Structural Studies on Optical Resolution *via* Diasteroisomeric Salt Formation. Enantiomer Separation for *cis*-Permethrinic Acid [*cis*-2,2-Dimethyl-3-(2,2-dichlorovinyl)cyclopropanecarboxylic Acid]

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The pH dependence of enantiomer separation by optical resolution of *cis*-2,2-dimethyl-3-(2,2-dichlorovinyl)cyclopropanecarboxylic acid (I) with (*S*)-2-benzylaminobutanol (II) has been investigated. Thermodynamic constants, thermal behaviour, and the molecular and crystal structure were determined in order to evaluate and interpret the results of optical resolution.

Much work has been done in the field of optical resolution. The general compilations of Wilen and Newman[1,2] have helped experimental chemists. Jacques *et al.*[3] have made a general survey of the results on the properties and behaviour of enantiomers, racemates, and diastereoisomeric salts formed under the conditions of optical resolution. The mechanisms of resolution processes have been approached through the application of mathematical statistics,[4] by using the Ogston[5] three-point interaction model, taking into account both first-order (salt forming) and second-order interactions (such as the hydrogen bonds, C–H • • • O, Cl • • • Cl contacts, *etc.*) between the salt-forming components, and analysing the similarities and differences of these types of interactions in diastereoisomeric salts.[6]

The structure dependence of optical resolution is of interest. The crystal structure of diastereoisomeric bitartrates have been reported by Yoneda and co-workers,[7] Larsen,[8] and Fogassy *et al.*[9] Gould and Walkinshaw[10] studied the crystal structures of the diastereoisomer-like brucine and strychnine complexes of *N*-benzoylalanine enantiomers.

We have investigated the optical resolution, crystal structure, and thermal behaviour of diastereoisomeric salt pairs, with a view to find characteristic common features or differences, which could explain the results of optical resolution. As a model we have chosen the enantiomer separation of racemic *cis*-2,2-dimethyl-3-(2,2-dichlorovinyl)cyclopropanecarboxylic acid [permethrinic acid (I)] an intermediate in the preparation of the insecticide Permethrin. Optical resolution of the racemic acid has been accomplished by natural alkaloids,[11] with ephedrine and its derivatives,[12] with phenylglycine ethyl ester,[13] with (*S*)-(+)-*threo*-4-nitrophenyl-2-dimethylaminopropane-1,3-diol isomers[14] *etc.* To find a new, generally applicable resolving agent for the cyclopropanecarboxylic acid series, many synthetic chiral amine products have been tried. Optical resolution using (*S*)-(+)-2-benzylaminobutanol (an intermediate of the antidiabetic agent Ethambutol) was successful.[15] In order to find the relationship between the structural and the physicochemical parameters, the binary and ternary phrase diagrams (Figure 1), the thermodynamic constants, and the molecular and crystal structure for both diastereoisomeric salts of (*S*)-2-benzylaminobutanol with (1*S*)-*cis*- (SCPABA) and (1*R*)-*cis*-permethrinic acid (RCPABA) were determined.

