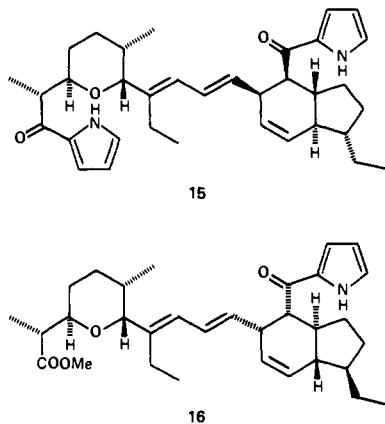methodology the diastereoisomer **16**[4] ([α]$^{25}_D$ +141.8° (CHCl₃, *c* 0.11), R_f = 0.15, silica, 10% ethyl acetate in petroleum ether) of X-14547A methyl ester was also synthesized from the less polar isomer of **7** and exhibited similar spectral properties to **12**.

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The described methodology not only produces the ionophore X-14547A in its natural enantiomeric form but also allows for ready access to a variety of interesting analogues of this natural product for property evaluation. Further synthetic and biological investigations in this area are continuing.

Novel Packing Material for Optical Resolution: (+)-Poly(triphenylmethyl methacrylate) Coated on Macroporous Silica Gel[1]

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Optically active poly(triphenylmethyl methacrylate) (PTrMA) is an efficient chiral packing material for liquid chromatographic resolution.[2-4] The polymer has chirality due to its helicity and is insoluble in organic solvents when the degree of polymerization exceeds about 60.[5] Various racemic compounds, particularly those having aromatic groups, were resolved by high-performance liquid
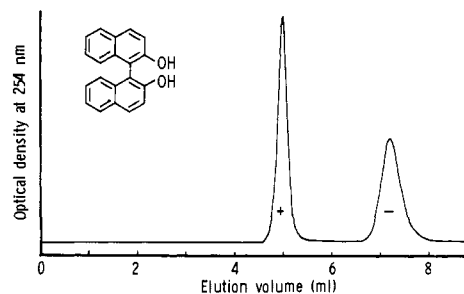
Figure 1. Resolution of 2,2′-dihydroxy-1,1′-binaphthyl (1). Column, 25 × 0.46 cm (i.d.); eluant, methanol; flow rate, 0.50 mL/min; temperature, 20 °C.

chromatography (HPLC) with the finely ground insoluble polymer.[4]

We report here preparation of a novel packing material for HPLC consisting of the soluble lower molecular weight (+)-PTrMA and the complete resolution of some racemic aromatic compounds on a column packed with packing prepared by coating macroporous silica gel with the soluble polymer. Interestingly, the new packing shows chiral recognition to a different degree than that displayed by the insoluble (+)-PTrMA packing; the former was successfully employed for completely resolving racemic compounds which are not separated with the latter. The new packing also made it possible to perform expeditious chromatography without lowering the degree of resolution.

Soluble (+)-PTrMA was prepared by the polymerization of the monomer with (+)-6-benzylsparteine–butyllithium complex. The reaction gave a soluble polymer of high optical rotation in a better yield[6] than the reaction with (−)-sparteine–butyllithium catalyst.[2,4,5] Macroporous spherical silica gel particles, LiChrospher SI 1000 (Merck),[7] were silanized with a large excess of dichlorodiphenylsilane and triethylamine at refluxing temperature in toluene.[8] The silanized gel (2.50 g) was coated with (+)-PTrMA (0.55 g) by using THF (10 mL) as solvent. The (+)-PTrMA-coated silica gel (ca. 2.5 g) thus obtained was slurry packed in a stainless steel tube [25 × 0.46 cm (i.d.)].[9]

2,2′-Dihydroxy-1,1′-binaphthyl, an interesting atropisomeric compound,[10,11] was completely resolved by this column, as shown in Figure 1, using methanol as eluant. Various 2,2′-disubstituted 1,1′-binaphthyls were also resolved efficiently as summarized in Table I, where the resolution data by the ground insoluble (+)-PTrMA column are also listed.[12] The separation factor, α, depends greatly on the substituents in the racemic compounds, and the two columns give different values. The (+)-PTrMA-coated silica gel column resolves **4** and **5** almost completely, although the ground (+)-PTrMA column does not work effectively

(1) Chromatographic Resolution. 4. For part 3, see: Okamoto, Y.; Okamoto, I.; Yuki, H. *J. Polym. Sci., Polym. Lett. Ed.*, in press.

