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Chiral separation of racemic amino acids with novel polyamides having *N*-α-acetyl-L-glutamyl residue as a diacid component

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Novel polyamides with asymmetric carbons in their main chains were obtained from aromatic diamines, 4,4′-diaminodiphenylmethane (DADPM) or 1,3-phenylenediamine (1,3-PDA), and *N*-α-protected L-glutamic acid, *N*-α-acetyl-L-glutamic acid (Ac-L-Glu-OH). Newly prepared polyamides showed optical rotation, implying that optically active polyamides were successfully obtained in the present study. These two types of chiral polyamides showed chiral recognition ability, which was studied by surface plasmon resonance (SPR) spectroscopy; they recognized D-glutamic acid in preference to the corresponding L-isomer. The adsorption selectivity was determined to be 1.66 for 1,3-PDA-Ac-L-Glu and 1.49 for DADPM–Ac-L-Glu. Enantioselective electrodialysis was studied adopting racemic *N*-α-acetyl-tryptophan (Ac-Trp) mixtures as model pairs of enantiomers. The membranes selectively transported Ac-D-Trp. Permselectivity toward the D-isomer reached 2.03.

1. Introduction

Production or acquisition of enantiomerically pure compounds is of great importance in diverse fields, such as pharmaceuticals, agrochemicals, foods, feeds, perfumes, and so forth, since enantiomers often show different physiological activities depending on their absolute configurations. For instance, it is a familiar example that L-glutamic acid, which is often used as a seasoning, tastes good, while the corresponding D-isomer gives different taste. Chiral separation with membranes is a promising method to obtain enantiomerically pure compounds economically and continuously among several methods for optical resolution. Separation of racemic mixtures by membranes is divided into two types of membrane systems, such as liquid [1–4] and solid (polymeric) [5–15] membranes. Even though membrane systems were different, in both membrane systems, all synthetic membranes possessed chiral microenvironment in them to discriminate a pair of enantiomers [1–15]. From those articles, the introduction of chiral environment into the synthetic membranes is indispensable so that we can obtain novel membranes for chiral separation. There are a couple of ways to prepare synthetic membranes for chiral separation; one is adopting materials possessing chiral environment as membrane materials [1–13]; the other is achiral materials are converted into membranes having chiral recognition sites [14,15]. In the present study, the authors intended to obtain novel synthetic membranes categorized into the former membrane systems, in other words, they tried to obtain membranes from polymeric materials with chiral environment. To this end, polyamides having chiral environment were adopted as membrane materials for optical resolution. Since polyamides themselves have amide linkages, which are expected to work well as functional moieties to recognize target substrate or support chiral recognition. Novel chiral polyamides were synthesized from aromatic diamines, such as 4,4′-diaminodiphenylmethane (DADPM) and 1,3-phenylenediamine (1,3-PDA), and *N*-α-protected L-glutamic acids, *N*-α-acetyl-L-glutamic acid (Ac-L-Glu-OH), which has an asymmetric carbon atom, in the presence of triphenyl phosphite (TPP) [16–21]. Membranes with chiral environment were prepared from these two types of novel polyamides and their chiral separation abilities were investigated.

2. Experimental section

2.1. Materials

N-α-Acetyl-L-glutamic acid (Ac-L-Glu-OH), triphenyl phosphite (TPP), 1,1,1,3,3,3-hexafluoro-2-propanol (HFIP), anhydrous LiCl, D-glutamic acid (D-Glu), L-glutamic acid (L-Glu), *N*-α-acetyl-D-tryptophan (Ac-D-Trp), *N*-α-acetyl-L-tryptophan (Ac-L-Trp), methanol, 1-octanethiol, ethanol, sodium azide (fungicide), and poly(hexamethylene terephthalamide/isophthalamide) ($6T/6I = 31.6/68.4$, mol/mol) were obtained from commercial sources and used as received. 1,3-Phenylenediamine (1,3-PDA) was purified by crystallization from diethyl ether [22] and 4,4′-diaminodiphenylmethane (DADPM) from H_2O [23]. 1-Methyl-2-pyrrolidinone

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(NMP), *N*,*N*-dimethylformamide (DMF), hexamethylphosphoramide (HMPA), dimethyl sulfoxide (DMSO), and pyridine (Py) were purified by the usual methods [24]. Water purified with an ultra-pure water system (Simpli Lab, Millipore S.A., Molsheim, France) was used.

2.2. General polycondensation procedure

Requisite amounts of chemicals were placed in a reaction flask fitted with a condenser and thermometer. The mixture was magnetically stirred at 80 °C for the prescribed time. The resulting viscous solution was poured into methanol under rapid stirring, and the prescribed product was washed with methanol and dried *in vacuo* for 3 d.

2.3. Characterization of the chiral polyamides

The inherent viscosity was determined with an Ubbelohde viscometer at a concentration of 5.0×10^{-3} g cm^{-3} in HFIP at 25 °C. The specific rotations were obtained with Horiba SEPA-200 polarimeter at 589 nm at ambient temperature in HFIP. The IR spectra were recorded by using a Perkin–Elmer Spectrum GX; 64 scans at a resolution of 4 cm^{-1} were collected with a membrane. The ^{1}H NMR (500 MHz) spectra were recorded in 1,1,1,3,3,3-hexafluoro-2-propanol-d_2 (HFIP-d_2) using a Bruker DRX-500 with tetramethylsilane (TMS) as an internal standard. Differential scanning calorimetry (DSC) measurements were performed with Shimadzu DSC-60. The heating rate was fixed to be 20 °C min^{-1} and the sample was purged with nitrogen at a flow rate of 50 cm^3 min^{-1}. The thermal stability of the polymers was evaluated on a Hi-Res Modulated TGA 2950 (TA instruments) under nitrogen at a heating rate of 10 °C min^{-1}. The chiral recognition of the prepared polyamides was evaluated by surface plasmon resonance using an SPR instrument (SPR670S, Nippon Laser Electronics Laboratory) [25].

