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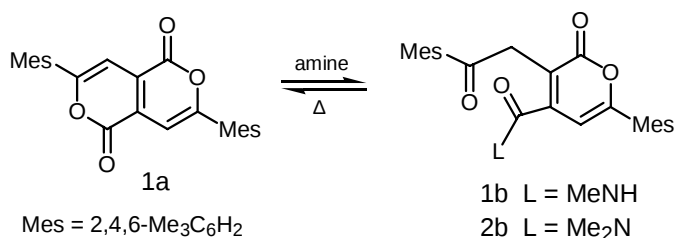
PROPERTIES OF THE KETO AMIDES FORMED BY AMINOLYSIS OF 3,7-DIARYLPYRANO[4,3-*c*]PYRAN-1,5-DIONE DERIVATIVES: A SOLID-STATE REACTION, CRYSTAL STRUCTURES, AND THERMAL ANALYSIS

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Abstract – Aminolysis of 3,7-diarylpyrano[4,3-*c*]pyran-1,5-dione derivatives gave keto amides, which upon heating returned back to the original compounds in the solid state. X-Ray crystallographic analysis of the keto amides showed proximate orientations of the ketone and the amide groups. TGA and DTA of the keto amides clarified a kind of solid-state reaction which occurred in appearance without melting, but microscopically proceeded via melting of the keto amides, structural change, and crystallization of the products.

Solid-state reactions are attracting a considerable attention, since they do not require disposal of solvents and often lead to pure products.¹ Color changes of solid materials have been a current interest in material science.² A variety of solid-state reactions (solvent-free reactions) have been reported. Reactions of amines with carbonyl compounds have been studied.³ In a previous paper, we reported that aminolysis of 3,7-dimesitylpyrano[4,3-*c*]pyran-1,5-dione (**1a**) with MeNH₂ gave a keto amide (**1b**),



which returned back to **1a** in the solid state upon heating above 300 °C for 10 min.⁴ In this paper we wish to report the properties of a series of keto amides (**1b** – **8b**) derived from fluorescent 3,7-diarylpyrano[4,3-*c*]pyran-1,5-diones (**1a** and **3a** – **8a**).

RESULTS AND DISCUSSION

Keto amides (**2b** – **8b**) were prepared as follows. In order to change the amide moiety of **1b**, the compound (**1a**) was treated with Me_2NH to give an *N,N*-dimethyl amide (**2b**). One of the mesityl groups in **2b** seemed to affect steric effect for the neighboring ketone group. Subsequently, the mesityl groups in **2b** were replaced with phenyl groups, and a compound (**3a**)⁵ was converted to an amide (**3b**) with Me_2NH , since aminolysis with MeNH_2 gave a ring tautomer (**A**) in the ring chain tautomerism. The amide (**3b**) was unstable, and returned back to **3a** during recrystallization from boiling EtOAc or

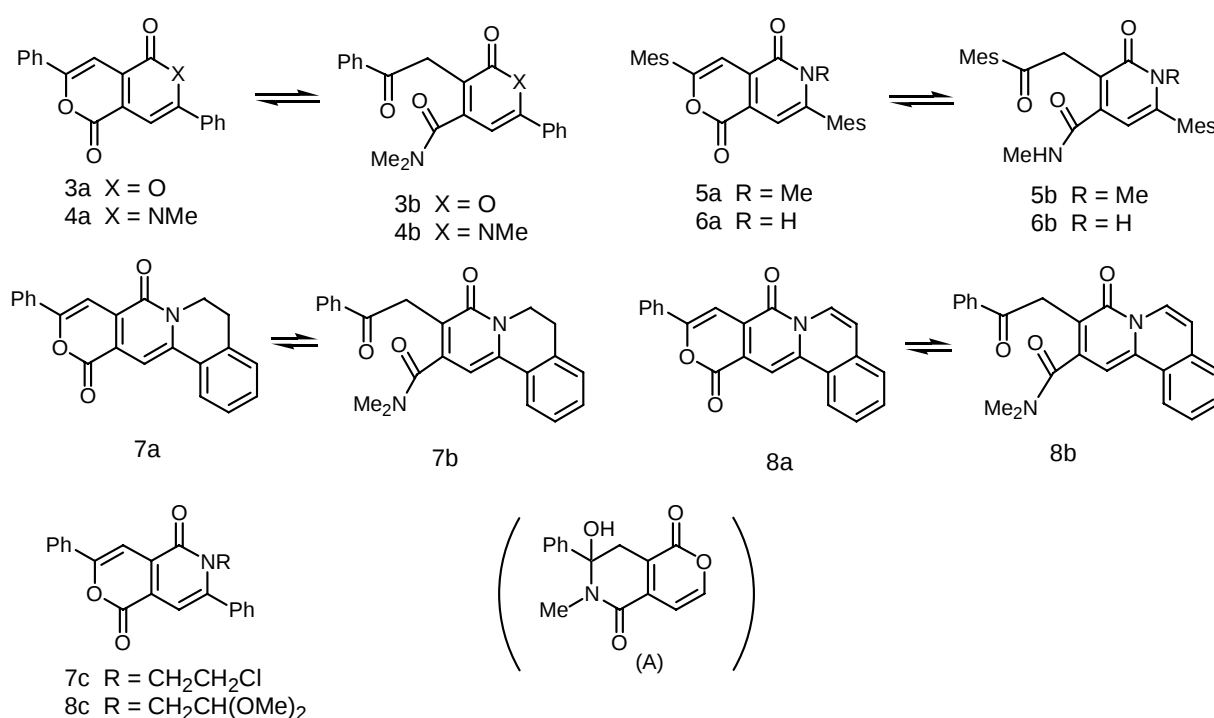
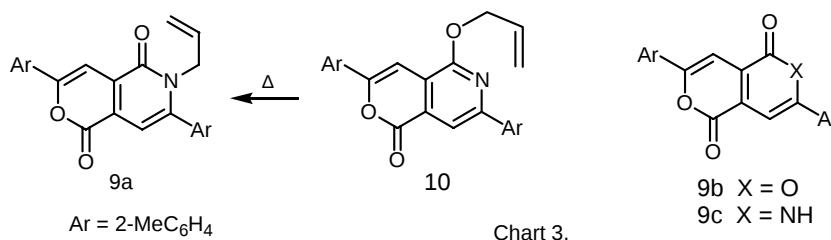


