Structures and Fluorescence of Secondary Products Produced from the Cope-Knoevenagel Reaction of 2-Phenylpropionaldehyde with Methyl Cyanoacetate

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The Cope-Knoevenagel reaction of 2-phenylpropionaldehyde (**7**) with methyl cyanoacetate (**8**) produced methyl (*E*)-2-cyano-4-phenylpent-2-enoate (**9**) and the two highly fluorescent secondary products, 2-amino-3-carbomethoxy-6-phenyl-4-(1-phenylethyl)pyridine (**10**) and 3-cyano-6-phenyl-4-(1-phenylethyl)-2-pyridone (**11**). The structure of **10** was determined by X-ray crystallography while the structure of **11** was confirmed by the conversion of **9** into **11**. The mechanism of their formation is discussed. Fluorescence of **10** and **11** and the related compounds are also described.

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In the previous paper [1], we reported the Knoevenagel reaction of *p*-substituted benzaldehydes with ethyl cyanoacetate in ethanolic ammonia, which yielded reduction products 2-cyano-3-phenylpropanamides (**1**), oxidation products 2,6-dihydroxy-3,5-dicyano-4-phenylpyridines (**2**), and dimeric products 3,5-dicyano-4,6-diphenyl-5-ethoxycarbonyl-2-pyperidones (**3**) possessing *p*-substituent(s) at the phenyl ring(s). Compounds **3** were assumed to be formed by the cycloaddition of the primary products (*E*)-2-cyano-3-phenylacrylates (**4**) [2] and (*E*)-2-cyano-3-phenylacrylamides (**5**). The Cope-Knoevenagel reaction [3] of *p*-substituted benzaldehydes with cyanoacetate produced **4** as the main products accompanied with very small amounts of **2** [1]. We also studied the Cope-Knoevenagel reaction of *p*-substituted acetophenones with cyanoacetate, which afforded the primary products *p*-substituted (*E*)-2-cyano-3-phenylbut-2-enoates in high yields along with the small amounts of the secondary products 3-cyano-6-methyl-4,6-bis(*p*-substituted phenyl)-5,6-dihydro-2-pyridones **6** [4].

In this paper we will describe the Cope-Knoevenagel reaction of 2-phenylpropionaldehyde (**7**) with methyl cyanoacetate (**8**).

Results and Discussion.

Reaction Products.

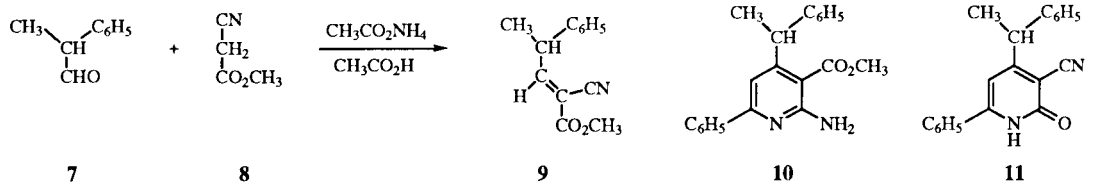
The Cope-Knoevenagel reaction of **7** with **8** afforded the expected primary product, methyl (*E*)-2-cyano-4-phenylpent-2-enoate (**9**) [5] in 28% yield and the two secondary products, a substituted pyridine $C_{21}H_{20}N_2O_2$, mp 150-151° (**10**) and a substituted pyridone $C_{20}H_{16}N_2O$, mp 240-241° (**11**) in 1% and 4.7% yield, respectively (Scheme 1). Either 2-amino-3-carbomethoxy-6-phenyl-4-(1-phenylethyl)pyridine (**10**) or 2-amino-3-carbomethoxy-5-phenyl-6-(1-phenylethyl)pyridine (**10'**) could be assigned to the structure of the lower-melting secondary product taking into account the formation mechanism and the ir (Nujol: ν NH 3450, 3300, 3200, C=O 1700 cm^{-1}) and the ^{1}H-nmr data [deuteriochloroform: δ 1.64 (d, J = 7 Hz), 4.87 (q, J = 7 Hz), 7.23 (s) α-phenethyl, 3.83 (s) methyl ester, 5.85 (s) NH_2, 6.98 (s) CH-pyridine, 7.9 (m), 7.4 (m) phenyl]. Similarly, the higher-melting product was assumed to possess the structure 3-cyano-6-phenyl-4-(1-phenylethyl)-2-pyridone (**11**) or 3-cyano-5-phenyl-6-(1-phenylethyl)-2-pyridone (**11'**) based on the ir (Nujol: ν C≡N 2225, lactam C=O 1650 cm^{-1}) and the ^{1}H-nmr spectra [deuteriochloroform: δ 1.72 (d, J = 7 Hz), 4.59 (q, J = 7 Hz), 7.35 (s) α-phenethyl, 6.44 (s) CH-pyridone, 7.75 (m), 7.55 (m) phenyl].