(2) Yuki, H.; Okamoto, Y.; Okamoto, I. *J. Am. Chem. Soc.* **1980**, *102*, 6356.

(3) Nakazaki, M.; Yamamoto, K.; Maeda, M. *J. Org. Chem.* **1981**, *46*, 1985.

(4) Okamoto, Y.; Okamoto, I.; Yuki, H. *Chem. Lett.* **1981**, 835.

(5) (a) Okamoto, Y.; Suzuki, K.; Ohta, K.; Hatada, K.; Yuki, H. *J. Am. Chem. Soc.* **1979**, *101*, 4763. (b) Okamoto, Y.; Suzuki, K.; Yuki, H. *J. Polym. Sci., Polym. Chem. Ed.* **1980**, *18*, 3043.

(6) (+)-6-Benzylsparteine was prepared from (−)-sparteine; [α]$^{25}_D$ +30.4° (*c* 1, EtOH) (Leonard, N. J.; Thomas, P. D.; Gash, V. W. *J. Am. Chem. Soc.* **1955**, *77*, 1552). The polymerization was carried out by adding 5 mol % of the catalyst to the monomer in toluene at −78 °C. Polymer soluble in THF and insoluble in methanol was obtained almost quantitatively. This was reprecipitated from a THF solution into a mixture of hexane–benzene (2:1) to remove oligomers; yield 87%, [α]$^{25}_D$ +343° (*c* 0.5, THF).

(7) Mean particle size, 10 μm; mean pore diameter, 100 nm; specific surface area, 20 m²/g.

(8) The carbon content of the silanized gel was found to be 1.9% by elementary analysis which corresponds to 0.13 mmol of diphenylsilyl group/gram of support.

(9) Theoretical plate numbers of the column for acetone and benzene were 6800 and 4700, respectively, at a flow rate of 0.50 mL/min. The void volume was estimated to be 3.33 mL with water. HPLC was accomplished on a JASCO TRI ROTAR-II equipped with a JASCO UV-100-III detector and by using methanol as eluant at 20 °C. Racemates used are either well-known compounds or their derivatives.

(10) Newcomb, M.; Toner, J. L.; Helgeson, R. C.; Cram, D. J. *J. Am. Chem. Soc.* **1979**, *101*, 4949 and references cited therein.

(11) (a) Noyori, R.; Tomino, I.; Tanimoto, Y. *J. Am. Chem. Soc.* **1979**, *101*, 3129. (b) Noyori, R.; Tomino, I.; Nishizawa, M. *Ibid.* **1979**, *101*, 5843. (c) Nishizawa, M.; Noyori, R. *Tetrahedron Lett.* **1980**, *21*, 2821. (d) Nishizawa, M.; Yamada, M.; Noyori, R. *Ibid.* **1981**, *22*, 247.

(12) Insoluble (+)-PTrMA (1.3 g) in the size range 20–44 μm was packed in a stainless-steel tubing [25 × 0.46 cm (i.d.)]. Flow rate of methanol was 0.72 mL/min and the void volume was 3.4 mL. The theoretical plates of the column for acetone was 2200.

Table I. Resolution of Racemic 2,2'-Disubstituted 1,1'-Binaphthyls

substituent	compd	(+)-PTrMA-coated silica gel column[a]				ground (+)-PTrMA column[b]			
		$k'_1{}^c$	$k'_2{}^d$	α^e	$R_s{}^f$	$k'_1{}^c$	$k'_2{}^d$	α^e	$R_s{}^f$
HO	I	0.50^g	1.17	2.37	3.83	1.50^g	3.20	2.13	2.39
CH$_3$O	2	4.76^g	8.23	1.73	0.93	9.67^g	15.9	1.65	1.39
NH$_2$	3	1.67^g	2.32	1.39	1.08	5.62^g	15.9	2.80	2.52
Br	4	3.77	5.32	1.41	1.06	9.0	9.0	~1	~0
CH$_3$	5	3.01	4.30	1.43	1.63	6.1	6.1	~1	~0

[a] See Figure 1. [b] See ref 11; data for 1 and 2 were cited from ref 4. [c] Capacity factor of the enantiomer eluting first = (retention volume of enantiomer – void volume)/(void volume). [d] Capacity factor of the enantiomer eluting last. [e] Separation factor $= k'_2/k'_1$. [f] Resolution factor $= 2 \times$ (distance between two peaks)/(sum of bandwidths of two peaks). [g] Configuration of enantiomer was R.