Chart 2.

during column chromatography. The mesityl groups in **1b** and **2b** would affect steric protection for the ketone groups. Similarly, a compound (**4a**)⁴ was converted to an amide (**4b**), which was thermally more stable than **3b**. On the other hand, a compound (**5a**)⁴ was treated with MeNH_2 to give an amide (**5b**) bearing an *N*-methyl 2-pyridone ring. A compound (**6a**) was prepared from **1a** in very low yield (2.6%) by aminolysis with NH_3 followed by cyclization with POCl_3 . Aminolysis of **6a** with MeNH_2 afforded an amide (**6b**) bearing a 2-pyridone ring. Each **5b** and **6b** gave a stable single crystal which was subjected to X-ray crystallographic analysis. We planned to prepare compounds (**7a** and **8a**) by fixing one of the benzene rings in **4a** with a methylene bridge or a double bond. Upon treating with AlCl_3 , a compound (**7c**)⁴ gave the compound (**7a**), which yielded an amide (**7b**) with Me_2NH . The compound (**7c**) was prepared from **3a** by aminolysis with 2-aminoethanol followed by treatment with POCl_3 . On the other hand, a compound (**8c**) was prepared from **3a** by aminolysis with aminoacetaldehyde dimethyl

acetal followed by TFA treatment. Upon treating with AlCl_3 , the compound (**8c**) afforded the compound (**8a**) bearing the extended π conjugation. Similarly, **8a** was converted to an amide (**8b**) with Me_2NH . In the ^1H NMR spectra of **2b**, **5b** and **6b**, the signals of the methylene protons attached to mesitoyl groups appear as singlet (2H), whereas the signals of the methylene protons adjacent to the benzoyl groups in **3b**, **4b**, **7b**, and **8b** are very broad, or not observed perhaps due to the molecular movement.



Tautomerism between 2-pyridone and 2-hydroxypyridine has been well studied.⁶ A crystal structure of a 4-substituted-2-pyridone has been reported.⁷ A 2-pyridone form of **6b** was clarified by X-ray analysis, as described below. Lactam-lactim tautomerism has also been well studied. It was shown by absorption spectral data that **6a** existed in a lactam form. Furthermore, an equilibrium between a lactam (**9a**) bearing an *N*-allyl group and a lactim (**10**) with an *O*-allyl group was examined in order to compare their stability. In this experiment, a compound (**9b**)⁴ bearing 2-methylphenyl groups was used as a starting compound. Upon aminolysis with allylamine followed by cyclization with POCl_3 , **9b** gave the compound (**9a**, UV-VIS λ_{max} 394 nm). On the other hand, **9b** was converted to **9c** (UV-VIS 395 nm) by aminolysis with NH_3 followed by treatment with POCl_3 . The reaction of **9c** with allyl bromide in the presence of Ag_2O afforded **10**, which showed the λ_{max} at shorter wavelength (368 nm) relative to that of **9a**. Upon heating at 270° for 1 h, **10** underwent a sigmatropic reaction to give **9a** exclusively, indicating that **9a** was more stable than **10**. Accordingly, the compounds (**6a** and **9c**) exist in a stable lactam form.

ABSORPTION AND FLUORESCENCE SPECTRA

Absorption and fluorescence spectral data of the compounds (**1a**, **2b**, and **3a,b** – **8a,b**) are summarized in Table 1. The compounds (**5a** and **6a**) exhibit their λ_{max} at the same region, and the λ_{max} of the compounds (**5b** and **6b**) are observed at almost the same region. These data are in line with the lactam form of **6a** and the 2-pyridone form of **6b**, respectively. The benzene rings in the compounds (**7a** and **7b**) are fixed with methylene bridges, and their λ_{max} appear at longer wavelengths relative to those of the compounds (**4a** and **4b**), indicating the bathochromic shifts caused by the coplanar benzene rings, respectively. The compounds (**8a** and **8b**) have the extended π conjugation ($-\text{N}-\text{CH}=\text{CH}-$ benzene ring), and exhibit the λ_{max} at longer wavelengths relative to those of the compounds (**7a** and **7b**), indicating the bathochromic shifts due to the double bonds by 50 and 68 nm, respectively. The compounds (**1a** and **3a**

– **8a**) are fluorescent, and the λ_{max} of fluorescence (F_{max}) are summarized in Table 1. The compound (**1a**) shows a large Stokes shift by 90 nm. The compound (**8b**) is also fluorescent and indicates F_{max} at 445 nm.