2.4. Preparation of membranes

It was hard to obtain self-standing membranes from the present chiral polyamides. From this, membrane performance was tried to study by using styles of blended membranes. In the present study, amorphous polyamide, poly(hexamethylene terephthalamide/isophthalamide) (6*T*/6*I* = 31.6/68.4, mol/mol) was adopted as a membrane matrix for blended membranes. Blended membranes were prepared from HFIP solution. The chiral polyamide (50.0 mg) and the equal amount of amorphous polyamide were dissolved in 2.0 cm^3 of HFIP. The HFIP solution thus prepared was poured into a flat laboratory dish (7.5 cm in diameter) and the solvent was allowed to evaporate at 25 °C for 12 h. The obtained membrane was dried at 50 °C for an additional 3 h. The thickness of the membrane thus obtained was 19–24 μm.

2.5. Enantioselective electrodialysis

An aqueous or a 50 vol.% aqueous ethanol solution of racemic Ac-Trp was placed in both chambers of the permeation cell, of which solution volume was 40 cm^3 each. The concentration of each racemic Ac-Trp was fixed to be 1.0×10^{-3} mol dm^{-3}. The electrodialysis was carried out at 40 °C with stirring, and with a constant applied voltage of 3.0 V between platinum electrodes (10 mm square; distance between the electrodes, 65 mm). Aliquots were drawn from the permeate side at each sampling time. The amounts of Ac-D-Trp and Ac-L-Trp that transported through the membrane were determined by liquid chromatography (LC) [JASCO PU 1580, equipped with a UV detector (JASCO UV 1570)] employing CHIRALPAK MA(+) column [50 × 4.6 mm (i.d.)] (Daicel Chemical Ind., Ltd.). A mixture of acetonitrile and aqueous copper sulfate solution was used as a mobile phase.

The flux, J_D or J_L (mol cm^{-2} h^{-1}) is defined as

$$J = Q/At \tag{1}$$

where Q (mol) is the amount of transported Ac-Trp, A (cm^2) is the effective membrane area, and t (h) is the time. Hereafter, subscripts of D and L mean the D-isomer of Ac-Trp and the L-isomer of that, respectively.

The permselectivity (separation factor) $\alpha_{D/L}$ is defined as the ratio J_D/J_L divided by the concentration ratio [Ac-D-Trp]/[Ac-L-Trp].

$$\alpha_{D/L} = (J_D/J_L)/([\text{Ac-D-Trp}]/[\text{Ac-L-Trp}]) \tag{2}$$

2.6. Adsorption selectivity

The membranes were immersed in a 1.0×10^{-3} mol dm^{-3} racemic Ac-Trp solution in an aqueous or a 50 vol% aqueous ethanol solution and the mixtures were allowed to equilibrate at 40 °C. A 0.02 wt.% sodium azide was added as fungicide. Aliquots of the

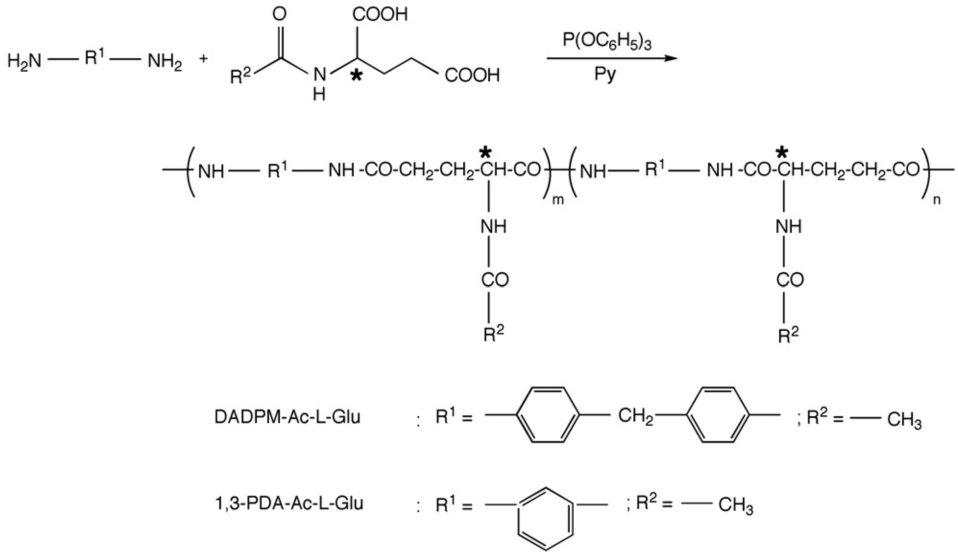

Fig. 1. Synthetic scheme of chiral polyamides having a glutamyl derivative residue.

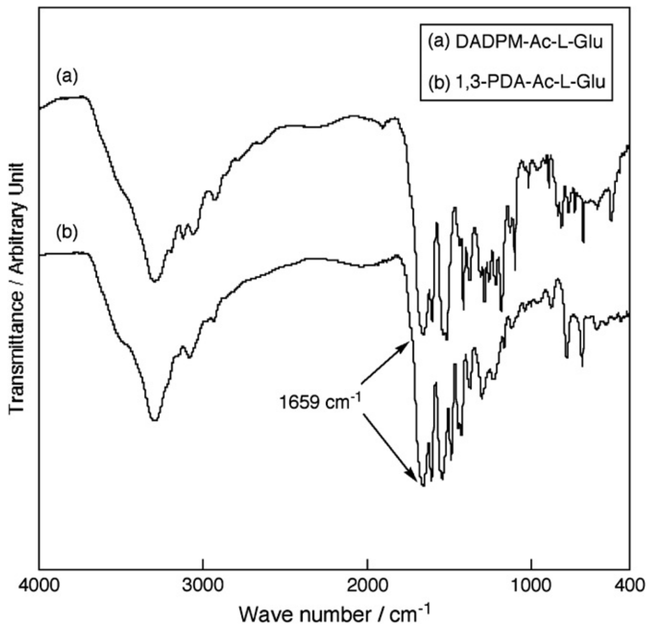

Fig. 2. IR spectra of polyamides with Ac-L-Glu residue as a component.

solution at the initial stage and after equilibrium had been reached were used for quantitative estimation by LC instrument described above.