The cyclic structures **10** and **11** are considered to be formed from the primary product **9** or its equivalent, another molecule of **7**, and ammonia as described later. Their alternative structures **10'** and **11'**, on the other hand, could be formed by the combination of **8**, ammonia, and the aldol obtained from the two molecules of **7**, namely 3-hydroxy-2-methyl-2,4-diphenylpentanal. The X-ray crystallography and synthesis from the intermediate **9** established the structures **10** and **11**, respectively, as described below.

X-ray Crystallography of **10**.

The X-ray diffraction data of **10** were obtained with a Mac Science MXC-3 diffractometer; $C_{21}H_{20}N_2O_2$, FW 332.37, Space group $P\bar{1}$, a = 10.3316(17) Å, b = 13.2581(21) Å, c = 7.4609(7) Å, α = 90.548(11)°, β = 110.051(9)°, γ = 111.913(11)°, D_{calc} = 0.951 g cm^{-3},

Scheme 1



7 **8** **9** **10** **11**

V = 872.59(20) Å^3, Z = 2, λ(MoKα) = 0.71073 Å, μ = 0.766 cm^{-1}, Number of observed reflections = 5471, number of reflections with F > 3σ(F) = 2578, number of independent reflections = 2480, number of used reflections = 1763, final R = 0.057, R_w = 0.055.

Figure 1 shows the molecular structure in the crystal. A phenyl and an α-phenethyl group are located at the 6- and 4-positions, respectively, of the central pyridine ring, which confirmed the structure **10**, *i.e.*, 2-amino-3-carbomethoxy-6-phenyl-4-(1-phenylethyl)pyridine. The phenyl group in the α-phenethyl group lies close to a methoxycarbonyl group. The dihedral angle between the

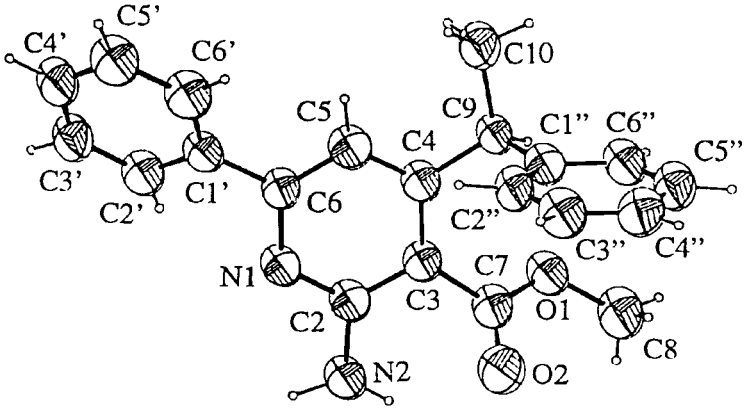


Figure 1. Molecular structure of **10** in the crystalline form with atomic numbering.

planes of the pyridine ring and the 6-phenyl group is 41.2° and that between the pyridine ring and the ester function is 41.4°. The bond lengths and valence angles are given in Tables 1 and 2, respectively.

Synthesis of **11** from **9**.

In order to confirm the structure of the other secondary product, Cope-Knoevenagel reaction of the primary product **9** with the starting aldehyde **7** was examined since the proposed structure **11** as 3-cyano-6-phenyl-4-(1-phenylethyl)-2-pyridone could be derived from **7**, **9**, and ammonia. Silica gel tlc analysis of the reaction mixture revealed the presence of the two expected secondary products in addition to the starting materials. Column chromatographic separation afforded **11** in 11% yield and a trace amount of **10** along with the recovered **9** (50%). The result has validated the proposed structure **11** for the other secondary product.

Mechanism of Formation of **10** and **11**.

The structures of the pyridine **10** and the pyridone **11** are composed of two molecules of the aldehyde **7** and each one molecule of the cyanoacetate **8** and ammonia. The Knoevenagel condensation product **9** from **7** and **8** can be considered as an intermediate to the formation of **10** and **11** as described above. Possible mechanisms for these reactions are shown in Scheme 2. The reaction of **9** at the β-position with the second molecule of **7** is considered to yield 2-cyano-5-phenyl-3-(1-phenylethyl)hexa-2,4-dienoate or its equivalent. The reactions with an ammonia molecule at the cyano group and at the ester function also take place to give an amidine **12** and an amide **13**, respectively. Ring closure of these compounds followed by demethylation and oxidation results in the pyridine **10** and the pyridone **11**. The double bond in **12** and **13** must have the *E*- and *Z*-configuration, respectively, to enable the cyclization to **10** and **11**. The primary Knoevenagel con-