Table 1. Absorption and Fluorescence Spectral Data of **1a**, **2b** and **3a,b** – **8a,b**

Compounds	$\lambda_{\text{max}}(\text{nm})$	$F_{\text{max}}(\text{nm})$	Keto amides	$\lambda_{\text{max}}(\text{nm})$
1a	388	478	2b	316
3a	429	480	3b	340
4a	425	454	4b	323
5a	383	452	5b	324
6a	383	453	6b	323
7a	447	461	7b	351
8a	497	506	8b	419

CRYSTAL STRUCTURES

X-Ray crystallographic analysis was carried out for **5b**, **6b** and **8b** in order to know the orientations of the aroyl and the amide moieties.⁸ The ORTEP views of **5b**, **6b** and **8b** are shown in Figure 1 (a), (b), and (c), respectively. The bond distances of the carbonyl groups in **5b** [C(1)-O(1) 1.230(2) Å] and **8b** [1.232(3) Å] are slightly shorter than that in **6b** [1.249(2) Å], but these data support that **6b** exists in a 2-pyridone form. The mesityl and 2-pyridone rings in **5b** and **6b** are twisted with respect to each other, and the torsion angle in **5b** [C(4)-C(5)-C(20)-C(21)] is 87.3°(2), and that in **6b** is 76.9°(2). The *N*-methyl amide carbonyl groups and the 2-pyridone rings in **5b** and **6b** are also twisted with respect to each other, and the torsion angle in **5b** [O(3)-C(18)-C(3)-C(2)] is 41.6° and that in **6b** is 41.4°, whereas the corresponding torsion angle in **8b** [O(3)-C(22)-C(3)-C(2)] is 70.4°. Due to these torsion, the ketonic carbonyl and the *N*-methyl amide carbonyl groups are brought close, and the distance between the ketonic oxygen O(2) and the amide carbonyl carbon C(18) in **5b** is 4.05 Å, and the corresponding distances in **6b** and **8b** are 3.33 and 3.50 Å, respectively. Interestingly, the distance between the methylene carbon C(7) and the amide carbonyl oxygen O(3) in **5b** is 3.02 Å as shown in Figure 1 (d), and the corresponding distances in **6b** and **8b** are 2.98 Å and 3.21 Å, respectively. Furthermore, the distance between one of the hydrogen atoms on C(7) and the amide carbonyl oxygen O(3) in **5b** is estimated to be 2.28 Å, and those in **6b** and **8b** are 2.37 and 2.60 Å, respectively. These distances are shorter than the sum of the van der Waals radii (H 1.20 and O 1.52 Å), suggesting the C-H...O interaction between the methylene hydrogen and the amide carbonyl oxygen O(3).⁹ The proximate orientations of the ketonic and the

amide carbonyl groups in **5b**, **6b**, and **8b** are in line with the observed conversion to the original compounds (**5a**, **6a**, and **8a**),

