene (30-73mM) were irradiated under the same conditions as above.

Identifications.—The photoproducts obtained by the preparative irradiations of the aziridines (1a, b, d, and e) (> ca. 80% conversions) in Ar-purged methanol were identical with authentic specimens prepared as follows.

(a) N-Ethylbenzamide (2a) and N-Ethyl-p-methylbenzamide (2b).—Benzoyl chloride (1.8 g, 13 mmol) was added dropwise to a mixture of aqueous (70%) ethylamine (8.3 ml, 13 mmol) and NaOH (0.6 g, 15 mmol) in water (300 ml) maintained at below 0 °C. The reaction mixture was extracted with CH₂Cl₂ and the organic layer was washed with water. Evaporation of CH₂Cl₂ in vacuo followed by recrystallization from hexane gave (2a) (1.8 g, 90%), δ_H(CDCl₃) 1.22 (3 H, t, J 7.1 Hz), 3.49 (2 H, qd, J 6.6, 1.8 Hz), 6.29 (1 H, br), and 7.53 (5 H, m) (Found: C, 72.6; H, 7.6; N, 9.3; O, 10.4. C₉H₁₁NO requires C, 72.5; H, 7.4; N, 9.4; O, 10.7%). Similarly, the reaction of *p*-methylbenzoyl chloride with aqueous ethylamine in the presence of NaOH gave 77% (2b), δ_H(CDCl₃) 1.23 (3 H, t, J7.1 Hz), 2.40 (3 H, s), 3.55 (2 H, qd, J6.7, 1.8 Hz), 6.25 (1 H, br), 7.22 (2 H, d, J 8.0 Hz), and 7.70 (2 H, d, J 8.0 Hz) (Found: C, 73.6; H, 8.0; N, 8.3; O, 9.6. C₁₀H₁₃NO requires C, 73.6; H, 8.0; N, 8.6; O, 9.8%).

(b) N-(2-Methoxyethyl)-p-methylbenzamide (3b), N-(2-N-(2-Methoxyethyl)-p-bromobenzamide and (**3d**), Methoxyethyl)-p-nitrobenzamide (3e).—Typically, to a solution of the aziridine (1b, d, or e) (ca. 250 mg) in methanol (150 ml), a catalytic amount of BF₃·OEt₂ was added under Ar and left for 30 min under stirring. After the addition of water (ca. 30 ml), the resulting mixture was extracted with 30% v/v benzene-CHCl₃ to give >90% of the title product. Compound (3b) showed δ_H(CDCl₃) 2.38 (3 H, s), 3.38 (3 H, s), 3.63 (4 H, m), 6.47 (1 H, br), 7.22 (2 H, d, J 8.2 Hz), and 7.72 (2 H, d, J 8.2 Hz) (Found: C, 68.6; H, 7.9; N, 7.3; O, 16.2. C₁₁H₁₅NO₂ requires C, 68.4; H, 7.8; N, 7.25; O, 16.6%). Compound (3d) showed $\delta_{H}(CDCl_{3})$ 3.38 (3 H, s), 3.58 (4 H, m), 6.56 (1 H, br), and 7.60 (4 H, s) (Found: C, 46.6; H, 4.9; N, 5.4; O, 12.4; Br, 30.7. C₁₀H₁₂BrNO₂ requires C, 46.5; H, 4.65; N, 5.4; O, 12.4; Br, 31.0%). Compound (3e) showed $\delta_{H}(CDCl_3)$ 3.40 (3 H, s), 3.60 (4 H, m), 6.98 (1 H, br), 7.85 (2 H, d, J 8.4 Hz), and 8.21 (2 H, d, J 8.4 Hz) (Found: С, 54.0; H, 5.4; N, 12.65; O, 27.95. $C_{10}H_{12}N_2O_4$ requires C, 53.6; H, 5.4; N, 12.5; O, 28.6%).

(c) N-(2-Methoxyethyl)-p-aminobenzamide (4).—Compound (3e) (110 mg, 0.49 mmol) dissolved in 78% v/v ethanol-water (80 ml) was refluxed for 5 h over a mixture of zinc dust (1.0 g, 15 mg-atom) and calcium chloride (33 mg, 0.3 mmol) under stirring. The mixture after filtration was concentrated and poured into excess of CHCl₃ to obtain the precipitate. The recrystallization of the resulting solid from methanol gave 52% of hygroscopic (4), v_{max} .(KBr) 3 450 and 3 325 (NH₂), 3 220 (NH), 1 627 (C=O), 1 553 (NH), 1 307 (C-N), and 1 110 (C-O-C) cm⁻¹; δ_{H} (CD₃OD) 3.30 (3 H, s), 3.48 (4 H, s), 6.58 (2 H, d, J 8.4 Hz), and 7.52 (2 H, d, J 8.4 Hz) (Found: C, 62.2; H, 7.5; N, 14.05. C₁₀H₁₄N₂O₂ requires C, 61.9; H, 7.2; N, 14.4%).

After irradiation of (1c) (4.5mM) in Ar-purged methanol for 33 h, the reaction mixture was concentrated and chromatographed on a silica gel column. Compound (3c) was eluted with CH_2Cl_2 , $\delta_H(CDCl_3)$ 3.43 (3 H, s), 3.70 (4 H, s), 3.83 (3 H, s), 6.17 (1 H, br), 6.84 (2 H, d, J 8.4 Hz), and 7.71 (2 H, d, J 8.4 Hz) (Found: C, 63.0; H, 7.4; N, 6.7; O, 22.6. $C_{11}H_{15}NO_3$ requires C, 63.15; H, 7.2; N, 6.7; O, 23.0%).

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