The amount of Ac-Trp in the supernatant subtracted from the initial amount in the solution gave the amount of Ac-Trp adsorbed by the membrane. The adsorption selectivity $S_{A(D/L)}$ is defined as:

$$S_{A(D/L)} = ((\text{Ac-D-Trp})/(\text{Ac-L-Trp}))/([\text{Ac-D-Trp}]/[\text{Ac-L-Trp}]) \quad (3)$$

where (Ac-D-Trp) and (Ac-L-Trp) are the amounts of Ac-Trp adsorbed in the membrane, and [Ac-D-Trp] and [Ac-L-Trp] denote the concentrations in the solution after equilibrium was reached, respectively.

3. Results and discussion

3.1. Polycondensation

In general, polyamides are produced by the following methods, such as melt polycondensation, solution polycondensation, interfacial polycondensation, or solid polycondensation [26]. In the present study, the *N*-α-protected L-glutamic acid, Ac-L-Glu-OH, was adopted as a diacid monomer, which can introduce chiral environment in the obtained polyamides. When chiral polyamides were prepared by adopting general polycondensation reactions enumerated above, it would be anxious about the deprotection of the amino protecting group, acetyl moiety. To this end, chiral polyamides were prepared by means of triphenyl phosphite (TPP) so that carboxylic acids could be activated to react with amine moieties. The reaction scheme is shown in Fig. 1. IR spectra of newly prepared polyamides are shown in Fig. 2. In IR spectra, the amide I bands were observed at 1659 cm^{-1} in both polyamides, DADPM-Ac-L-Glu and 1,3-PDA-Ac-L-Glu. Fig. 3 shows a ^{1}H NMR spectrum of polyamide from 1,3-PDA and Ac-L-Glu-OH. From this, it can be confirmed that the amino protecting group, acetyl moiety, was preserved in the obtained polyamide. Though ^{1}H NMR spectrum of DADPM-Ac-L-Glu is not shown in the present article, acetyl moiety was found in the polyamide from DADPM and Ac-L-Glu-OH. From the IR and ^{1}H NMR spectra, it was concluded that expected polyamides were obtained from aromatic diamines 1,3-phenylenediamine (1,3-PDA) or 4,4′-diaminodiphenylmethane (DADPM), and *N*-α-acetyl-L-glutamic acid (Ac-L-Glu-OH).

It is not only interesting but also indispensable to study the suitable reaction conditions of polycondensation. Table 1 summarizes the results of polycondensation reaction from DADPM and Ac-L-Glu-OH. First, each monomer concentrations were fixed to be 3.00×10^{-1} mol dm^{-3}, the effect of various solvents on polycondensation reaction was investigated (Exp. No. 15–18). The viscosity of polymer solution was adopted as an index to study. From those experiments, the solvent system of NMP/LiCl was concluded to be a suitable medium for the present polycondensation reaction. In the next step, the suitable monomer concentration was studied. From the results for various monomer

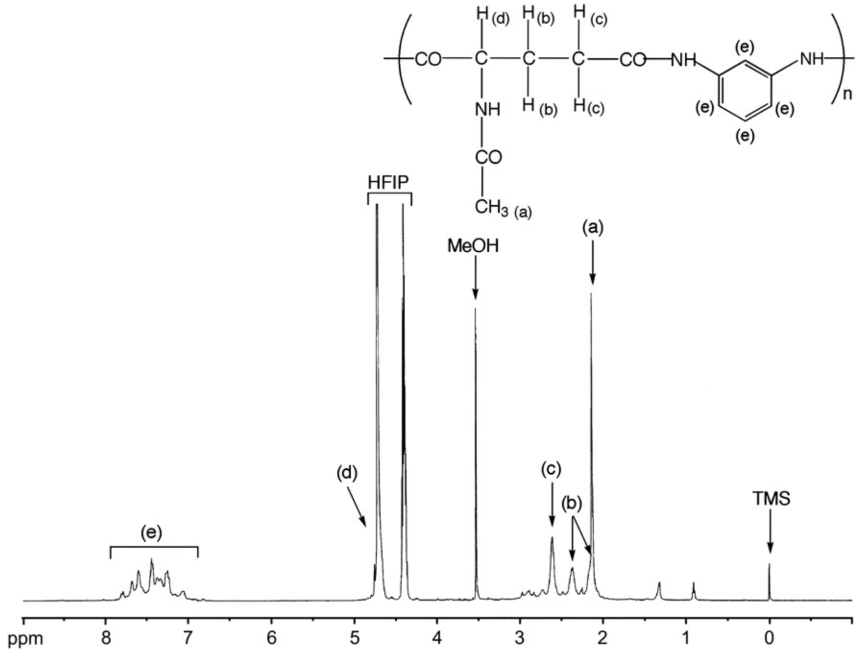

Fig. 3. ^{1}H NMR spectrum of 1,3-PDA-Ac-L-Glu (500 MHz, HFIP-d_2).