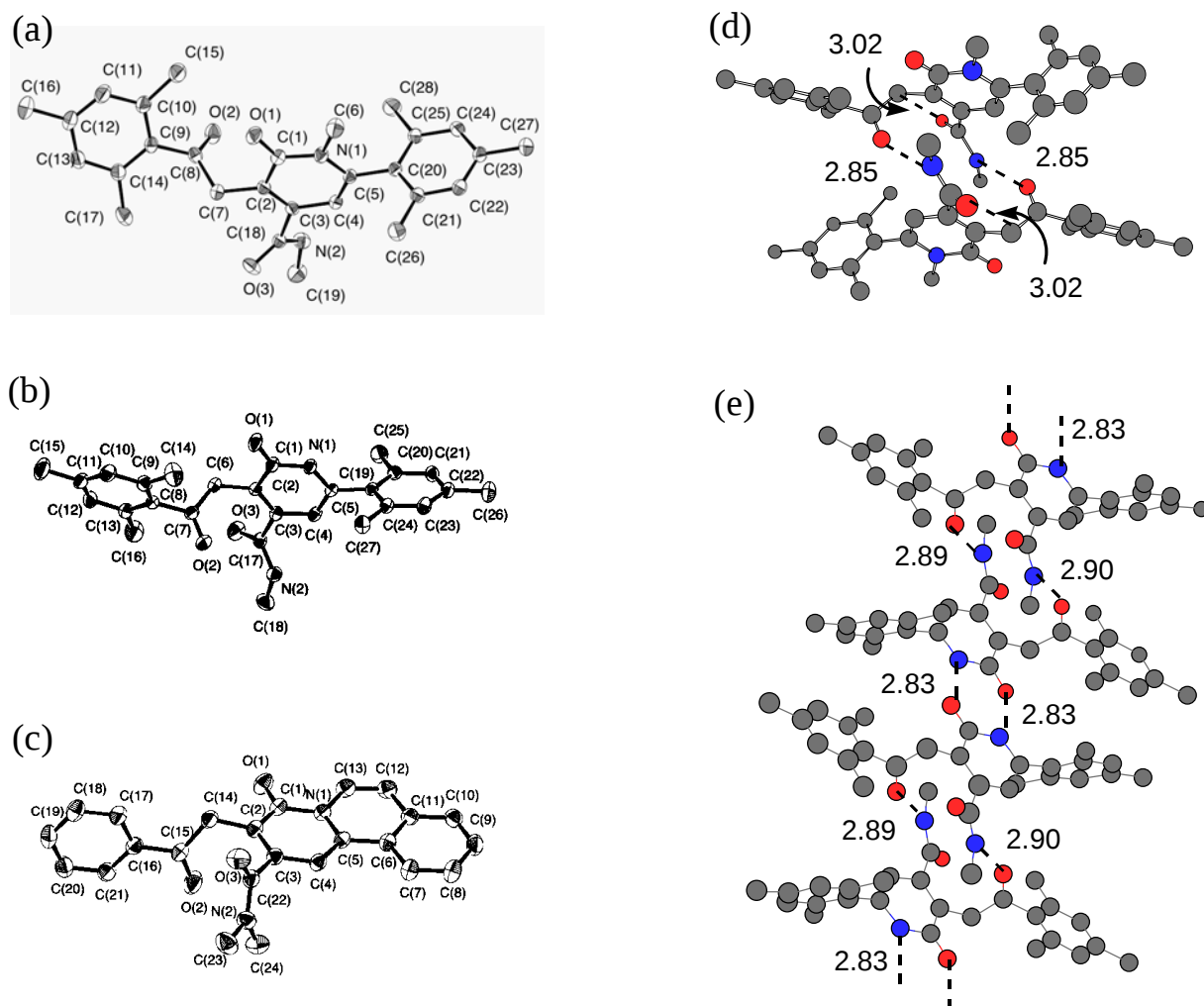


Figure 1. (a) ORTEP view of **5b**. (b) ORTEP view of **6b**. (c) ORTEP view of **8b**. (d) Hydrogen bonding in **5b**. (e) Hydrogen bonding network of **6b**.

respectively. As shown in Figure 1 (d), the compound **5b** exists in a dimeric form. A molecule of **5b** is linked to an adjacent molecule of **5b** by the N-H...O interaction between the N-H of the *N*-methyl amide group and the ketonic carbonyl oxygen (N-O distance 2.85 Å). As shown in Figure 1 (e), **6b** exists similarly in a dimeric form (N-O distances 2.89 and 2.90 Å), and each dimeric molecule arranges by the N-H...O interactions between the 2-pyridone N-H and the adjacent 2-pyridone carbonyl oxygen (N-O distance 2.83 Å), forming a one-dimensional supramolecular network. In a previous paper, we reported the inclusion ability of the one-dimensional network found in indolizino[8,7-*b*]indole derivatives.¹⁰ Subsequently, the inclusion ability of **6b** was examined, and it was confirmed by ¹H NMR that **6b** included CHCl₃ and benzene in host:guest ratios of 2:1 and 6:1, respectively.

THERMAL ANALYSIS

In mp determination, we sometimes observe sintering of the sample below the mp. Upon heating in mp apparatus, the crystals of **1b** did not melt below 300°, but there were changes in appearance. Upon heating, the crystals of **2b** melted at 185 – 187°, and bubbling occurred from the molten sample, and then the sample gradually changed to the crystals of **1a**. Upon heating, the crystals of **6b** became yellow and exclusively changed to **6a** above 300° in appearance without melting. These observations prompted us to reinvestigate the thermal properties of the keto amides (**1b** – **8b**) and the compounds (**1a** and **3a** – **8a**) with thermogravimetric analysis (TGA) and differential thermal analysis (DTA). The TGA and DTA data were recorded at a heating rate of 10 °C/min, and are summarized in Figure 2. In the DTA of the compounds (**1b** and **2b**), two endothermic peaks (a and b) and exothermic peaks (c) are observed. The peaks (a) will be due to melting of the compounds (**1b** and **2b**), and the peaks (c) will be attributed to heat of crystallization of the product (**1a**), respectively. The peaks (b) around 290° will be due to melting of the product (**1a**), because they are almost consistent with the peak (b) in the DTA of **1a**. Similarly, the peaks (b) in the DTA of the compounds (**3b** and **6b** – **8b**) are due to melting of the products (**3a** and **6a** – **8a**), respectively, because the crystals (**3a** and **6a** – **8a**) showed the endothermic peaks at the corresponding temperatures. The DTA of the compounds (**4b** and **5b**) show only peaks (a) due to