Scheme 2

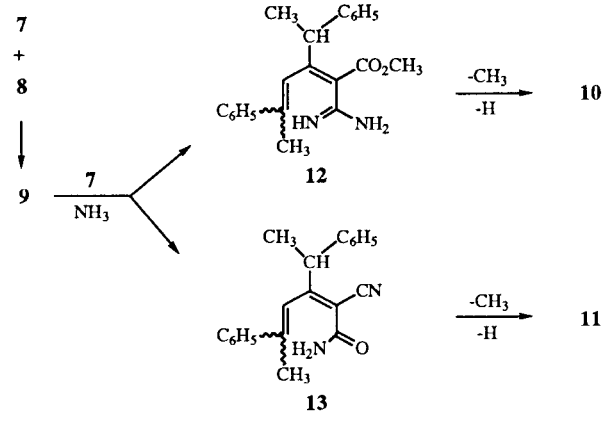


Table 1

Bond Distances(Å) of **10** [a]

from		to	dist	from		to	dist	from		to	dist
N1	-	C2	1.3346(5)	N1	-	C6	1.3596(8)	C2	-	C3	1.4176(7)
C2	-	N2	1.3815(9)	C3	-	C4	1.4188(8)	C3	-	C7	1.4574(6)
C4	-	C5	1.3618(6)	C4	-	C9	1.5371(7)	C5	-	C6	1.3919(7)
C6	-	C1'	1.4716(5)	C7	-	O1	1.3404(7)	C7	-	O2	1.2237(8)
O1	-	C8	1.4322(7)	C1'	-	C2'	1.3926(7)	C1'	-	C6'	1.3979(8)
C2'	-	C3'	1.3631(6)	C3'	-	C4'	1.3919(9)	C4'	-	C5'	1.3842(9)
C5'	-	C6'	1.3739(7)	C9	-	C10	1.5559(10)	C9	-	C1"	1.5288(7)
C1"	-	C2"	1.3825(8)	C1"	-	C6"	1.3809(6)	C2"	-	C3"	1.3956(8)
C3"	-	C4"	1.3590(7)	C4"	-	C5"	1.3880(10)	C5"	-	C6"	1.3896(8)

[a] The standard deviation of the least significant figure of each bond length is given in parentheses.

Table 2

Bond Angles(°) of **10** [a]

	angle		angle		angle
C2 - N1 - C6	117.69(4)	N1 - C2 - C3	123.96(5)	N1 - C2 - N2	114.65(5)
C3 - C2 - N2	121.29(4)	C2 - C3 - C4	117.12(4)	C2 - C3 - C7	118.61(5)
C4 - C3 - C7	124.17(4)	C3 - C4 - C5	118.00(5)	C3 - C4 - C9	121.16(4)
C5 - C4 - C9	120.84(5)	C4 - C5 - C6	121.68(6)	N1 - C6 - C5	121.40(4)
N1 - C6 - C1'	116.09(4)	C5 - C6 - C1'	122.51(5)	C3 - C7 - O1	114.80(5)
C3 - C7 - O2	124.56(5)	O1 - C7 - O2	120.59(4)	C7 - O1 - C8	117.10(5)
C6 - C1' - C2'	121.10(5)	C6- C1' - C6'	120.65(4)	C2' - C1' - C6'	118.25(4)
C1' - C2' - C3'	121.22(5)	C2' - C3' - C4'	120.32(5)	C3' - C4' - C5'	119.09(5)
C4' - C5' - C6'	120.66(6)	C1' - C6' - C5'	120.43(5)	C4 - C9 - C10	112.99(4)
C4 - C9 - C1"	111.94(5)	C10 - C9 - C1"	108.50(5)	C9 - C1" - C2"	121.88(4)
C9 - C1" - C6"	119.92(5)	C2" - C1" - C6"	118.12(5)	C1" - C2" - C3"	120.39(5)
C2" - C3" - C4"	120.38(6)	C3" - C4" - C5"	120.66(6)	C4" - C5" - C6"	118.26(5)
C1" - C6" - C5"	122.17(5)				

[a] The standard deviation of the least significant figure of each bond angle is given in parentheses.

densation product **9** possesses the *E*-configuration [2b,2c,6], which might account for the much lower yield of **10** from **7** and **9** compared with that from **7** and **8**. The last step in these reactions involves the loss of a methyl group from the sp^3 carbon, which is facilitated by the aromatization of the six-membered heterocycle. The result is of interest since the reactions of cyanoacetate with benzaldehydes [1] and with acetophenones [4] afforded substituted piperidones **3** and dihydropyridones **6**, respectively, containing quaternary sp^3 carbon atom in the ring.

