Chemoselective Polyamidation

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ABSTRACT: A convenient method for the synthesis of polyamides containing hydroxyl, amino, and carboxyl substituents on the aromatic rings of the backbones has been developed. These polymers were prepared readily by the chemoselective polyamidation of dicarboxylic acids with diamines containing various functional groups using the activating agent diphenyl(2,3-dihydro-2-thioxo-3-benzoxazolyl)phosphonate (**1**). The direct polycondensation (one-step) of 5-hydroxy or 5-aminoisophthalic acid with diamines proceeded smoothly under mild conditions and produced the desired polyamides with inherent viscosities up to 0.92 dl g^{-1} . Furthermore, the carboxyl-substituted polyamides from dicarboxylic acids and 3,5-diaminobenzoic acid were prepared by the two-step procedure. The model reaction was studied in detail to demonstrate the feasibility of the chemoselective polyamidation.

KEY WORDS Chemoselective Polyamidation / Direct Polycondensation /
Activating Agent / Dicarboxylic Acid / Diamine /

The synthesis of proteins in the living cells involves the building of different amino acids into the proper sequences and spatial arrangements to produce specific protein molecules under mild conditions, and the proteins produced are perfectly monodisperse polymers. This process is an ideal one in the synthesis of polymers, including the activation of amino acids, followed by aminolysis, the high chemoselectivity, the sequential regulation, and the control of the molecular weight.

About 15 years ago, a direct polycondensation using activating agents had been initiated to realize for the *in situ* activation of carboxylic acids, followed by condensation under mild conditions. Now, this method has been developed as a useful method for the synthesis of polyamides, polyesters, and other condensation polymers, where organophosphorus reagents have been found useful for the activation of carboxylic acids.¹

The next target is to establish the method

on the chemoselective polycondensation using the activating agents. A reaction is said to be chemoselective when a functional group is selectively attacked in the presence of a different functional group. The chemoselective polycondensation is carried out by the direct polycondensation of multifunctional dicarboxylic acids and diamines without special protection of the acyl-sensitive groups.

In the preceding paper,² we briefly reported the synthesis of polyamides from dicarboxylic acids and diamines containing various functional groups using diphenyl(2,3-dihydro-2-thioxo-3-benzoxazolyl)phosphonate (**1**) as the activating agent. We now report details of our studies on the chemoselective polyamidation.

EXPERIMENTAL

Materials

N-Methyl-2-pyrrolidone (NMP) and hexamethylphosphoramide (HMPA) were purified

by vacuum distillation and stored over 4-Å molecular sieves. 4,4'-Oxydianiline (ODA), 4,4'-methylenedianiline (MDA), and 4,4'-sulfonyldianiline (SDS) were purified by recrystallization from tetrahydrofuran, cyclohexane, and ethanol-chloroform, respectively. Benzoic acid (**2a**), isophthalic acid (**2b**), terephthalic acid (**2c**), sebacic acid (**2d**), 4,4'-oxybis(benzoic acid) (**2e**), 5-hydroxyisophthalic acid (**2f**), 5-aminoisophthalic acid (**2g**), and 3,5-diaminobenzoic acid (**2h**) were purified by recrystallization. Pyridine (Py) and triethylamine (TEA) were purified by the usual methods. Other reagents and solvents were obtained commercially and used as received.

The activating agent diphenyl(2,3-dihydro-2-thioxo-3-benzoxazolyl)phosphate (**1**) was prepared according to the reported procedure.²

N-(4'-Hydroxyphenyl)benzamide (**4**). The activating agent **1** (0.422 g, 1.1 mmol) was added to a solution of **2a** (0.122 g, 1 mmol), *p*-aminophenol (0.101 g, 1 mmol), and TEA (0.14 ml, 1 mmol) in NMP (1 ml) at room temperature. The solution was stirred for 1 h and poured into 1% aqueous sodium hydrogen carbonate. The precipitate was filtered, washed with water, and dried. The yield was 0.209 g (98%). Recrystallization from toluene afforded white crystals. mp 217–218°C (lit.³ 216–217°C).