Table 1
Polycondensation reaction of 44′-diaminodiphenylmethane (DADPM) and Ac-L-Glu-OH by means of triphenyl phosphite

Exp. no.	Monomer conc.[a], mol dm^{-3}	DADPM, g (mol)	Ac-L-Glu-OH, g (mol)	Triphenyl phosphite, g (mol)	Solvent/Py, cm^3/cm^3	LiCl, g	Yield, g (%)	η_{inh}[b], g^{-1} cm^3
11[c]	5.00×10^{-2}	1.4867 (7.500×10^{-3})	1.4188 (7.500×10^{-3})	4.6551 (1.500×10^{-2})	NMP/Py 120/30	6.000	2.464 (84.8)	21
12[c]	1.00×10^{-1}	0.5948 (3.000×10^{-3})	0.5675 (3.000×10^{-3})	1.8617 (6.000×10^{-3})	NMP/Py 24/6	1.200	0.838 (72.2)	55
13[c]	1.50×10^{-1}	0.5948 (3.000×10^{-3})	0.5675 (3.000×10^{-3})	1.8617 (6.000×10^{-3})	NMP/Py 16/4	0.800	0.800 (75.6)	47
14[c]	2.00×10^{-1}	0.5948 (3.000×10^{-3})	0.5675 (3.000×10^{-3})	1.8617 (6.000×10^{-3})	NMP/Py 12/3	0.600	1.065 (91.6)	63
15[d]	3.00×10^{-1}	0.5948 (3.000×10^{-3})	0.5675 (3.000×10^{-3})	1.8617 (6.000×10^{-3})	NMP/Py 8/2	0.400	0.838 (80.6)	29
16[d]	3.00×10^{-1}	0.5948 (3.000×10^{-3})	0.5675 (3.000×10^{-3})	1.8618 (6.000×10^{-3})	DMF/Py 8/2	0	0.766 (65.9)	24
17[d]	3.00×10^{-1}	0.5948 (3.000×10^{-3})	0.5675 (3.000×10^{-3})	1.8617 (6.000×10^{-3})	HMPA/Py 8/2	0	0.900 (77.4)	18
18[d]	3.00×10^{-1}	0.5948 (3.000×10^{-3})	0.5675 (3.000×10^{-3})	1.8617 (6.000×10^{-3})	DMSO/Py 8/2	0	0.210 (18.1)	15

[a] Monomer conc. = $[\text{DADPM}]_0 = [\text{Ac-L-Glu-OH}]_0$.
[b] Measured at a concentration of 5.0×10^{-3} g cm^{-3} in HFIP at 25 °C.
[c] Polymerization temp., 80 °C; polymerization time, 3 h.
[d] Polymerization temp., 80 °C; polymerization time, 1 h.

concentrations summarized in Exp. No. 11–15 in Table 1, the suitable monomer concentration was determined to be 2.00×10^{-1} mol dm^{-3} for the polycondensation reaction of DADPM and Ac-L-Glu-OH. In the case of the polycondensation of 1,3-PDA and Ac-L-Glu-OH, the suitable monomer concentration was determined to be 2.00×10^{-1} mol dm^{-3} as summarized in Table 2.

3.2. *Thermal analyses*

Fig. 4 displays DSC thermographs of the newly obtained polyamides. The values of glass transition temperatures (T_g) for these polyamides were determined to be 40.7 °C for 1,3-PDA-Ac-L-Glu and 32.1 °C for DADPM-Ac-L-Glu, respectively. The results that T_g for DADPM-Ac-L-Glu was lower than that for 1,3-PDA-Ac-L-Glu are due to the fact that the amide linkage density in the former polyamide was lower than that for the latter. At 131.5 °C for 1,3-PDA-Ac-L-Glu (Fig. 4(a)) and at 156.4 °C for DADPM-Ac-L-Glu ((b)), crystallization occurred with an exotherm. After crystallization, endotherms, indicating the melting, were observed. In the present study, the heating rate was too high to observe clear thermographs of melting. Finally, there were broad endotherms due to thermal decomposition.

Fig. 5 shows thermogravimetric analysis (TGA) thermographs for a couple of polyamides. From this, it was concluded that thermal stability of both polyamides was not so good, which might be due to the fact that there were amino protecting groups in them.

Table 2
Polycondensation reaction of 1,3-phenylenediamine (1,3-PDA) and Ac-L-Glu-OH by means of triphenyl phosphite

Exp. no.	Monomer conc.[a], mol dm^{-3}	PDA, g (mol)	Ac-L-Glu-OH, g (mol)	Triphenyl phosphite, g (mol)	NMP/Py, cm^3/cm^3	LiCl, g	Yield, g (%)	η_{inh}[b], g^{-1} cm^3
21[c]	5.00×10^{-2}	0.2163 (2.000×10^{-3})	0.3783 (2.000×10^{-3})	1.2411 (4.000×10^{-3})	32/8	1.600	trace (trace)	–
22[d]	2.00×10^{-1}	0.4326 (4.000×10^{-3})	0.7567 (4.000×10^{-3})	2.4822 (8.000×10^{-3})	16/4	0.800	0.959 (80.7)	45
23[d]	3.00×10^{-1}	0.6490 (6.000×10^{-3})	1.1350 (6.000×10^{-3})	3.7234 (1.200×10^{-2})	16/4	0.800	1.361 (79.3)	35
24[d]	4.00×10^{-1}	0.8653 (8.000×10^{-3})	1.5134 (8.000×10^{-3})	4.9645 (1.600×10^{-2})	16/4	0.800	1.812 (76.2)	24
25[d]	5.00×10^{-1}	0.8112 (7.500×10^{-3})	1.4188 (7.500×10^{-3})	4.6542 (1.500×10^{-2})	12/3	0.600	1.637 (73.4)	27

[a] Monomer conc. = $[\text{1,3-PDA}]_0 = [\text{Ac-L-Glu-OH}]_0$.
[b] Measured at a concentration of 5.0×10^{-3} g cm^{-3} in HFIP at 25 °C.
[c] Polymerization temp., 80 °C; polymerization time, 48 h.
[d] Polymerization temp., 80 °C; polymerization time, 3 h.