Fluorescence of **10**, **11**, and Related Compounds.

Intense fluorescence is observed for the secondary products **10** (λ 417 nm, Φ_f 0.24) and 11 (λ 425 nm, Φ_f 0.03) and their fluorescence spectra are shown in Figures 2 and 3. The emission intensity of **10** is ten times as large as that of **11**. In the pyridine **10** a carbomethoxy group is present at C(3) as a $-M_f$ auxofluorophore and an amino group at C(2) as a $+M_f$ auxofluorophore which contributes to the strong fluorescence of this compound.

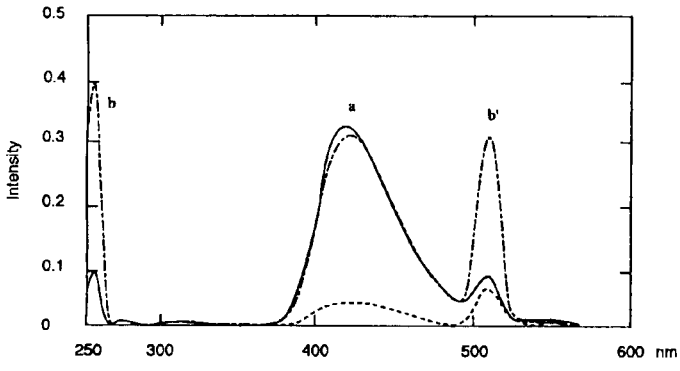


Figure 2. Fluorescence spectra of **10**.

——— Ethanol solution.
------ *p*H 6.
·-·-·-·- *p*H 8.

a: Fluorescence of **10**.
b, b': Scattered light.

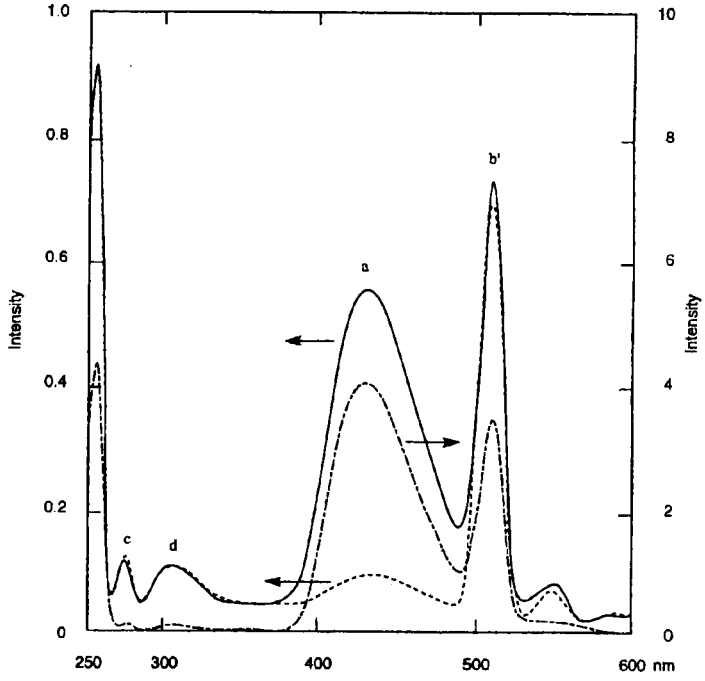


Figure 3. Fluorescence spectra of **11**.

——— Ethanol solution.
------ *p*H 6.
·-·-·-·- *p*H 8.

a: Fluorescence of **11**.
b, b': Scattered light.
c: Raman band of solvent.
d: Band due to solvent and/or cell.

The fluorescence intensity of **10** and **11** is remarkably dependent upon the *p*H of the solution although the emission wavelength remained unchanged by the addition of acid or base. Figure 4 shows the *p*H dependence of the

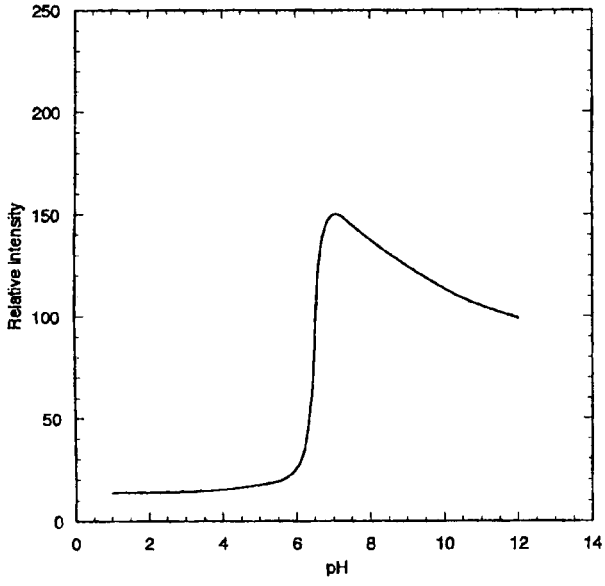


Figure 4. *p*H dependence of fluorescence intensity of **10**.