N,N'-Diphenyl-5-hydroxyisophthalamide (**5**). To a solution of **2f** (0.182 g, 1.0 mmol), aniline (0.18 ml, 2 mmol), and TEA (0.28 ml, 2 mmol) in NMP (1 ml) was added the activating agent **1** (0.767 g, 2 mmol). The product was isolated as described above. The yield was 0.322 g (97%). Recrystallization from methanol afforded white crystals. mp 264–265°C. IR (KBr) ν 3280 (O–H), 1650 cm^{-1} (C=O). ¹³C NMR : observed value (calculated value):

(C-1) 123.5 (124.3), (C-2) 128.4 (128.4), (C-3)

120.3 (120.6), (C-4) 138.9 (139.3), (C-5) 164.9, (C-6) 136.5 (137.0), (C-7) 120.3 (119.6), (C-8) 117.4 (117.7), (C-9) 157.2 (154.8). *Anal.* Calcd for $\text{C}_{20}\text{H}_{16}\text{N}_2\text{O}_3$: C, 72.28%; H, 4.85%, N, 8.43%. Found: C, 72.42%, H, 4.94%; N, 8.22%.

N,N'-Diphenyl-5-aminoisophthalamide (**6**). This compound was prepared from **2g** (0.181 g, 1 mmol), and aniline (0.18 ml, 2 mmol) as described above. The yield was 0.301 g (91%). Crystallization from chloroform yielded white crystals. mp 246°C (by DTA). IR (KBr) ν 3280 (N–H), 1650 cm^{-1} (C=O). ¹³C NMR:

(C-1) 123 (124.3), (C-2) 128.3 (128.4), (C-3) 120.3 (120.6), (C-4) 138.9 (139.3), (C-5) 164.9, (C-6) 135.9 (135.9), (C-7) 115.5 (118.1), (C-8) 113.8 (117.1), (C-9) 148.6 (145.7). *Anal.* Calcd for $\text{C}_{20}\text{H}_{17}\text{N}_3\text{O}_2$: C, 72.49%; H, 5.17%; N, 12.68%. Found: C, 72.31%; H, 5.04%; N, 12.41%.

Kinetic Measurement

Equimolar amounts of **2a** and substituted aniline was reacted in the presence of **1** in NMP at 25°C for a specified time. Rates of the aminolysis reaction were followed by measuring the weights of the isolated products. The overall second order rate constants were calculated from the slopes of the reciprocal plots of $(a-x)$ versus time (t) following the rate equation $1/(a-x) - 1/a = kt$, where a and x are the initial concentration of **2a** and the concentration of product at any time.

Selective Activation of Carboxyl Group

The competitive reaction of two benzoic acids with aniline was carried out in the presence of **1** at room temperature for a specified time. The products were isolated described above. The product ratio was determined by ¹H NMR spectroscopy.

Polycondensation

Typical examples of the polycondensations follows.

Polyamide (7b) from 2f and MDA. To a solution of **2f** (0.182 g, 1 mmol) and MDA (0.198 g, 1 mmol), and TEA (0.28 ml, 2 mmol) in NMP (1 ml) was added the activating agent **1** (0.843 g, 2.2 mmol). The mixture was stirred at room temperature until **1** was dissolved completely in NMP, and then at 80°C for 4 h. The resulting viscous solution was diluted with NMP (5 ml) and poured into methanol (500 ml). The polymer that precipitated was filtered and was refluxed in methanol for 2 h. The fibrous polymer was collected and dried in vacuo at 100°C. The yield was 0.343 g (99%). The inherent viscosity of the polymer in concentrated sulfuric acid was 0.72 dl g⁻¹ at a concentration of 0.5 g dl⁻¹ at 30°C. IR (film) ν 3300 (N-H), 1650 cm⁻¹ (C=O). ¹³C NMR {(CD₃)₂SO}:

(C-1) 164.7, (C-2) 136.8 (136.4), (C-3) 120.3 (119.6), (C-4) 117.3 (117.7), (C-5) 157.1 (154.8), (C-6) 136.5 (136.4), (C-7) 120.3 (120.5), (C-8) 128.5 (129.1), (C-9) 136.4 (133.2), (C-10) 42.2. *Anal.* Calcd for C₂₁H₁₇N₂O₃·H₂O: C, 69.60%; H, 5.00%; N, 7.73%. Found: C, 69.95%; H, 4.66%; N, 7.06%.