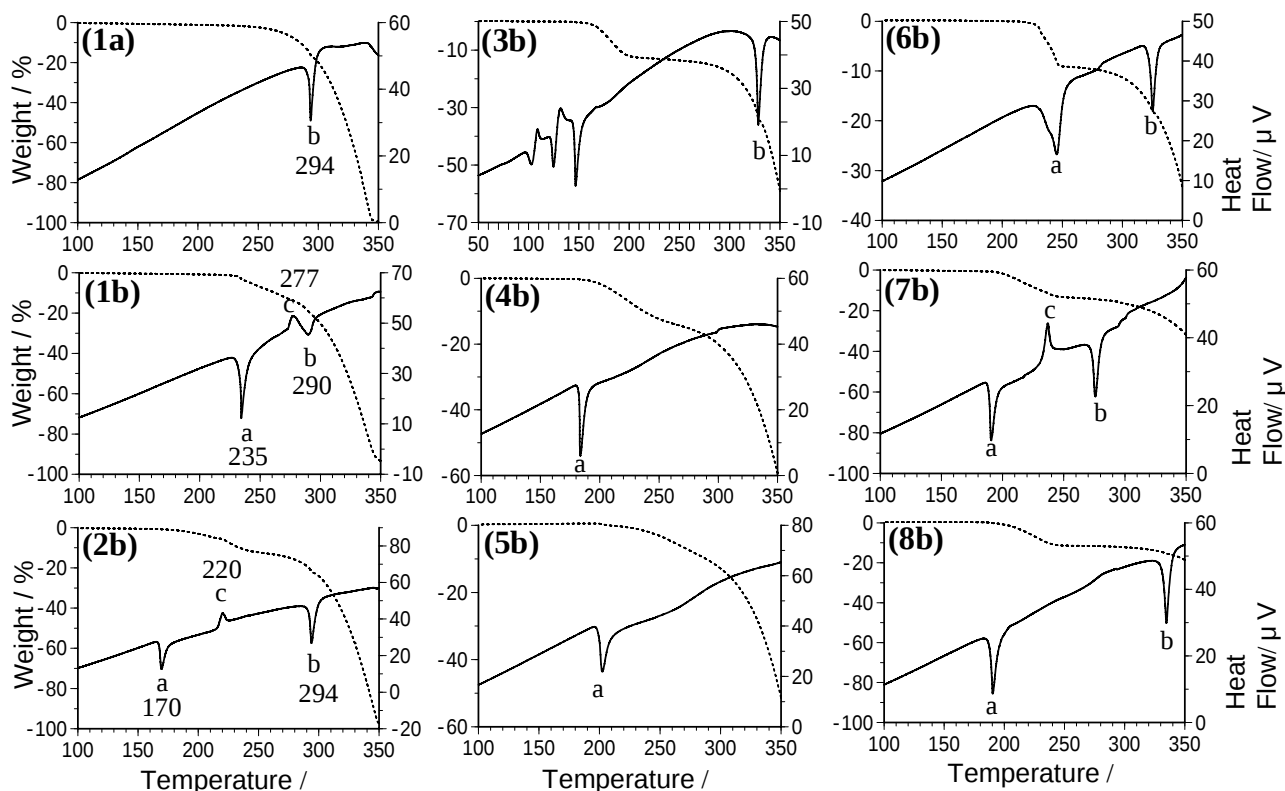


Figure 2. TGA (·····) and DTA (—) thermograms of the compounds (**1a** and **1b** – **8b**).

melting, and indicate that crystallization of the products (**4a** and **5a**) does not occur, since the temperatures of the peaks (a) were different from those of the endothermic peaks in the DTA of the crystals (**4a** and **5a**), respectively. The peaks (a) in the compounds (**6b** – **8b**) will also be due to melting, respectively. The TGA of (**1b**) and (**2b**) show that the weight losses begin at the temperatures around the peaks (a), and suggest that the structural changes from **1b** to **1a** and from **2b** to **1a** occur. Then, sublimation of the product (**1a**) is observed. The DTA thermogram of (**3b**) is complicated, and its TGA shows that the weight loss begins after three endothermic peaks are observed, suggesting the presence of several steps for the formation of **3a**. Hence, the compound (**8b**) might undergo the structural changes via (C) or (D) to give a plausible intermediate (E), as shown below. Elimination of Me₂NH from (E) might afford the molten product (**8a**). Crystallization of the molten products (**1a**, **3a**, and **6a** – **8a**) during heating will be a characteristic of these compounds.

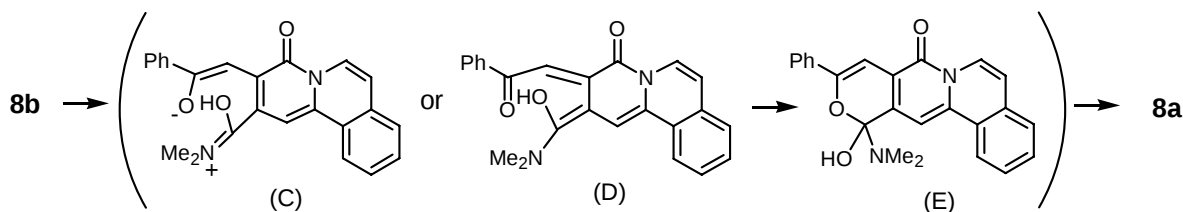


Chart 4.

Attempts to find a reversible reaction between **8b** and the supposed intermediate (E) were unsuccessful. The yellow crystals of **8b** became red before melting in mp apparatus, but did not show the color change by irradiation with Hg high pressure lamp or with Nd:YAG laser (355 nm).

CONCLUSION

Aminolysis of 3,7-diarylpyrano[4,3-*c*]pyran-1,5-dione derivatives (**1a** and **3a** – **8a**) gave the keto amides (**1b** – **8b**), which upon heating returned back to the original compounds (**1a** and **3a** – **8a**) in the solid state, respectively. X-Ray crystallographic analysis of the keto amides (**5b**, **6b** and **8b**) showed the proximate orientations of the ketone and the amide groups. The TGA and DTA of the keto amides and their original compounds clarified a kind of solid-state reaction which occurred without melting in appearance, but proceeded microscopically via melting, structural change, and crystallization of the products. A compound such as **8a** would have potential usefulness as a fluorescent marker for amines, since the derived keto amides such as (**8b**) are fluorescent, and the amines are released only by heating.

EXPERIMENTAL

All melting points are uncorrected. UV-VIS spectra were measured on a Shimadzu UV-1650PC in CHCl₃. ¹H NMR spectra were measured on a Bruker AC300 (300 MHz) in CDCl₃, using a CHCl₃

signal ($\delta_{\text{H}} = 7.26$) as an internal standard. TGA and DTA thermograms were recorded on a Rigaku TG 8120. Column chromatography was performed with silica gel 60 (90 – 230 mesh, Merck) and CHCl_3 .