**Table II.** Resolution of Racemic Trans-Disubstituted Cyclic Compounds[a]

racemate	R	compd	(+)-PTrMA-coated silica gel column		ground (+)-PTrMA column[b]	
			$\alpha\ (\pm)^c$	R_s	$\alpha\ (\pm)^c$	R_s
⬡—COR / —COR	OPh	6	1.22 (+)	0.4	1.29 (+)	1.50
	NHPh	7	6.31 (−)	2.30	3.54 (−)	1.48
⬡—OCOR / —OCOR	Ph	8	2.16 (+)	4.26	1.45 (+)	1.68
	(CH$_2$)$_6$CH$_3$	9	1.18	0.6	1.12	0.6^c
⬡—OCOPh / —OCOPh		10	1.61 (+)	2.94	1.66 (+)	2.07
⬜—COR / —COR	OPh	11	1.27 (−)	1.45	1.20 (−)	0.7
	NHPh	12	1.78 (+)	3.03	1.18 (+)	0.6^d
△—R / —CONHPh	CONHPh	13	1.24 (−)	0.5	1.18 (−)	0.6^d
	Ph	14	1.44 (−)	1.35	1.46 (−)	0.98
O△—Ph / —R	H	15	1.22 (−)^e	0.87	~1	~0
	Ph	16	5.21 (−)^f	5.30	2.17 (−)^f	2.39

[a] See Table I. [b] Cited from ref 4 except for the data of 11 and 12. [c] Separation factor and rotation of enantiomer eluting first. [d] Flow rate, 0.20 mL/min. [e] (−)-(S). [f] (−)-(1S,2S).

in this case. For a diamino derivative **3**, however, the latter column exhibited more satisfactory resolution.

Resolution of some trans-1,2- and 1,3-disubstituted cyclic compounds were also effected (Table II). The (+)-PTrMA-coated silica gel column showed equal or better separation compared with the ground (+)-PTrMA column for most compounds except for a 1,2-cyclohexanedicarboxylic acid derivative **6**. A very high separation factor, $\alpha = 5.21$, was obtained for *trans*-stilbene oxide (**16**).

The chromatogram of phenothrin, 3-phenoxybenzyl chrysanthemate (**17**),[13] a commercially available insecticidal pyreth-

17

roid, is shown in Figure 2. Four stereoisomers, (+)- and (−)-*trans*-**17** and (+)- and (−)-*cis*-**17**, were identified on the chromatogram.[14] With the ground (+)-PTrMA column, the isomeric mixture **17** showed only one peak at an elution volume of 21 mL.
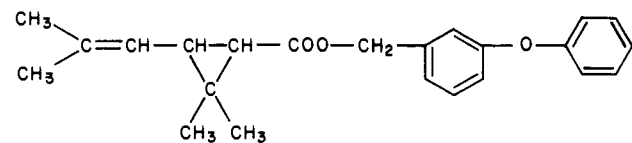
Base-line resolution was also accomplished for many other racemates including 2,2,2-trifluoro-1-(9-anthryl)ethanol, ($k'_1 = 0.51$, $\alpha = 1.67$) a useful fluoro alcohol found by Pirkle,[15] and the tris(acetylacetonates) of Co(III) ($k'_1 = 0.46$, $\alpha = 1.32$) and Cr(III) ($k'_1 = 0.49$, $\alpha = 1.28$). So far partial resolution by chromatography has been attained for some acetylacetonates.[16]

The capacity factors of all the racemates on the "coated" type column were much smaller than those on the "ground" type column, indicating that the former column allows more efficient
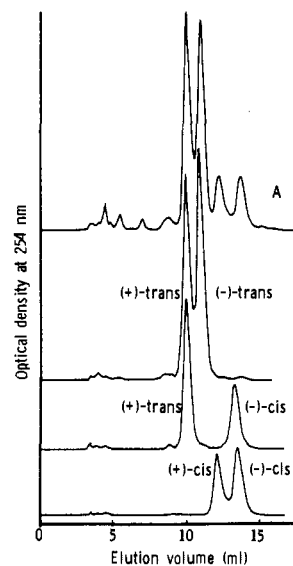