Polyamide (8b) from 2g and MDA. The activating agent **1** (0.843 g, 2.2 mmol) was added at room temperature with stirring to a solution of **2g** (0.181 g, 1 mmol), MDA (0.198 g, 1 mmol), and TEA (0.28 ml, 2.0 mmol) in NMP. The mixture was stirred at room temperature for 24 h. The polymer was isolated as described above. The yield was 0.316 g (92%). The inherent viscosity was 0.32 dl g⁻¹ in NMP (C=0.5 g dl⁻¹ at 30°C). IR (KBr): ν 3300 (N-H), 1650 cm⁻¹ (C=O). ¹³C NMR {(CD₃)₂SO}:

(C-1) 165.5, (C-2) 136.4 (135.9), (C-3) 115.6 (117.1), (C-4) 115.4 (117.1), (C-5) 148.6 (145.9), (C-6) 137.0 (136.4), (C-7) 120.3 (120.5), (C-8) 128.5 (129.1), (C-9) 135.9 (133.2), (C-10) 42.2. *Anal.* Calcd for C₂₁H₁₇N₃O₂·H₂O: C, 69.79%; H, 5.30%; N, 11.63%. Found: C, 70.66%; H, 5.03%; N, 11.40%.

Polyamide (9a) from 2b and 2h. The activating agent **1** (0.805 g, 2 mmol) was added to a solution of **2b** (0.166 g, 1 mmol), and TEA (0.28 ml, 2 mmol) in NMP (2 ml). After 30 min, **2h** (0.152 g, 1 mmol) was added. Stirring was continued at room temperature for 12 h. The polymer was isolated as described above. A 99% yield of the polymer having an inherent viscosity of 0.46 dl g⁻¹ in NMP (c=0.5 g dl⁻¹ at 30°C) was obtained. IR (KBr): ν 3300 (N-H), 1700 (COOH), 1650 cm⁻¹ (C=O). ¹³C NMR {(CD₃)₂SO}:

(C-1) 165.0 (C-2) 134.7 (135.0), (C-3) 127.0 (126.9), (C-4) 130.7 (130.4), (C-5) 128.4 (127.9), (C-6) 139.3 (139.2), (C-7) 116.3 (117.8), (C-8) 116.8 (117.9), (C-9) 131.3 (130.4), (C-10) 166.8. *Anal.* Calcd for C₁₅H₁₀N₂O₄·H₂O: C, 60.00%; H, 4.03%; N, 9.33%. Found: C, 60.79%; H, 4.32%; N, 8.80%.

Polyamide (10) from Isophthaloyl Chloride and Methyl 3,5-Diaminobenzoate. The solution of methyl 3,5-diaminobenzoate (0.166 g, 1 mmol) in NMP (2 ml) was cooled to a mush with a dry ice-acetone bath. To this was added solid isophthaloyl chloride (0.203 g, 1 mmol) in one portion, and the cooling bath was changed to an ice-water bath. The mixture was stirred

for 30 min at 0°C or below and for additional 12 h. During this time a viscous solution of polymer formed. The polymer was isolated as described above. A 99% yield of the polymer having an inherent viscosity of 0.40 dl g⁻¹ in NMP ($c=0.5$ g dl⁻¹ at 30°C) was obtained. IR (film): ν 3300 (N-H), 1710 (COOCH₃), 1650 cm⁻¹ (C=O). ¹³C NMR {(CD₃)₂SO}:

(C-1) 165.0, (C-2) 134.6 (135.0), (C-3) 127.0 (126.9), (C-4) 130.7 (130.4), (C-5) 128.4 (127.9), (C-6) 139.5 (138.7), (C-7) 116.4 (116.2), (C-8) 116.4 (115.9), (C-9) 130.0 (129.6), (C-10) 165.7, (C-11) 52.1 (51.0). *Anal.* Calcd for C₁₆H₁₂N₂O₄ 1/2 H₂O: C, 62.95%; H, 4.29%; N, 9.17%. Found: C, 63.05%; H, 4.20%; N, 8.67%.