Preparation of 2b, 3b, 4b, 7b, and 8b. A typical procedure is described for the preparation of **2b**. A mixture of **1a**⁴ (80 mg, 0.20 mmol), 2M-methanolic Me_2NH (1 mL, 2 mmol), and CH_2Cl_2 (2 mL) was stirred at rt for 1 d. The mixture was concentrated under reduced pressure to give a residue, which was crystallized from EtOAc and hexane to give **2b** (78 mg, 88%): mp 185 – 187 °C (EtOAc); UV 316 nm (ϵ 12100); ^1H NMR δ = 2.28 (6H, s), 2.29 (6H, s), 2.30 (3H, s), 2.33 (3H, s), 3.05 (3H, s), 3.14 (3H, s), 4.11 (2H, br s), 6.10 (1H, s), 6.87 (2H, s), and 6.94 (2H, s). *Anal.* Calcd for $\text{C}_{28}\text{H}_{31}\text{NO}_4$: C, 75.48; H, 7.01; N, 3.14. Found: C, 75.31; H, 6.95; N, 3.14. **3b** (yield 68%): mp 145 – 148 °C (MeOH); UV 340 nm (ϵ 18200); ^1H NMR δ = 3.03 (3H, s), 3.06 (3H, s), 6.59 (1H, s), 7.45 – 7.90 (8H, m), and 8.03 (2H, d, $J = 7.3$ Hz). *Anal.* Calcd for $\text{C}_{22}\text{H}_{19}\text{NO}_4$: C, 73.11; H, 5.30; N, 3.88. Found: C, 72.95; H, 5.24; N, 4.13. **4b** (81%): mp 188 – 190 °C (MeOH); UV 323 nm (ϵ 12400); ^1H NMR δ = 3.01 (3H, s), 3.04 (3H, s), 3.40 (3H, s), 6.06 (1H, s), 7.33 – 7.65 (8H, m), and 8.08 (2H, d, $J = 7.2$ Hz). *Anal.* Calcd for $\text{C}_{23}\text{H}_{22}\text{N}_2\text{O}_3$: C, 73.78; H, 5.92; N, 7.48. Found: C, 73.56; H, 5.89; N, 7.51. **7b** (85%): mp 196 – 197 °C (EtOAc – hexane); UV 351 nm (ϵ 16700); ^1H NMR δ = 3.00 – 3.10 (4H, m), 3.04 (3H, s), 3.05 (3H, s), 6.61 (1H, s), 7.20 – 7.80 (7H, m), and 8.08 (2H, d, $J = 7.3$ Hz). *Anal.* Calcd for $\text{C}_{24}\text{H}_{22}\text{N}_2\text{O}_3$: C, 74.59; H, 5.74; N, 7.25. Found: C, 74.19; H, 5.80; N, 7.57. **8b** (67%): mp 195 – 198 °C (EtOAc); UV-VIS 397 (ϵ 18000) and 419 nm (17900); Fluorescence λ_{max} 445 and 459 nm; ^1H NMR δ = 3.02 (3H, s), 3.08 (3H, s), 7.09 (1H, d, $J = 7.8$ Hz), 7.24 – 7.67 (7H, m), 8.09 (2H, d, $J = 7.8$ Hz), 8.27 (1H, d, $J = 7.8$ Hz), and 8.80 (1H, d, $J = 7.8$ Hz). *Anal.* Calcd for $\text{C}_{24}\text{H}_{20}\text{N}_2\text{O}_3$: C, 74.98; H, 5.24; N, 7.29. Found: C, 74.95; H, 5.20; N, 7.23.

Preparation of 5b and 6b. A typical procedure is described for the preparation of **5b**. A mixture of **5a**⁴ (42 mg, 0.10 mmol), 40% methanolic MeNH_2 (0.1 mL, 1 mmol), and CH_2Cl_2 (0.5 mL) was allowed to stand at rt for 5 h. The mixture was concentrated under reduced pressure to give a residue, which was separated with column chromatography to give **5b** (38 mg, 84%): mp 209 – 210 °C (EtOAc – hexane); UV 324 nm (ϵ 11100); ^1H NMR δ = 2.09 (6H, s), 2.30 (3H, s), 2.33 (3H, s), 2.37 (6H, s), 2.91 (3H, d, $J = 4.8$ Hz), 3.22 (3H, s), 4.21 (2H, s), 6.15 (1H, s), 6.67 (1H, q, $J = 4.8$ Hz), 6.88 (2H, s), and 6.95 (2H, s). *Anal.* Calcd for $\text{C}_{28}\text{H}_{32}\text{N}_2\text{O}_3$: C, 75.65; H, 7.26; N, 6.30. Found: C, 75.51; H, 7.33; N, 6.26. **6b** (100 %): mp > 300 °C (CHCl_3 – hexane); UV 323 nm (ϵ 9700); ^1H NMR δ = 2.16 (6H, s), 2.20 (6H, s), 2.27 (3H, s), 2.31 (3H, s), 2.92 (3H, d, $J = 4.9$ Hz), 4.06 (2H, s), 6.16 (1H, s), 6.69 (1H, q, $J = 4.9$ Hz), 6.85 (2H, s), 6.89 (2H, s), and 10.69 (1H, br s). *Anal.* Calcd for $\text{C}_{27}\text{H}_{30}\text{N}_2\text{O}_3$: C, 75.32; H, 7.02; N, 6.51. Found: C, 75.21; H, 7.09; N, 6.53.

Inclusion Property of 6b. Recrystallization of **6b** from CHCl_3 gave an inclusion complex of **6b**· CHCl_3 (2:1), and that from benzene yielded **6b**·benzene (6:1). The host:guest ratios were determined by ^1H NMR after drying the obtained crystals at rt for 2 d. No inclusion complex was obtained by recrystallization from toluene, EtOAc, acetone, *i*-PrOH, and EtOH, respectively.