Figure 2. Separation of phenothrin (**17**) isomers by the (+)-PTrMA-coated silica gel column. Chromatographic conditions are the same as those for Figure 1. A is the chromatogram of (±)-trans and (±)-cis mixture.

and rapid separation. The (+)-PTrMA-coated packing showed a few additional merits. The packing gave constantly higher theoretical plates of the column than the ground packing. Further, the durability is improved by the coating procedure. The (+)-PTrMA-coated column lost only about 15% of the polymer after continuous use for 1 month. This brought about a little decrease in the capacity factors k' but no change of the theoretical plates and the separation factors α in the resolution of **1**.[17] The

(13) Fujimoto, K.; Itaya, N.; Okuno, Y.; Kadota, T.; Yamaguchi, T. *Agric. Biol. Chem.* **1973**, *37*, 2681.

(14) All isomers were synthesized at Sumitomo Chemical Co., Ltd.

(15) Pirkle, W. H.; House, D. W. *J. Org. Chem.* **1979**, *44*, 1957.

(16) Fay, R. C.; Girgis, A. Y.; Klabunde, U. *J. Am. Chem. Soc.* **1970**, *92*, 7056.

(17) The ground type column also lost a small portion of PTrMA after continuous use for 1 month, which resulted in a decrease of theoretical plate number of the column.

PTrMA-coated macroporous silica gel packing may be useful not only for the resolution of racemate but also for more general separation by liquid chromatography. The different chiral recognition ability of the soluble (+)-PTrMA-coated packing and the ground insoluble (+)-PTrMA packing is an important and interesting phenomenon from the viewpoint of not only resolution but also polymer chemistry. A further study on this is now in progress.

A variety of chiral polymers have been made,[18] but only a few of them have been used as effective packings in liquid chromatography.[19] The deriving force of chiral recognition in these resolutions is mainly polar interaction such as hydrogen bond. The PTrMA packings showed higher resolution in the reversed-phase system with methanol as eluant than in the normal-phase system with hexane.[2,4] Nonpolar interaction between the packing and a racemic compound appears to be a main factor in the chiral recognition in the present chromatography.

(18) For review see: "Optically Active Polymers"; Selegny, E., Ed.; Reidel: Dodrrecht, 1979.
(19) For review, see: (a) Krull, I. S. *Adv. Chromatogr.* **1978**, *16*, 175. (b) Blaschke, G. *Angew. Chem., Int. Ed. Engl.* **1980**, *19*, 13.

Solvation of Ion Paris. Solvation Complexes between the Ion-Paired 9-Fluorenone Anion Radical and Dipolar Aprotic Solvents

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Ethereal and more polar aprotic solvents are characterized by their strong cation and weak anion solvation power; therefore it has been naturally assumed that only cationic solvation by aprotic solvents can modify the structures of ion pairs and hence indirectly perturb the spin density distribution of the ion-paired anions. No report published so far describes the formation of solvation complexes between an ion-paired anion and aprotic solvents.

In this communication, using as solvents binary mixtures of toluene and dipolar aprotic solvents (dielectric constant > 15),[1] e.g., dimethyl sulfoxide (Me$_2$SO), *N,N*-dimethylacetamide (DMA), *N,N*-dimethylpropionamide (DMP), and hexamethylphosphoramide (HMPA), we present that the 9-fluorenone anion radical (Fl$^-$) complexes both a cation and a solvent molecule. In addition, the solvation processes of ion pairs in binary mixtures are described. The carbonyl ^{13}C hyperfine splitting of Fl$^-$,[2] which increases with an increase in cationic field acting on the carbonyl oxygen, can function as an ESR probe for studying the present solvation phenomena as it is sensitive to environmental factors.