Authentic Polyamide (11). Polyamide 10 (0.317 g, 1 mmol) was dissolved in NMP (5 ml). To this was added an aqueous solution of 1*N*-sodium hydroxide, and stirred at room temperature for 5 h. The resulting solution was poured into water. Acidification of the solution with excess hydrochloric acid gave precipitate, which was filtered, washed with water, and was refluxed in methanol for 2 h. The fibrous polymer was collected and dried *in vacuo* at 100°C. The yield was 0.282 g (98%). The inherent viscosity of the polymer in concentrated sulfuric acid was 0.38 dl g⁻¹ at a concentration of 0.5 g dl⁻¹ at 30°C. IR (film) ν 3300 (N-H), 1700 (C=O), 1650 cm⁻¹ (C=O). ¹³C NMR {(CD₃)₂SO}:

(C-1) 165.2, (C-2) 134.7 (135.0), (C-3) 127.1

(126.9), (C-4) 131.0 (130.4), (C-5) 128.6 (127.9), (C-6) 139.4 (139.2), (C-7) 116.7 (117.8), (C-8) 117.0 (117.9), (C-9) 131.4 (130.4), (C-10) 166.9.

RESULTS AND DISCUSSION

Model Reaction

To achieve a chemoselective polyamidation (eq 1),

(X, Y:OH, NH₂, COOH)

an active intermediate or a base has to satisfy the following requirements.

- 1) Differentiation between a hydroxyl group and an amino group.
- 2) Differentiation between the two amino groups with different pK_a values.
- 3) Differentiation between the two carboxyl groups with different pK_a values.

In the preceding paper,² we showed diphenyl(2,3-dihydro-2-thioxo-3-benzoxazolyl)phosphate (**1**) was the new activating agent for the synthesis of amides and polyamides. It is generally accepted that the lower the selectivity, the greater is the reactivity. The activating agent **1** reacts with carboxylic acid to form an active intermediate, mixed carboxylic-phosphonic anhydride (**3**), the reactivity of which toward nucleophiles is lower than that

of acid chlorides. Thus, a chemoselective amidation was expected. By using this activating agent **1**, the following model compound work was performed by the direct procedure (one-step) to determine if the desired model compounds were formed in quantitative yields to constitute a polymer-forming reaction. This procedure consists of adding **1** to a solution of carboxylic acid and amine in NMP

that contains a tertiary organic base to form a carboxylate anion.

Differentiation between a Hydroxyl Group and an Amino Group with the Active Intermediate 3. The reaction of *p*-aminophenol with benzoic acid (**2a**) was performed to get information whether the active intermediate **3** derived from **1** and **2a** can differentiate or not between a hydroxyl group and an amino group (eq 2).

The reaction proceeded smoothly at room temperature to give the selective *N*-acylated product, 4'-hydroxybenzanilide (**4**) quantitatively. Furthermore, the synthesis of *N,N'*-diphenyl-5-hydroxyisophthalamide (**5**) from **2f** and aniline was carried out in the presence of **1**. The reaction was completed in 1 h at room temperature and the desired diamide **5** was obtained in quantitative yield (eq 3).

These results show that the active intermediate **3** does not react with a hydroxyl group which is less nucleophilic than an amino group.

Differentiation between the Two Amino

Table I. Overall second order rate constants for the reaction of **2a** with substituted anilines in NMP at 25°C in the presence of **1**^a

Substituted aniline X-C ₆ H ₄ -NH ₂	pK _a ^b	Rate constant
		mol l ⁻¹ min ⁻¹
<i>p</i> -CH ₃ O-	5.3	7.3
H	4.2	1.1
<i>m</i> -Cl	3.5	0.078
<i>m</i> -NO ₂	2.5	0.0068

^a Reaction was carried out with 1 mmol of each reactant at 25°C in the presence of **1** (1 mmol).

^b At 25°C, in water.