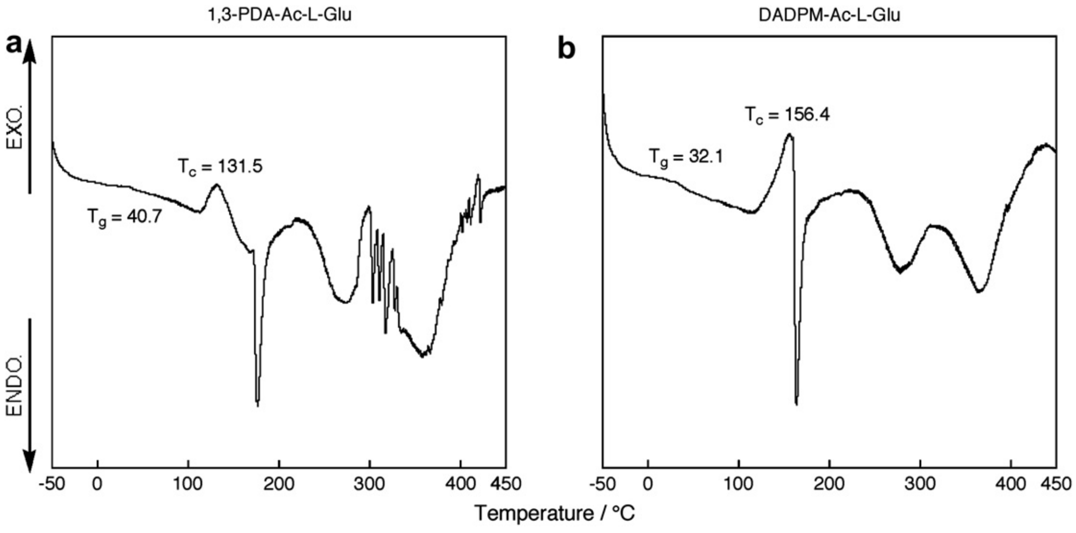

Fig. 4. DSC curves of 1,3-PDA-Ac-L-Glu (a) and DADPM-Ac-L-Glu (b). (Heating rate, 20 °C min^{-1}; N_2 flow, 50 cm^3 min^{-1}.)

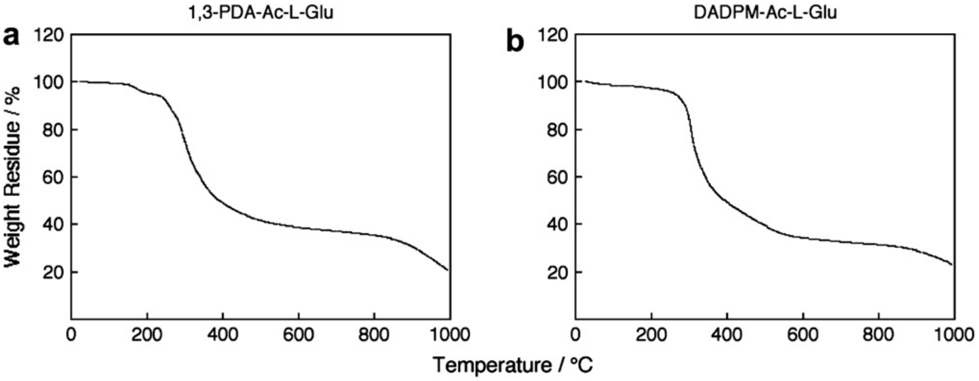

Fig. 5. TGA curves of 1,3-PDA-Ac-L-Glu (a) and DADPM-Ac-L-Glu (b). (Heating rate, 10 °C min^{-1}.)

3.3. *Chiroptical properties*

The optical rotation ($[\alpha]_D$) of the newly prepared polyamides is given in Table 3, together with that of the diacid monomer, Ac-L-Glu-OH. This revealed that optically active polyamides were successfully obtained via polycondensation reaction activated by TPP. The $[\alpha]_D$ value of 1,3-PDA-Ac-L-Glu was slightly higher than that of Ac-L-Glu-OH, while that of DADPM-Ac-L-Glu decreased in comparison with that for the corresponding diacid monomer, which might result from the tortility of the polyamide chain that counteracts the chirality in a certain extent.

3.4. *Adsorption selectivity estimated by SPR spectroscopy*

From the results of chiroptical study described above, it is expected that the chiral polyamides newly obtained in the present study gave chiral recognition ability. To this end, chiral recognition ability of these two types of polymers was preliminarily evaluated by surface plasmon resonance (SPR) spectroscopy. Compared with usual adsorption experiments for the evaluation of chiral recognition ability [12–15], SPR spectroscopy provides a rapid and facile evaluation method. Fig. 6 shows a time course of the angle changes ($\Delta\theta$) of the 1,3-PDA-Ac-L-Glu chiral polyamide film responding to the addition of substrate D-Glu or L-Glu at the same concentration of 1.00×10^{-3} mol dm^{-3} or 5.00×10^{-4} mol dm^{-3}. The observed shift in the incidence angle ($\Delta\theta$) was plotted as a function of the substrate concentration and shown in Fig. 7. Apparent adsorption isotherms of D-Glu and L-Glu for these two types of polyamide films gave straight lines passing through the origin, implying that both D-Glu and L-Glu were non-specifically adsorbed on those chiral polyamide films. As can be seen in the figures, D-Glu was adsorbed in preference to L-Glu on these polyamides. The adsorption selectivity $S_{A(D/L)}$ in SPR study, is defined by the ratio of $\Delta\theta$ for D-Glu to that of L-Glu [25]. The calculated adsorption slectivities are given in Fig. 7. This adsorption selectivity is thought to be due to the fact that the present polyamides have chiral environment (asymmetric carbons) in their main chains. If the polyamide were prepared adopting *N*-α-protected D-glutamic acid derivative as a diacid monomer instead of the L-isomer of Ac-Glu-OH, they would give adsorption selectivity toward L-Glu contrary to the results observed in the present study. From results given in Fig. 7, it can be expected that the chiral polyamides newly obtained in the present study are applicable to specialty materials for membrane, sensor, chromatography, catalyst, and so forth.