The ion pair between Fl$^-$ and a sodium ion in toluene exists in the form of a diamagnetic ionic dimer or higher aggregates and shows a very weak and featureless ESR signal. Addition of small amounts of dipolar aprotic solvents (less than 10^{-2} mole fraction) gives rise to well-resolved hyperfine patterns. The ^{13}C splitting first decreases with an increase of the mole fraction of aprotic solvents and then approaches a limiting value (a_C) characteristic of each solvent when the mole fraction is 0.2–0.3 (Figure 1). a_C keeps constant until the ion pair dissociates into the free ions in a mole fraction of greater than 0.6 (the concentration of Fl$^-$ ≃
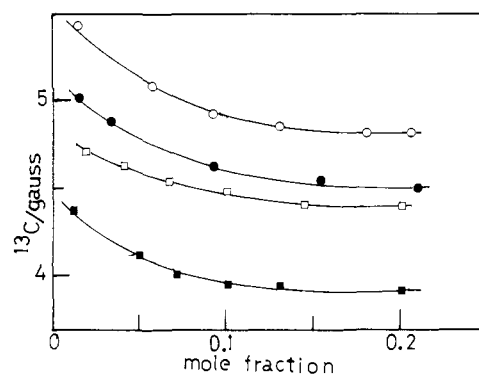
(1) A. J. Parker, *Q. Rev., Chem. Soc.*, **16**, 163 (1962).
(2) 9-Fluorenone containing 90.9% enriched carbonyl ^{13}C was used.

Figure 1. Change of the ^{13}C splitting by the additions of dipolar aprotic solvents to the toluene solution: (○) Me$_2$SO; (●) DMA; (□) DMP; (■) HMPA.
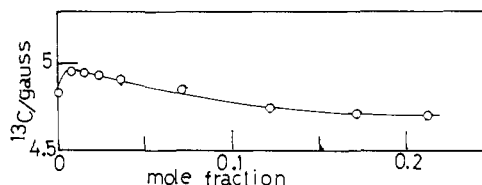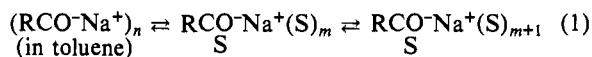

Figure 2. Change of the ^{13}C splitting by the addition of Me$_2$SO to the THF solution.

10^{-4} mol). a_C decreases in the order Me$_2$SO > *N,N*-dimethylformamide (DMF) > DMA > DMP > HMPA. This order is the decreasing order of Gutmann's acceptor number (AN), which expresses the strength of anion solvation power by solvents,[3] and also the ^{13}C splitting of the free Fl$^-$ decreases in this order.[4] These features could be explained according to reaction 1

$$(\text{RCO}^-\text{Na}^+)_n \rightleftarrows \underset{S}{\text{RCO}^-\text{Na}^+(S)_m} \rightleftarrows \underset{S}{\text{RCO}^-\text{Na}^+(S)_{m+1}} \quad (1)$$
$$\text{(in toluene)}$$

where S is a dipolar aprotic solvent molecule. The solvation of the ion pair proceeds in two steps. In the first step, both the cation and the anion forming the ion pair are solvated by aprotic solvents. This step is responsible for decomposition of clustered ion pairs in toluene into monomeric ion pairs. The negative charge localized on the carbonyl oxygen attracts the positive end of a solvent dipole to form a solvation complex, and as a result, the oxygen atom is subject to additional cationic field. The solvation of the anion is completed at this step. With increasing fraction of aprotic solvents further solvation of the cation proceeds (the second step); this increases in solvation of the cation increases the cation–anion separation and reduces the ^{13}C splitting. At the end of the second step ^{13}C splitting approaches a_C. Except for HMPA a good linear relation between AN and a_C of each solvent was found (a similar linear relation between AN and ^{13}C splitting of the free Fl$^-$ was previously obtained).[4] This implies that the difference in a_C between the mixtures may almost entirely arise from the difference in anion solvation power between aprotic solvents. The value of a_C of each solvent is independent of temperature. Over a smaller range of mole fraction, on the other hand, the ^{13}C splitting decreases with decreasing temperature to converge to a_C at low temperatures. This indicates that the second step of reaction 1 is exothermic, and on lowering the temperature the equilibrium shifts to the direction of increasing solvation of the cation. After completion of the solvation shell, the ^{13}C splitting becomes independent of temperature. Thus, the dependences of the ^{13}C splitting both on temperature and on mole fraction of aprotic solvents can be interpreted in terms of the same equilibrium between solvation complexes.

Another evidence for the complex formation between the ion-paired anion and dipolar aprotic solvents was obtained by the

(3) (a) V. Gutmann, *Struct. Bonding (Berlin)*, **12**, 113 (1973); (b) *ibid.*, **15**, 141 (1973); (c) *Electrochim. Acta*, **21**, 661 (1976).
(4) K. Nakamura, *Chem. Lett.*, 301 (1980).