Figure 1. Hammett plot of log *k* vs. pK_a.

Groups with Different pK_a Values with the Active Intermediate 3. The overall second order rate constants for the reaction of **2a** with substituted anilines in NMP in the presence of **1** were determined, where the aminolysis of the active intermediate **3** is an important, probably rate-determining. The results are shown in Table I. The rate constants changed by more than 10³ when substituted anilines were varied from *p*-methoxyaniline to *m*-nitroaniline. Hammett plot of log *k* vs. pK_a is shown in Figure 1. The linear relationship between these values was observed. The active intermediate **3** can differentiate between the amino groups with the difference of pK_a values about 2. Then,

the reaction **2g** with aniline was carried out at room temperature. The desired diamide, *N,N'*-diphenyl-5-aminoisophthalamide (**6**) was obtained quantitatively, which indicates that the intermediate **3** can differentiate between the more nucleophilic amino group in aniline and the amino group in **2g** (eq 4).

Differentiation between the Two Carboxylic Groups with Different pK_a Values with Organic Bases. The selective activation of carboxylic groups with organic bases was studied. The results of competitive reaction of *p*-nitrobenzoic acid and *p*-methoxybenzoic acid with aniline in the presence of **1** are shown in Table II (eq 5).

By using weak bases, such as pyridine (Py) and quinoline, the two carboxyl groups with the difference of pK_a values about 1 can nearly differentiated. A steric factor is important to increase the selectivity. Then, the competitive

Table II. Selective activation of carboxyl groups with organic bases^a

Base	pK_a^b	Yield	Product ratio ^c
		g	A : B
Quinoline	5.0	0.177	95 : 5
Pyridine	5.2	0.204	97 : 3
<i>N</i> -Ethylmorpholine	7.7	0.235	74 : 26
Triethylamine	10.9	0.230	69 : 31

^a Reaction was carried out with 1 mmol of each carboxylic acid using the activating agent **1** (1 mmol) in NMP (1 ml) at room temperature for 1 h in the presence of base.

^b At 25°C, in water.

^c Product ratio was determined by ¹H NMR spectroscopy.

reaction between substituted benzoic acids with aniline was carried out with using Py as a base. The selective amidation was observed in the reaction between *p*-nitrobenzoic acid and *o*-methoxybenzoic acid (Table III). These results suggest that the selective activation of carboxylic acids depends not only on thermodynamic factor but also kinetic one.

Polymer Synthesis

On the basis of these results, the chemoselective polyamidation was carried out in the presence of **1**.

Synthesis of Hydroxy-Substituted Polyamide (7). The direct polycondensation of **2f** with diamines, such as 4,4'-oxydianiline (ODA) and 4,4'-methylenedianiline (MDA) was carried out with the activating agent **1** in NMP (eq 6). The results are listed in Table IV.

Relatively high molecular weight polyamides **7** were obtained at room temperature. The reaction temperature on the polycondensation showed a favorable effect on the molecular

Table III. Selective activation of carboxyl groups with Pyridine^a

Carboxylic acid				Yield	Product ratio ^c
R ¹ -COOH	pK _a ^b	R ² -COOH	pK _a	g	A : B
4.2		4.1	0.124	84 : 16
4.2		3.9	0.132	67 : 33
2.9		4.5	0.157	83 : 17
2.2		4.5	0.181	82 : 18
3.4		4.1	0.200	99 > : < 1
3.4		3.9	0.233	84 : 16

^a Reaction was carried out with 1 mmol of each carboxylic acid using the activating agent **1** (1 mmol) in NMP (1 ml) at room temperature for 1 h in the presence of pyridine (1 mmol).

^b At 25°C, in water.

^c Product ratio was determined by ¹H NMR spectroscopy.

Table IV. Polycondensation of 5-hydroxyisophthalic acid **2f** with diamines using activating agent **1**^a

Diamine	NMP	Temp	Time	Polymer		
	ml	°C	h	Type	Yield	η_{inh}^b
					%	dl g ⁻¹
ODA	2.0	r.t.	24	7a	99	0.55
ODA	2.0	80	4	7a	99	0.92
MDA	1.0	r.t.	24	7b	98	0.32
MDA	2.0	80	4	7b	99	0.72

^a Polycondensation was carried out 1 mmol of each monomer using 2.2 mmol of **1** in the presence of 2 mmol of TEA.