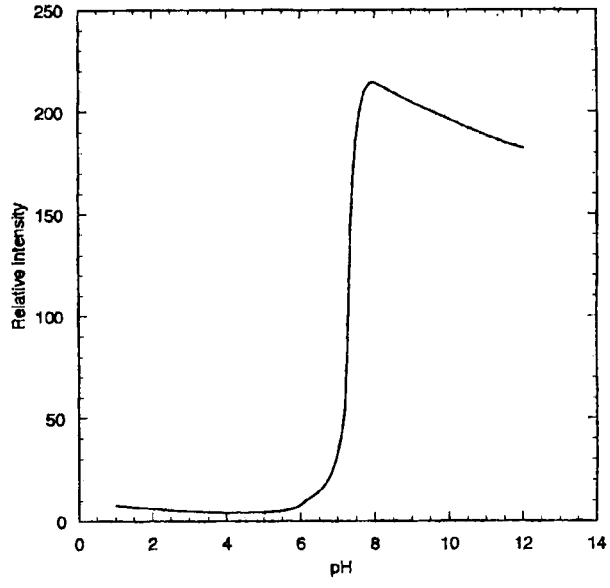


Figure 5. *p*H dependence of fluorescence intensity of **11**.

fluorescence intensity of the aminopyridine **10**, which indicates that the protonated form of **10** is only slightly fluorescent. The increasing *p*H at the basic condition, however, resulted in the gradual decrease of the fluorescence intensity, which is probably due to the quenching by hydroxide ions. The fluorescence intensity of the pyridone **11**, on the other hand, increased markedly by the addition of the small amount of alkali to the neutral solution as shown in Figure 5. Further addition of alkali again caused the decrease of the fluorescence. In the acidic solution the fluorescence of **11** is also very weak exhibiting similar *p*H-profile to that of **10**. These *p*H-dependent changes in fluorescence intensity of **10** and **11** are reversible.

In Table 3 are summarized uv absorption and fluorescence data of **10**, **11**, and the related compounds measured in ethanol solutions. In addition to the compounds **1**, **2**, **3**, and **5**, the Table includes 2,4-dicyano-3-methyl-3-(*p*-substituted phenyl)glutarimides (**14a-c**), 7,9-dioxo-8-azaspiro[4,5]decane-6,10-dicarbonitrile (**15**), and 3-methyl-3-(*p*-chlorophenyl)glutaric acid (**16**) [7].

The quantum yield of the aminopyridine **10** (Φ = 0.24) is eight times as large as that of the pyridone **11**. Only 2-cyanohydrocinnamamide **1** with *p*-methoxy substituent exhibited fluorescence of the similar intensity and all other compounds in the Table showed much weaker fluorescence. The dihydroxypyridines **2** show strong uv

Table 3

Fluorescence Data of the Secondary Products **10** and **11** and the Related Compounds

Compound [a]		Absorption (Ethanol) λ_{max} nm (log ε)	λ_{ex} nm/λ_{em} nm	Φ_f [b]	
1	(OCH_3)	228 (4.50), 274 (3.21), 281 sh (3.13)	245/297	1.1×10^{-1} (1.5×10^{-2})	[c]
2	(H)	206 (4.30), 259 (4.32), 345 (4.28)	330/410	9.3×10^{-5} (1.3×10^{-3})	[c]
	(OCH_3)	207 (4.29), 263 (4.37), 287 (3.67), 344 (4.30)	280/400	4.3×10^{-5} (7.5×10^{-4})	[c]
	(Cl)	206 (4.33), 259 (4.34), 346 (4.24)	330/410	2.1×10^{-4} (1.0×10^{-3})	[c]
	(NO_2)	203 (4.40), 266 (4.42), 310 (4.08), 345 (3.97)	330/380-500	4.3×10^{-5} (1.6×10^{-3})	[c]
3	(H)	215 (4.13), 230 (2.60), 263 (2.70)	250/280	4.1×10^{-3} (5.3×10^{-2})	[c]
	(OCH_3)	205 (3.78), 233 (3.84), 277 (2.80), 281 (2.77)	245/295	9.5×10^{-3} (1.1×10^{-2})	[c]
5	(OCH_3)	238 (4.04), 334 (4.43)	280/350	7.5×10^{-5} (6.1×10^{-4})	[c]
10		250 (4.33), 355 (4.03)	280/417	2.4×10^{-1} (1.6×10^{-3})	
11		251 (4.20), 355 (4.25)	280/428	3.0×10^{-2} (1.5×10^{-3})	
14a	(H)	219 (3.62), 265 sh (3.17), 290 (3.19)	290/330-500	1.8×10^{-3} (5.2×10^{-3})	
b	(Cl)	228 (3.64), 265 (2.79), 290 (2.33)	245/330-500	8.0×10^{-4} (1.2×10^{-4})	
c	(Br)	232 (3.77), 266 sh (2.86), 274 sh (2.72), 296 sh (2.42)	280/320-500	5.5×10^{-4} (3.5×10^{-4})	
15		212 (3.56), 240 sh (2.85), 335 (2.41)	290/330-500	8.5×10^{-3} (1.2×10^{-1})	[d]
16		224 (3.69), 266 (2.77)	250/290	3.4×10^{-3} (7.4×10^{-2})	