Table 3
Specific rotations of chiral polyamides[a]

Chiral polyamide	$[\alpha]_D$, °
Ac-L-Glu-OH	−9.9
1,3-PDA-Ac-L-Glu	−11.6
DADPM-Ac-L-Glu	−4.4

[a] In HFIP, $c = 1.00$ g dL^{-1}, $L = 10$ cm.

3.5. *Chiral separation*

As one of promising applications of chiral polyamides to chemical industry, the application of these polymeric materials to membrane separation was studied. The durability of the membranes from the chiral polyamides obtained in the present study was not enough to keep self-standing membranes by themselves for a long period. From this, the membrane performance was studied by adopting a form of blended membrane. As described in

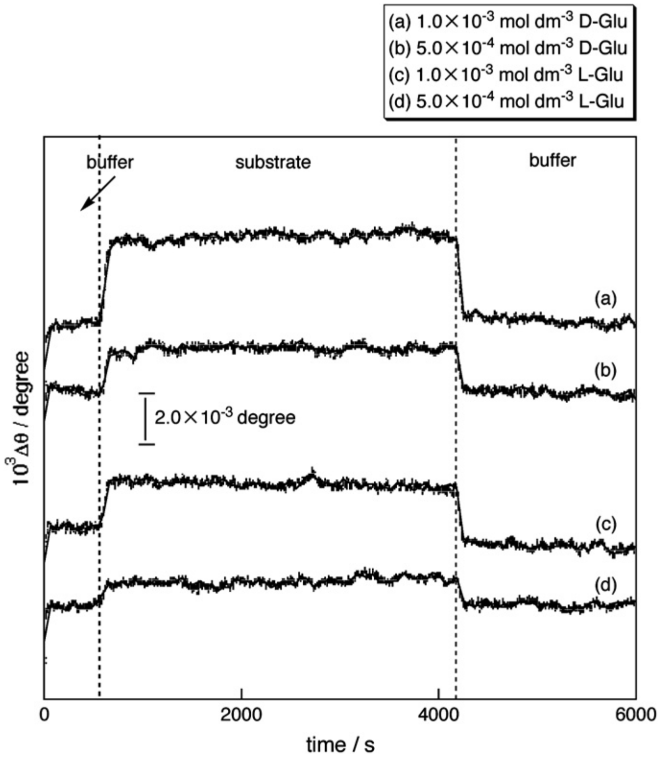

Fig. 6. Typical time courses of the angle change ($\Delta\theta$) of SPR responding to the addition of D-Glu or L-Glu from aqueous NaN_3 solution to the 1,3-PDA-Ac-L-Glu film. (The sensor part was first stabilized by a 0.02 wt.% aqueous NaN_3 buffer solution and then flowed by a D-Glu or L-Glu solution for 60 min, and finally washed by a 0.02 wt.% aqueous NaN_3 buffer solution; (a) [D-Glu] = 1.0×10^{-3} mol dm^{-3}; (b) [D-Glu] = 5.0×10^{-4} mol dm^{-3}; (c) [L-Glu] = 1.0×10^{-3} mol dm^{-3}; (d) [L-Glu] = 5.0×10^{-4} mol dm^{-3}.)

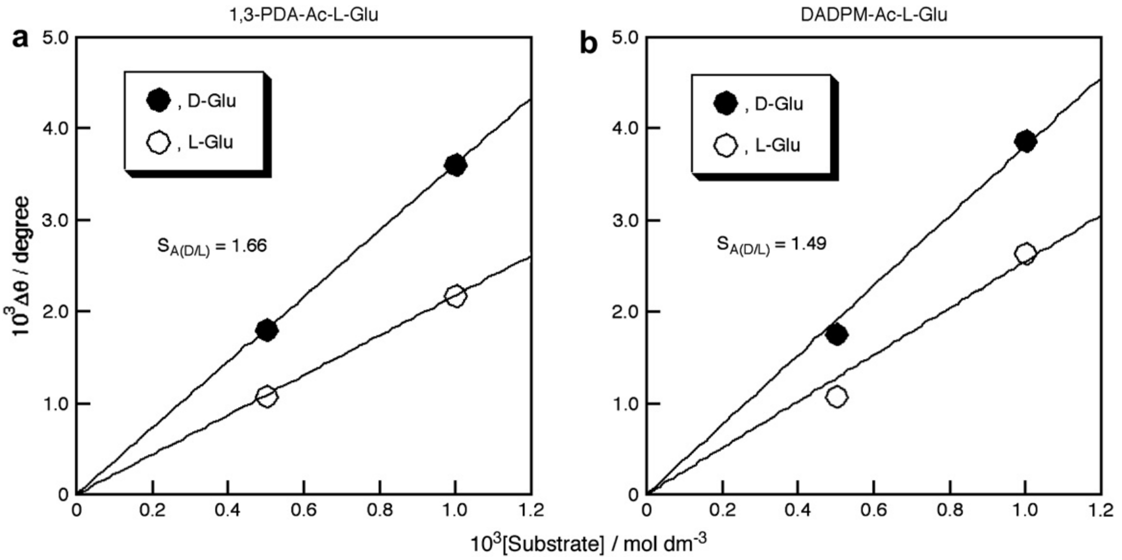

Fig. 7. Adsorption isotherms of D-Glu and L-Glu on the chiral polyamide films at 27 °C.