^b Measured at a concentration of 0.5 g dl⁻¹ in concentrated sulfuric acid at 30°C.

weight of polymers, where polyamides with inherent viscosities up to 0.92 dl g⁻¹ were obtained. We found that the system employing the activating agent **1** was mild and provided a high degree of selectivity for amide rather

than ester bond formation during polymerization.

Synthesis of Amino-Substituted Polyamide (8). The direct polycondensation of **2g** with diamines was performed (eq 7).

The condensation with ODA proceeded smoothly at room temperature and gave relatively high molecular weight polyamide **8**. A gelation was observed in the polycondensation with 4,4'-sulfonyldianiline (SDS) because of the small difference of the basicity of amino groups in **2g** and SDS (Table V).

Synthesis of Carboxyl-Substituted Polyamide (9). The authentic polyamide (**11**) was prepared by the polycondensation of isophthaloyl chloride with methyl 3,5-diaminobenzoate, followed by alkaline hydrolysis (eq 8).

The polyamide **9a** synthesis from isophthalic acid (**2b**) and 3,5-diaminobenzoic acid (**2h**) was performed by using the activating agent **1** (eq 9).

Polycondensation proceeded smoothly and gave a polyamide with inherent viscosity of 0.52 dl g^{-1} . However, from the comparison with the ^{13}C NMR spectrum of the authentic polyamide **11**, the polyamide **9a** obtained by the direct procedure was found to have a few branch points at carboxyl groups of **2h**. (The characterization of polyamides will be discussed in the next section.) This branching reaction reflects the insufficient selectivity for carboxyl groups with organic bases. Therefore, the two step procedure was applied for the synthesis of polyamide **9**. The two-step procedure involves two separate steps: (1) Activation of the carboxylic acid component, *i.e.*, generation of the active intermediate, active amide from **1** and the carboxylic acid,

Table V. Polycondensation of 5-aminoisophthalic acid **2g** with diamines using activating agent **1**^a

Diamine	NMP	Time	Polymer		
	ml	h	Type	Yield	η_{inh}^b
				%	dl g^{-1}
ODA	2.0	2	8a	Gel.	
ODA	4.0	24	8a	89	0.74
MDA	2.0	24	8b	91	0.27
MDA	1.0	24	8b	92	0.32
SDS	2.0	24	8c	Gel.	

^a Polycondensation was carried out 1 mmol of each monomer using 2.2 mmol of **1** in the presence of 2 mmol of TEA.

^b Measured at a concentration of 0.5 g dl^{-1} in NMP at 30°C .

and (2) Condensation of this intermediate with the amine (eq 10).

The conversion of carboxylic acids to the active diamides **12** was carried out by the addition of the activating agent **1** to a solution of dicarboxylic acids in HMPA at room temperature for 30–180 min, and then diamine **2h** was added. The results of several representative polyamide synthesis by the two-step procedure are summarized in Table VI. Polycondensation proceeded smoothly and gave the desired polyamides **9** which were free from branching.

Polymer Characterization

The IR spectra of the polyamides were consistent with model compounds and known analogues. All polyamides prepared showed characteristic N–H, amide I, and amide II

bands in the range 3280–3300, 1650–1660, and 1510–1540 cm^{-1} , respectively. In addition, peaks associated with hydroxyl, amino, and carboxyl groups were also observed for polyamide **7**, **8**, and **9**, respectively. Elemental analyses also supported the formation of the expected polymers.

The most conclusive spectral evidence for the proposed polyamide structures and especially for the selective amidation, was provided by ^{13}C NMR. A typical ^{13}C NMR spectrum of polymer **7b** is shown in Figure 2 together with assignments of the observed resonances. The calculated chemical shifts are all within ± 2 ppm of observed values. No peak of ester carbonyl group was found, clearly indicating the formation of the expected polyamide **7b**.