[a] *p*-Substituent of the phenyl group is shown in parentheses. [b] Concentration in g/l of the solution for the quantum yield measurement is given in parentheses. [c] Reference [1]. [d] Reference [7].

absorption but their excited states undergo thermal relaxation almost exclusively resulting in weak luminescence. The effect of *p*-chloro and *p*-methoxy substituents in the phenyl group upon the fluorescence quantum yield is ambivalent in **2**, 2-pyrrolidones **3**, and glutarimides **14**. Very broad (330-500 nm) and weak emission band is observed for **14**, the ir spectra of which indicate partial enolization of the carbonyl group.

EXPERIMENTAL

2-Amino-3-carbomethoxy-6-phenyl-4-(1-phenylethyl)pyridine (**10**) and 3-Cyano-6-phenyl-4-(1-phenylethyl)-2-pyridone (**11**).

A mixture of 100 g (0.74 mole) of 2-phenylpropionaldehyde (**7**) with 236 g (2.4 moles) of methyl cyanoacetate (**8**), 40 g (0.52 mole) of ammonium acetate, and 120 g (2 moles) of acetic acid in 400 ml of benzene was refluxed at 120° for 26 hours in a Dean-Stark apparatus, and 70 ml of an aqueous layer containing acetic acid and ammonium acetate was separated out. After washing with 2 *M* sodium hydrogen carbonate solution and with water, the reaction mixture was evaporated to yield 194 g of residual oil from which 15.63 g of crude **11** crystallized out. Recrystallization from 95% ethanol gave 10.41 g of **11** as colorless needles. The residual oil was subjected to silica gel column chromatography, and elution with chloroform-carbon tetrachloride (3:7) afforded 44.6 g (28%) of (*E*)-2-cyano-4-phenylpent-2-enoate (**9**) [5a] as colorless oil, bp 155-165°/5 Torr, 2.36 g (1%) of **10** recrystallized from 95% ethanol, and 0.14 g of **11**. Total yield of **11** amounted to 10.55 g (4.7%).

Compound **10** had mp 150-151°; ir (Nujol): ν NH 3450, 3300, 3200, ν C=O 1700 cm^{-1}; ^1H nmr (deuteriochloroform): δ 1.64 (d, 3H, J = 7 Hz), 3.83 (s, 3H), 4.87 (q, 1H, J = 7 Hz), 5.85 (s, 2H), 6.98 (s, 1H), 7.23 (s, 5H), 7.9 (m, 2H), 7.4 (m, 3H); ^{13}C nmr (deuteriochloroform): δ 21.7 (CH_3-α-phenethyl), 41.2 (CH-α-phenethyl), 51.9 (OCH_3), 107.1 (3-pyridine), 110.7 (5-pyridine), 126.2 (4"-phenyl), 127.1, 127.6, 128.3, 128.5 (2',3',5',6',2",3",5",6"-phenyl), 129.3 (4'-phenyl), 138.8 (1"-phenyl), 145.0 (1'-phenyl), 158.4 (4-pyridine), 158.5 (6-pyridine), 158.6 (2-pyridine), 168.7 (C=O): ms: m/z 332 (77.6), 317 (14.9), 300 (100), 285 (8.8), 271 (7.3), 150 (10.6), 105 (6.4), 104 (7.3); uv (ethanol): λ_{max} nm (log ε) 249 (4.32), 343 (4.04) in neutral solution, 255 (4.27), 345 (4.15) in acidic solution, 248 (4.60), 340 (4.36) in basic solution.

Anal. Calcd. for $C_{21}H_{20}N_2O_2$: C, 75.90; H, 6.20; N, 8.43. Found: C, 75.86; H, 6.09; N, 8.42.