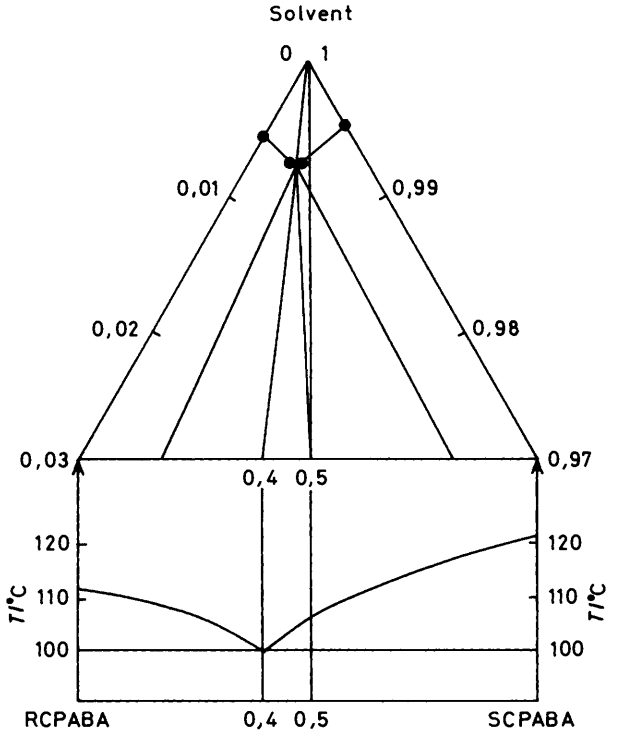


Figure 1. Binary and ternary phase diagrams of SCPABA and RCPABA (the theoretical binary phase diagram was calculated by the Schröder–van Laar equation[3])

Results and Discussion

The pure diastereoisomeric salts were prepared by means of the optical resolution method detailed in the Experimental section.

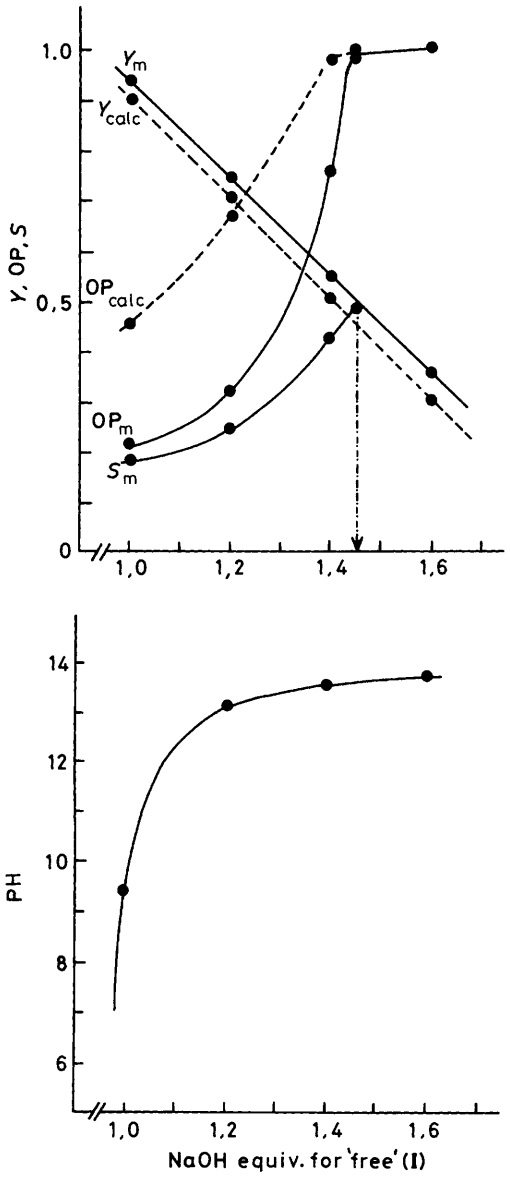


Figure 2. Changes in optical purity (O.P.), yield (Y), and optical yield (S) of SCPABA and in pH with variation of the amount of sodium hydroxide during the optical resolution of *cis*-permethrinic acid (m = measured, calc. = calculated values)

The solubility and dissociation constants were derived on the basis of our thermodynamic equilibrium model.[16] (The base and acid constants required for the calculations were measured by potentiometric titration in aqueous acetone medium optimized for the resolution efficiency: K_b 1.66 × 10^{-9} and K_a 8.9 × 10^{-6} mol dm^{-3}.) The model is valid only if the ability of the diastereoisomeric salts to form associates can be neglected. For conglomerate-forming salts this condition can be regarded as fulfilled. The binary phase diagram of the less soluble SCPABA and of its more soluble diastereoisomer (RPCABA) proved their conglomerate-forming ability (Figure 1).

The binary and the ternary phase diagrams exhibit similar shape. The eutectic compositions in the two diagrams are almost identical (in accordance with the consideration of Jacques [3]), and the ratio of the solubility constants tends to unity (K_{sR}/K_{sS} 1.25).