Section 2, amorphous polyamide, poly(hexamethylene terephthalamide/isophthalamide) ($6T/6I = 31.6/68.4$, mol/mol) was adopted as a membrane matrix for blended membranes.

First, chiral separation ability of these membranes was investigated by using concentration difference of racemic Ac-Trp as a driving force for membrane transport. The observed flux was below 2.5×10^{-10} mol cm^{-2} h^{-1}. The flux value below 2.5×10^{-10} was not so enough to quantitatively discuss membrane performance. To this end, electrodialysis, adopting potential difference as a driving force for membrane transport, was adopted to obtain higher flux values than those by dialysis. Time-transport curves of racemic Ac-Trp through the 1,3-PDA-Ac-L-Glu blended membranes are shown in Fig. 8, and those through DADPM-Ac-L-Glu blended membranes in Fig. 9, respectively. In the membrane transport, permselectivity is expected to depend on solvent composition, in other words, polarity. To this end, membrane transport experiments were studied in an aqueous solution and a 50 vol.% aqueous ethanol solution.

As expected from preliminary experimental results of chiral recognition ability estimated by SPR spectroscopy, the D-isomer of Ac-Trp was transported through both types of membranes in both an aqueous and a 50 vol.% aqueous ethanol solutions. Both blended membranes gave higher permselectivity toward Ac-D-Trp in an aqueous than that in an aqueous ethanol. In order to elucidate the factors governing permselectivity of these blended membranes, adsorption selectivity toward racemic Ac-Trp mixtures was studied. The results are summarized in Table 4. The D-isomer of Ac-Trp, of which absolute configuration is same as that of D-Glu, was preferentially incorporated into the membranes, though the adsorption selectivity toward Ac-D-Trp was not so high. The principal reason for the decrease in adsorption selectivity is thought to attribute to the fact that a half of membrane consists of an achiral polyamide, in other words, the concentration of chiral environment was reduced by half. In both blended membranes, the adsorption selectivity toward the D-isomer increased when the medium was changed to an aqueous ethanol solution from an aqueous one. From this, it can be deduced that hydrogen bond was one of the dominant factors to govern chiral recognition of racemic Ac-Trp. Using permselectivity ($\alpha_{\mathrm{D/L}}$) and adsorption selectivity ($S_{\mathrm{A(D/L)}}$), diffusivity selectivity ($S_{\mathrm{D(D/L)}}$) was obtained by the following equation:

$$S_{\mathrm{D(D/L)}} = \alpha_{\mathrm{D/L}}/S_{\mathrm{A(D/L)}} \tag{4}$$

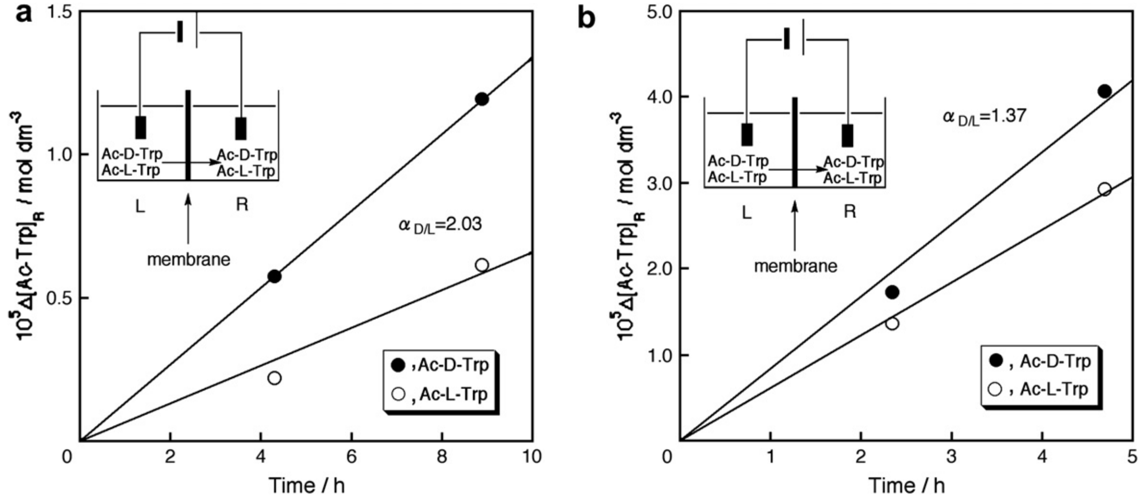

Fig. 8. Time-transport curves of racemic Ac-Trp's through the 1,3-PDA-Ac-L-Glu blended membranes in H_2O (a) and 50 vol.% aqueous ethanol solution (b) at 40 °C. ($\Delta E = 3.0$ V.)