Preparation of 6a. A mixture of **1a** (801 mg, 2.0 mmol), 7M methanolic NH_3 (12 mL, 84 mmol), and CH_2Cl_2 (24 mL) was stirred at rt for 2 d, and concentrated under reduced pressure. To a mixture of the residue and CH_2Cl_2 (14 mL) was added POCl_3 (1.4 mL, 15 mmol). The mixture was stirred at rt for 1 d, neutralized with aq. NaHCO_3 , and extracted with CHCl_3 . The extracts were washed with saturated aq. NaCl, dried over Na_2SO_4 , and concentrated under reduced pressure. Crystallization of the residue from CHCl_3 and MeOH gave **1a** (604 mg). The mother liquor was concentrated under reduced pressure and separated with column chromatography to give **6a** (21 mg, 2.6%. 14% based on recovered **1a**) along with **1a** (42 mg, total recovery 646 mg, 81%). **6a**: mp > 300 °C (CHCl_3 – MeOH); UV-VIS 282 (ϵ 16100) and 383 nm (17300); Fluorescence λ_{max} 453 nm; ^1H NMR δ = 2.20 (6H, s), 2.28 (6H, s), 2.32 (3H, s), 2.33 (3H, s), 6.79 (1H, s), 6.88 (1H, s), 6.96 (4H, s), and 9.39 (1H, br s). *Anal.* Calcd for $\text{C}_{26}\text{H}_{25}\text{NO}_3$: C, 78.17; H, 6.31; N, 3.51. Found: C, 78.10; H, 6.16; N, 3.51.

Preparation of 7a. A mixture of **7c** (76 mg, 0.20 mmol), AlCl_3 (0.60 g, 4.5 mmol), and chlorobenzene (10 mL) was heated under reflux for 2 h. To the reaction mixture was added water, and then CHCl_3 . The organic layer was washed (2% HCl, water, and saturated aq. NaCl), dried (Na_2SO_4), and concentrated under reduced pressure. Crystallization of the residue from CHCl_3 and hexane gave **7a** (53 mg, 78%): mp 285 – 286 °C; UV-VIS 328 (ϵ 11400), 421 (27300) and 447 nm (26400); Fluorescence λ_{max} 461 nm; ^1H NMR δ = 3.06 (2H, t, J = 6.3 Hz), 4.39 (2H, t, J = 6.3 Hz), 7.28 – 7.52 (7H, m), 7.52 (1H, s), and 7.85 – 7.97 (3H, m). High resolution MS Calcd for $\text{C}_{22}\text{H}_{15}\text{NO}_3$: M, 341.1052. Found; 341.1048.

Preparation of 7c. A mixture of **3a** (316 mg, 1.0 mmol), 2-aminoethanol (0.3 mL, 4.8 mmol), and CH_2Cl_2 (20 mL) was stirred at rt for 1 d. To the mixture was added POCl_3 (1.0 mL, 11 mmol). The resulting mixture was stirred at rt for 2 d, neutralized with saturated aq. NaHCO_3 , and extracted with CHCl_3 . The extracts were dried over Na_2SO_4 , and concentrated under reduced pressure. Crystallization of the residue from CHCl_3 and MeOH gave **7c** (248 mg, 66%), which was identical with that reported in a previous paper.⁴

Preparation of 8a. A mixture of **3a** (316 mg, 1.0 mmol), aminoacetaldehyde dimethyl acetal (4.0 mL, 37 mmol), and CH_2Cl_2 (40 mL) was stirred at rt for 5 d, washed with 5% HCl to remove excess amine, dried over Na_2SO_4 and concentrated under reduced pressure. To the mixture of the residue and CH_2Cl_2 (8 mL) was added TFA (0.4 mL, 5 mmol). The mixture was stirred at rt for 1 h, washed (aq. NaHCO_3 , and then saturated aq. NaCl), dried (Na_2SO_4), and concentrated under reduced pressure to give

8c, which was used to next Friedel-Crafts type cyclization without further purification. A mixture of the obtained **8c**, AlCl_3 (400 mg, 3.0 mmol), and CH_2Cl_2 (8 mL) was stirred at rt for 1 h, and worked up as described above to give a residue, which was triturated in MeOH to yield a powder of **8a** (219 mg, 65%): mp $>300^\circ\text{C}$; UV-VIS 287 (ϵ 23700), 465 (19800), and 497 nm (21300); Fluorescence λ_{max} 506 and 537 nm; ^1H NMR δ = 7.19 (1H, d, J = 8.0 Hz), 7.40 – 7.70 (6H, m), 7.62 (1H, s), 7.96 (2H, dd, J = 8.1 and 1.7 Hz), 8.13 (1H, s), 8.47 (1H, m), and 8.84 (1H, d, J = 7.8 Hz). High resolution MS Calcd for $\text{C}_{22}\text{H}_{13}\text{NO}_3$: M, 339.0896. Found: 339.0894.

Preparation of 9a. A mixture of **9b**⁴ (103 mg, 0.30 mmol), allylamine (0.5 mL, 7 mmol), and CH_2Cl_2 (2 mL) was stirred at rt overnight, and concentrated under reduced pressure. To a solution of the residue in CH_2Cl_2 (2 mL) was added POCl_3 (0.5 mL, 5 mmol). The mixture was stirred at rt overnight, worked up as described above, and separated with column chromatography to give **9a** (32 mg, 28%): mp $143 - 146^\circ\text{C}$ (MeOH); UV-VIS 295 (ϵ 14700) and 394 nm (19900); ^1H NMR δ = 2.19 (3H, s), 2.55 (3H, s), 4.16 (1H, dd, J = 14.7 and 5.5 Hz), 4.76 (1H, dd, J = 14.7 and 5.7 Hz), 4.83 (1H, d, J = 17.2 Hz), 5.13 (1H, d, J = 10.3 Hz), 5.77 (1H, m), 6.79 (1H, s), 7.18 – 7.45 (7H, m), 7.20 (1H, s), and 7.57 (1H, d, J = 8.0 Hz). *Anal.* Calcd for $\text{C}_{25}\text{H}_{21}\text{NO}_3$: C, 78.31; H, 5.52; N, 3.65. Found: C, 78.10; H, 5.57; N, 3.78.