It can be postulated that isomer separation using (*S*)-2-benzylaminobutanol is practically impossible. However with regard to the unusual ratio of the dissociation constants (K_{dR}/K_{dS} 1.87), it is worth investigating the pH dependence of the efficiency of a given resolution. The individual constants are given in Table 1. The pH dependence of optical resolution has been mentioned in only a few papers, as an experimental observation,[17] and with the aim of calling attention to the phenomenon;[18] it was later approached by means of calculations.[16] However, the reason for it has so far not been evaluated. The efficiency of a resolution can be influenced by the pH only, if the dissociation constants are different for the diastereoisomers (otherwise the changes in dissociation would be identical and no effect could be observed). As the diastereoisomeric salts (SCPABA and RCPABA) decompose in acidic medium (permethrinic acid precipitates), the pH dependence was investigated in basic medium, using sodium hydroxide in excess. Figure 2 shows the results of resolution, where the molar ratio of racemate to resolving agent was 2:1, while the amount of the achiral auxiliary reagent (NaOH) varied from 1 to 1.6 equiv. (calculated for 'free' isomer acid content).

The hydrogen ion concentration varies according to a regular titration curve, while the yield (Y) decreases linearly as the amount of sodium hydroxide increases. The optical purity (O.P.) increases regularly, while the optical yield ($S = Y \times$ O.P.) has a maximum at [NaOH] 1.45 equiv. At this point the optically pure, less soluble SCPABA salt should precipitate, with a yield of 50%. As can be seen in Figure 2, our experimental data fit well to the calculated curves, *i.e.* the thermodynamic equilibrium model gives a good prediction in those cases where the thermodynamic constants for the diastereoisomeric salts (see Table 1) are known.

The other possibility to establish the pH dependence of this resolution is to recover the excess of RCPABA remaining in solution. After neutralization of the resolution mixture, the excess of RCPABA crystallizes in optically pure form (see Scheme), as under neutral conditions ($[H^+] = \sqrt{K_a \cdot K_b}$) the solubility difference is overcompensated by the RCPABA excess. The diastereoisomer composition in the mother liquor corresponds to that of the eutectic in the binary phase diagram.

X-*Ray Investigations.*—In order to find a correlation between the solid-state structure and the pH dependence of the resolution the crystal structures of the two diastereoisomeric salts were determined. In spite of the small solubility ratio, the crystal data (cell dimensions, space group, density, and number of molecules per unit cell) differ significantly (Table 1). Owing to the small diffracting volume of the single crystal of SCPABA, only a limited number of reflections could be collected, and therefore only the bond lengths in RCPABA will be discussed.

RCPABA. Bonds in the cyclopropane ring follow Allen's additivity rule.[19] The C(1)–C(3) bond opposite the dimethyl group is longer [1.535(4) Å] than the two bonds opposite the electron-acceptor groups [C(1)–C(2) 1.512(4) Å; C(2)–C(3) 1.511(4) Å]. Bonds in the cation do not have unusual values. Both oxygen atoms in the carboxylate anion in RCPABA are equivalent: C(4)–O(1) 1.263(4) and C(4)–O(2) 1.256(4) Å. Accordingly both are electron-donor atoms in hydrogen bonds [N(1)–H(2N)···O(1) and N(1)–H(1N)···O(2); Table 2].

The hydrogen-bonding system forms a long chain along the *a* axis. A third hydrogen bond is formed between the hydroxy group [O(3) attached to C(9)] and the O(1) atom. Two of the hydrogen bonds [N(1)–H(1N)···O(2) and O(3)–H(30)···O(1)] are acting between the carboxylate of the same *cis*-permethrinic acid molecule and the ethanolamine moiety of the 2-benzylaminobutanol molecule (see Figure 3).