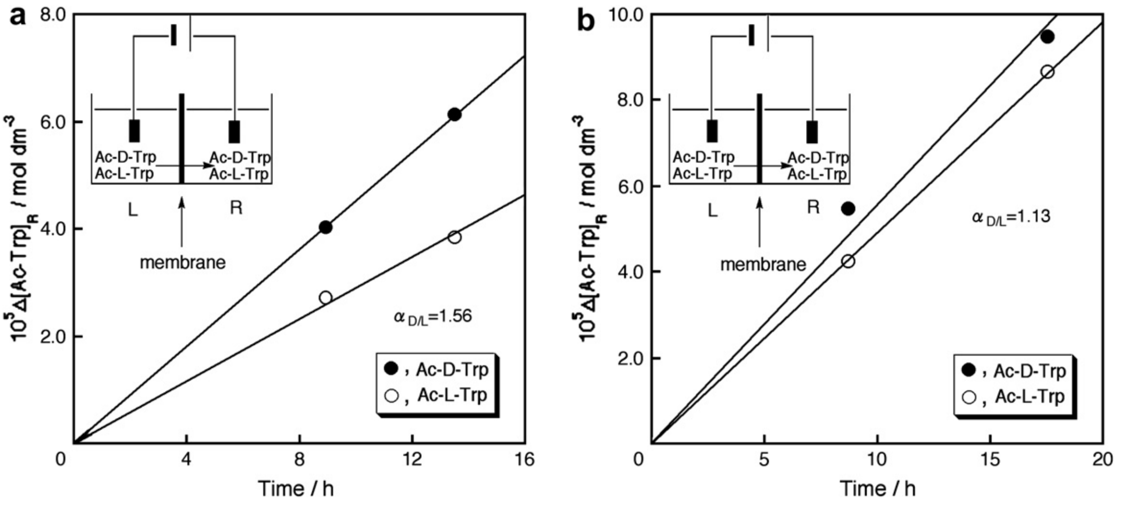

Fig. 9. Time-transport curves of racemic Ac-Trp's through the DADPM-Ac-L-Glu blended membranes in H_2O (a) and 50 vol.% aqueous ethanol solution (b) at 40 °C. ($\Delta E = 3.0$ V.)

Table 4
Adsorption selectivity of chiral polyamide membranes

Membrane	Medium	(As-D-Trp)/mem, mol/g-mem.	(Ac-L-Trp)/mem, mol/g-mem.	$S_{A(D/L)}$
1,3-PDA-Ac-L-Glu	In H_2O	1.10×10^{-4}	1.08×10^{-4}	1.02
	In EtOH/H_2O	6.33×10^{-5}	6.08×10^{-5}	1.04
DADPM-Ac-L-Glu	In H_2O	1.26×10^{-4}	1.22×10^{-4}	1.03
	In EtOH/H_2O	8.10×10^{-5}	7.01×10^{-5}	1.16

The estimated diffusivity selectivity and other results are summarized in Table 5. Excepting the diffusivity selectivity of DADPM-Ac-L-Glu blended membrane in an aqueous ethanol solution, which was close to unity, diffusivity selectivities for others were determined to be over unity. In other words, the diffusivity of Ac-D-Trp, which was preferentially incorporated into the membrane, was higher than the corresponding enantiomer, Ac-L-Trp. In chiral separation, the enantiomer, which was selectively incorporated into the membrane, was liable to receive more resistance than opposite enantiomer in migration within the membrane due to more affinity interaction from the membrane. As a result, it was often observed that the selectively adsorbed enantiomer was slowly transported than the optical antipode [6,7,12,27,28]. In the present study, however, it can be said from Table 5 that the chiral separation synergetically dependent on both adsorption and diffusivity selectivity like optical separation reported previously [8,13]. The estimated diffusivity selectivity decreased with the addition of ethanol into aqueous feed solution. The blended membrane might be microscopically swollen by the addition of ethanol, though ethanol was principally non-solvent toward the present membrane materials. If the membrane studied in chiral separation had consisted of just chiral polyamide newly prepared, higher permselectivity would have been observed. It is an unsolved problem to obtain chiral polyamides, of which molecular weights are much more higher than those obtained in the present study, so that they can give self-standing durable membranes.

Table 5
Enantioselective electrodialysis with chiral polyamide membranes

Membrane	Medium	J_D, mol cm^{-2} h^{-1}	J_L, mol cm^{-2} h^{-1}	$\alpha_{D/L}$	$S_{A(D/L)}$	$S_{D(D/L)}$[a]
1,3-PDA-Ac-L-Glu	In H_2O	1.78×10^{-8}	8.78×10^{-9}	2.03	1.02	1.99
	In EtOH/H_2O	1.12×10^{-7}	8.19×10^{-8}	1.37	1.04	1.32
DADPM-Ac-L-Glu	In H_2O	6.03×10^{-8}	3.87×10^{-8}	1.56	1.03	1.51
	In EtOH/H_2O	7.41×10^{-8}	6.54×10^{-8}	1.13	1.16	0.98

[a] $S_{D(D/L)} = \alpha_{D/L}/S_{A(D/L)}$.

4. Conclusions

Novel polyamides having asymmetric carbons in their main chains were synthesized from aromatic diamines, 4,4′-diaminodiphenylmethane (DADPM) or 1,3-phenylenediamine (1,3-PDA), and *N*-α-protected L-glutamic acid, *N*-α-acetyl-L-glutamic acid (Ac-L-Glu-OH) in the presence of triphenyl phosphite (TPP). The observed optical rotation ($[\alpha]_D$) of the newly prepared polyamides revealed that optically active polyamides were successfully obtained in the present study. Chiral recognition ability of obtained polyamides was preliminarily studied by surface plasmon resonance (SPR) spectroscopy by adopting D-Glu or L-Glu as a model enantiomer. These two types of polyamides showed D-isomer adsorption selectivity and these were determined to be 1.66 for 1,3-PDA-Ac-L-Glu and 1.49 for DADPM-Ac-L-Glu, respectively. Chiral separation ability was studied by membrane transport of racemic Ac-Trp mixtures through blended membranes, adopting potential difference as a driving force for membrane transport. These membranes transported the D-isomer of Ac-Trp in preference to Ac-L-Trp. Permselectivity toward Ac-D-Trp reached 2.03 with 1,3-PDA-Ac-L-Glu blended membrane in an aqueous system and that for DADPM-Ac-L-Glu blended membrane gave permselectivity of 1.56 in the same aqueous system. The chiral polyamides, consisting of glutamyl residue as constitutional repeating units, have potential to be applicable to chiral separation membrane materials.

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