Preparation of 9c. A mixture of **9b** (206 mg, 0.60 mmol), 6% methanolic NH_3 (1 mL, 2.8 mmol), and CH_2Cl_2 (3 mL) was stirred at rt overnight, and concentrated under reduced pressure. To a solution of the residue in CH_2Cl_2 (3 mL) was added POCl_3 (0.5 mL, 5 mmol). The mixture was stirred at rt overnight, worked up as described above, and separated with column chromatography to give **9c** (74 mg, 36%. 60% based on recovered **9b**) along with **9b** (82 mg, 40% recovery). **9c**: mp $257 - 258^\circ\text{C}$ (CHCl_3 – hexane); UV-VIS 298 (ϵ 15300) and 395 nm (21100); ^1H NMR δ = 2.43 (3H, s), 2.54 (3H, s), 6.92 (1H, s), 7.10 (1H, s), 7.24 – 7.43 (7H, m), 7.57 (1H, m), and 9.66 (1H, br s). *Anal.* Calcd for $\text{C}_{22}\text{H}_{17}\text{NO}_3$: C, 76.95; H, 4.99; N, 4.08. Found: C, 77.06; H, 5.10; N, 4.05.

Preparation of 10. A mixture of **9c** (68 mg, 0.20 mmol), allyl bromide (0.5 mL, 6 mmol), silver (I) oxide (0.2 g, 0.9 mmol), and acetone (10 mL) was stirred at rt overnight. The mixture was separated with column chromatography and crystallized from MeOH to give **10** (54 mg, 74%): mp $93 - 95^\circ\text{C}$ (MeOH); UV-VIS 302 (ϵ 21100) and 368 nm (17600); ^1H NMR δ = 2.50 (3H, s), 2.53 (3H, s), 5.03 (2H, m), 5.30 (1H, dd, J = 10.4 and 1.3 Hz), 5.44 (1H, dd, J = 17.2 and 1.6 Hz), 6.14. (1H, m), 6.98 (1H, s), 7.27 – 7.40 (6H, m), 7.50 – 7.57 (2H, m), and 7.82 (1H, s). *Anal.* Calcd for $\text{C}_{25}\text{H}_{21}\text{NO}_3$: C, 78.31; H, 5.52; N, 3.65. Found: C, 77.96; H, 5.51; N, 3.75.

Thermal reaction of 10. Crystals of **10** (5 mg) were sealed in a glass tube, and heated in a salt bath at 270°C for 1 h. The ^1H NMR spectrum of the obtained sample was almost identical with that of **9a**.

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- 8 A single crystal of **5b** was formed by recrystallization from EtOAc – hexane. $C_{28}H_{32}N_2O_3$, $M = 444.57$, triclinic, space group $P1$, $a = 11.37(3) \text{ \AA}$, $b = 11.44(3) \text{ \AA}$, $c = 11.86(4) \text{ \AA}$, $\alpha = 61.5(4)^\circ$, $\beta = 75.5(5)^\circ$, $\gamma = 65.0(4)^\circ$, $V = 1227(4) \text{ \AA}^3$, $Z = 2$, $R = 0.0583$, $wR = 0.0982$, $GOF = 1.000$. A single crystal of **6b** was formed by recrystallization from EtOAc. $C_{27}H_{30}N_2O_3$, $M = 430.55$, triclinic, space group $P1$, $a = 11.236(5) \text{ \AA}$, $b = 11.538(5) \text{ \AA}$, $c = 12.213(3) \text{ \AA}$, $\alpha = 61.717(18)^\circ$, $\beta = 61.958(20)^\circ$, $\gamma = 83.57(3)^\circ$, $V = 1218.0(8) \text{ \AA}^3$, $Z = 2$, $R = 0.0616$, $wR = 0.1946$, $GOF = 1.004$. A single crystal of **8b** was formed by recrystallization from EtOAc. $C_{24}H_{20}N_2O_3$, $M = 384.43$, triclinic, space group $P1$, $a = 9.965(16) \text{ \AA}$, $b = 10.48(4) \text{ \AA}$, $c = 10.570(16) \text{ \AA}$, $\alpha = 99.22(7)^\circ$, $\beta = 117.03(8)^\circ$, $\gamma = 92.93(6)^\circ$, $V = 961(4) \text{ \AA}^3$, $Z = 2$, $R = 0.0696$, $wR = 0.2123$, $GOF = 1.002$. Crystal data of **5b**, **6b**, and **8b** have been deposited with Cambridge Crystallographic Data Centre: Deposition numbers CCDC-648602 for **5b**, CCDC-648603 for **6b**, and CCDC-648604 for **8b**. Copies of the data can be obtained free of charge via <http://www.ccdc.cam.ac.uk/conts/retrieving.html> (or from the Cambridge Crystallographic Data Centre, 12, Union Road, Cambridge, CB2 1EZ, UK; Fax: +44 1223 336033; e-mail: deposit@ccdc.cam.ac.uk).
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