Compound **11** had mp 241-242°; ir (Nujol): ν C≡N 2225, ν C=O 1650 cm^{-1}; ^1H nmr (deuteriochloroform): δ 1.72 (d, 3H, J = 7 Hz), 4.59 (q, 1H, J = 7 Hz), 6.44 (s, 1H), 7.35 (s, 5H), 7.75 (m, 2H), 7.55 (m, 3H); ^{13}C nmr (deuteriochloroform): δ 19.6 (CH_3-α-phenethyl), 43.5 (CH-α-phenylethyl), 101.1 (3-pyridine), 104.1 (5-pyridine), 115.0 (CN), 127.4 (4"-phenyl), 127.2, 127.5, 128.9, 129.4 (2',3',5',6',2",3",5",6"-phenyl), 131.7 (2-pyridine), 131.7 (4'-phenyl), 141.2 (1"-phenyl), 151.1 (1'-phenyl), 163.4 (4-pyridine), 168.0 (6-pyridine); ms: m/z 300 (100), 285 (20.5), 274 (7.6), 223 (3.9), 197 (12.5), 118 (7.5), 105 (26.6); uv (ethanol): λ_{max} nm (log ε) 251 (4.15), 355 (4.22) in neutral solution, 251 (4.12), 355 (4.22) in acidic solution, 249 sh (4.71), 325 (4.60) in basic solution.

Anal. Calcd. for $C_{20}H_{16}N_2O$: C, 80.00; H, 5.33; N, 9.33. Found: C, 79.98; H, 5.18; N, 9.40.

Reaction of **9** (20 g, 0.093 mole), **7** (18 g, 0.13 mole), ammonium acetate (8 g, 0.1 mole), and acetic acid (25 g, 0.42 mole) in benzene (300 ml) in essentially the same manner as described above yielded **11** (3.11 g, 11%) and recovered **9** (9.97 g, 50%). The presence of **10** in the reaction mixture was ascertained by silica gel tlc.

2,4-Dicyano-3-methyl-3-phenylglutarimide (**14a**).

A mixture of acetophenone (120 g, 1 mole), ethyl cyanoacetate (226 g, 2 moles), ammonium acetate (77 g, 1 mole), and ammonia (34 g, 2 moles) in 400 ml of 95% ethanol was kept at 0° for 4 days. Precipitated cyanoacetamide (92.0 g) was filtered off, and from the mother liquor crude **14a** crystallized out and was recrystallized from 95% ethanol to give 23.5 g (9.3%) of **14a**, mp 294-296° (lit mp 286-287° [8]); ir (Nujol): ν OH 3400, ν NH 3200, 3100, ν C≡N 2250 (isolated, weak), 2170 (conjugated, strong), ν C=O 1740, 1700, ν C=C 1580 cm^{-1}; ^1H nmr (deuteriodimethyl sulfoxide): δ 1.75 (s, 3H), 6.60 (s, 2H), 7.25 (s, 5H), 7.7 (broad, NH); ms: m/z 253 (37, M^+), 170 (100), 144 (50).

Anal. Calcd. for $C_{14}H_{11}N_3O_2$: C, 66.40; H, 4.35; N, 16.60. Found: C, 66.43; H, 4.29; N, 16.71.

2,4-Dicyano-3-methyl-3-(*p*-chlorophenyl)glutarimide (**14b**).

Cyanoacetamide (3.3 g, 0.04 mole) and ethyl (*Z*)-2-cyano-3-(*p*-chlorophenyl)but-2-enoate (8.5 g, 0.034 mole) were added to the solution of sodium ethoxide prepared from sodium (0.88 g, 0.04 mole) and ethanol (33 ml), and the mixture was stirred for 20 minutes. After standing overnight at room temperature, water and hydrochloric acid were added and the precipitates were recrystallized from ethanol to give 7.99 g (82%) of **13b**, mp 282-283°, colorless prisms; ir (Nujol): ν NH 3210, 3120, ν C≡N 2250, ν C=O 1740 (weak), 1705 (strong), ν C=C 1590, 1500 cm^{-1}; ^1H nmr (hexadeutrioacetone): δ 1.90 (s, 3H), 5.15 (s, 2H), 7.78 and 7.54 (A_2B_2, 4H), 11.1 (broad s, NH); ^{13}C nmr (hexadeuterioacetone): δ 18.0 (CH_3), 43.7 (quaternary C), 48.7 (CH), 114.1 (CN), 129.1 (CH-phenyl), 130.1 (CH-phenyl), 135.3 (C-phenyl), 138.8 (C-phenyl), 164 (CO); ms: m/z 289 (13, M^+), 287 (38, M^+), 204 (100), 178 (34), 177 (30), 101 (27.5).