Figure 3 shows the ^{13}C NMR spectra of the authentic polyamide **11** and polyamides **9a** prepared by the one-step and the one-pot procedures, respectively. In the authentic polyamide **11** and polyamide **9a** obtained by the two-step procedure. The peaks of carbon nuclei in amide carbonyl and carboxyl groups were observed at 165.2 and 166.9 ppm, respectively. No extra amide carbonyl peaks nor duplication of peaks were found, clearly indicating the formation of desired amide linkages during polymerization. On the other hand, the polyamide **9a** prepared by the one-step procedure was found to have extra

Table VI. Polycondensation of 3,5-diaminobenzoic acid **2h** with dicarboxylic acids using activating agent **1**^a

Dicarboxylic acid	HMPA	Activation time	Temp	Polymer		
	ml	min	°C	Type	Yield	η_{inh}^b
					%	dl g^{-1}
2b	2.0 ^c	30	r.t.	9a	99	0.46
2c	1.0	30	70	9b	99	0.47
2d	2.0	180	80	9c	70	0.22
2e	1.5	30	r.t.	9d	86	0.35

^a Polycondensation was carried out 1 mmol of each monomer using 2.2 mmol of **1** in the presence of 2 mmol of TEA.

^b Measured at a concentration of 0.5 g dl^{-1} in NMP at 30°C.

^c NMP was used as solvent.

Figure 2. ¹³C NMR spectrum of polyamide 7b in (CD₃)₂SO at 25°C.

Figure 3. ¹³C NMR spectra of authentic polyamide 11a and polyamides 9a prepared by the one-pot and the one-step procedures in (CD₃)₂SO at 25°C.

Figure 4. TG curves of polyamides 7a, 8a, and 9a in nitrogen.

peaks around peaks of amide and carboxyl groups which suggest some degree of branching at the carboxyl groups of **2h**.

The polyamides obtained were white or faint brown solids, soluble in concentrated sulfuric acid, methanesulfonic acid, and dipolar aprotic solvents at room temperature. Polyamides **7** and **9** were soluble in 5% aqueous sodium hydroxide solution. On the other hand, polyamide **8** was soluble in concentrated hydrochloric acid.

The thermal stability of the polymers was examined by thermogravimetry (TG). The samples were dried *in vacuo* at 150°C for 2 h, and subsequently subjected to TG, with representative curves shown in Figure 4. Polyamides **7a** and **8a** showed a 10% weight loss in nitrogen at 520°C and 475°C, respectively. Polyamide **9a** began to decompose at lower temperature, around 320°C due to the decarboxylation.

Through these polymerization, we observed the following. The active intermediate, mixed anhydride **3**, does not react with a hydroxy group less nucleophilic than an amino group. The intermediate can differentiate the more nucleophilic amino group in ODA, or MDA from the amino group in **2g**. The two-step procedure is effective for the preparation of carboxyl-substituted polyamide **9** from di-

carboxylic acids and **2h**.

In summary, we have demonstrated that the highly chemoselective polyamidation of multifunctional dicarboxylic acids and diamines without special protection of the acylation-sensitive groups can be achieved by the direct polycondensation using the activating agent **1**. This method will be utilized for the synthesis of polyamides containing hydroxyl, amino, and carboxyl substituents on the aromatic rings of the backbones.

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REFERENCES

- a) F. Higashi, *Yuki Gousei Kagaku Kyokaishi*, **40**, 922 (1982).
 - b) F. Higashi, *Yuki Gousei Kagaku Kyokaishi*, **47**, 994 (1989).
 - c) Y. Imai, *Sen'i Gakkaishi*, **40**, 137 (1984).
 - d) M. Ueda, *Koubunshi*, **35**, 128 (1986).
 - e) M. Ueda, *Yuki Gousei Kagaku Kyokishi*, **48**, 144 (1990).
- M. Ueda, A. Kameyama, and K. Hashimoto, *Macromolecules*, **21**, 19 (1988).
- K. Auwers and K. Sonnenstuhl, *Ber. Dtsch. Chem. Ges.*, **37**, 3937 (1904).