Anal. Calcd. for $C_{14}H_{10}N_3O_2Cl$: C, 58.53; H, 3.48; N, 14.63; Cl, 12.20. Found: C, 58.37; H, 3.60; N, 14.59; Cl, 12.15.

2,4-Dicyano-3-methyl-3-(*p*-bromophenyl)glutarimide (**14c**).

This compound was prepared in essentially the same manner as described above using ethyl (*Z*)-2-cyano-3-(*p*-bromophenyl)but-2-enoate in 69% yield, mp 245-248°, colorless prisms from ethanol; ir (Nujol): ν NH 3240, 3150, ν C≡N 2280, ν C=O 1735 (weak), 1720 (strong), ν C=C 1600, 1490 cm^{-1}; ^1H nmr (hexadeutrioacetone): δ 1.91 (s, 3H), 5.20 (s, 2H), 7.75 (arom, 4H), 11.0 (broad s, NH); ^{13}C-nmr (deutrioacetone): δ 17.9 (CH_3), 43.5 (quaternary C), 48.6 (CH), 114.0 (CN), 123.5 (C-phenyl), 129.3 (CH-phenyl), 133.1 (CH-phenyl), 139.2 (C-phenyl), 164.1 (CO); ms: m/z 333 (65, M^+), 331 (67, M^+), 250 (99), 248 (100), 224 (31), 222 (33), 223 (32), 221 (30), 169 (28), 143 (23).

Anal. Calcd. for $C_{14}H_{10}N_3O_2Br$: C, 50.60; H, 3.01; N, 12.65; Br, 24.10. Found: C, 50.59; H, 3.23; N, 12.56; Br, 24.13.

3-Methyl-3-(*p*-chlorophenyl)glutaric Acid (**16**).

A mixture of **13b** (4.5 g, 0.016 mole), 50% sulfuric acid (40 ml), and acetic acid (16 ml) was refluxed for 96 hours at 160°.

The reaction mixture was added to 200 ml of water and placed in a refrigerator for overnight to yield precipitates, which were recrystallized from water giving 3.43 g (84%) of **16**, mp 151-152°, colorless needles: ir (Nujol): ν OH 3340, 2500-3100, ν C=O 1720 cm^{-1}; ^1H nmr (hexadeutrioacetone): δ 1.60 (s, 3H), 2.93 (s, 4H), 7.45, 7.30 (A_2B_2, 4H); ^{13}C nmr (hexadeuterioacetone): δ 26.0 (CH_3), 31.9 (quaternary C), 45.0 (CH_2), 128.6 (CH-phenyl), 132.0 (C-phenyl), 146.3 (C-phenyl), 172.5 (CO); ms: m/z 258 (12, M^+), 256 (35, M^+), 238 (27), 197 (62), 155 (100), 152 (67).

Anal. Calcd. for $C_{12}H_{13}O_4Cl$: C, 56.14; H, 5.07; Cl, 13.84. Found: C, 55.97; H, 5.06; Cl, 13.83.

*p*H-Dependence of Fluorescence of **10** and **11**.

Fluorescence was measured with a JASCO PF-770 Fluorophotometer. To 3.5 ml of the ethanol solution of **10** (4.72×10^{-7} mole/l) or **11** (6.95×10^{-6} mole/l) was added repeatedly each 0.03 ml portion of 0.5 *M* or 1 *M* sodium hydroxide or hydrochloric acid solution. After each addition the fluorescence intensity was recorded and the *p*H of the solution was estimated by MERCK universal *p*H stick.

Quantum Yield of Fluorescence.

Fluorescence spectra were determined on a HITACHI MPF-4 Fluorophotometer, and each spectrum of the sample solution was reduced by the spectrum of the solvent determined under the same conditions. Dimethylaminobenzene, quinine, 2-aminopyridine, and rhodamine 6B were used as reference compounds of fluorescence intensity [9]. For standards of quantum yield, solutions of quinine in 0.5 *M* and 0.05 *M* sulfuric acid were used; for example, 1.4×10^{-3} g/l, λ_{ex} 330 nm/λ_{em} 454 nm, $\Phi_f = 0.55$.

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[7] Compound **14a** was reported in the literature [8], but in this paper **14a** was prepared under the conditions described by us [1]. Compounds **14b**, **14c**, and **16** were prepared according to the method published [8], while **15** is commercially available: Aldrich, #28139-5.

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[9] Spectra were corrected with the methods described in the literature; H. Kokubun, New Lecture on Experimental Chemistry, Vol **4**, *Chem. Soc. Japan* edited, Maruzen Co, 1976, p 550.