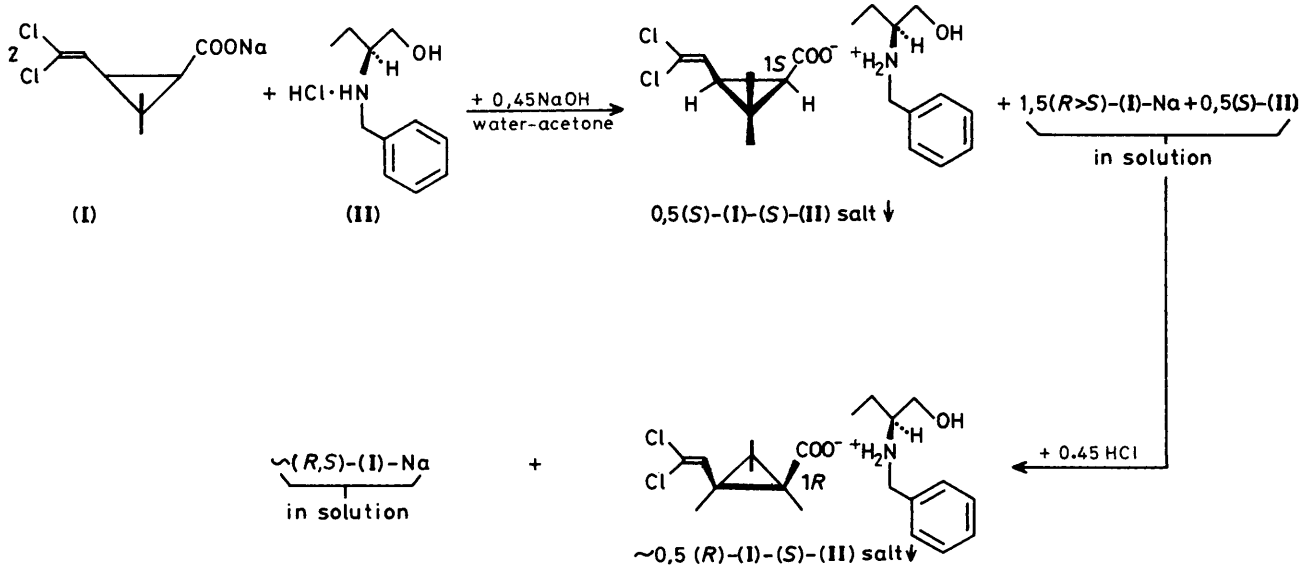
SCPABA. The C–O bond lengths in the carboxylate group seem to be slightly different [C(4)–O(1) 1.29(1) and C(4)–O(2) 1.24(1) Å] and only the O(1) oxygen atoms take part in salt bridge formation.

Table 1. Physicochemical parameters and crystal data

	RCPABA	SCPABA
Formulae	$C_{19}H_{27}Cl_2NO_3$	$C_{19}H_{27}Cl_2NO_3$
M_w	388	388
Solubility constant at 25 °C	K_{sR} 1.5 × 10^{-2} mol dm^{-3}	K_{sS} 1.2 × 10^{-2} mol dm^{-3}
Dissociation constant at 25 °C	K_{dR} 4.3 × 10^{-3} mol dm^{-3}	K_{dS} 2.3 × 10^{-3} mol dm^{-3}
M.p. (°C)	112	122
Heat of fusion (kJ mol^{-1})	51.22	50.83
a (Å)	6.209(1)	14.437(2)
b (Å)	7.885(1)	6.097(2)
c (Å)	10.853(2)	12.005(3)
α (°)	104.53(2)	
β (°)	93.03(2)	111.64(1)
γ (°)	91.49(2)	
V (Å^3)	513	983.4
Space group	$P\bar{1}$	$P2_1$
Z	1	2
D (g cm^{-3})	1.256	1.313
μ (cm^{-1})	30.24 (Cu-K_α)	3.46 (Mo-K_α)
Crystal size (mm)	0.3 × 0.5 × 0.25	0.8 × 0.05 × 0.03

Table 2. N–H · · · O and O–H · · · O hydrogen bridges in the diastereoisomeric salts

D–H · · · A	Symmetry	D · · · A (Å)	H · · · A (Å)	D–H · · · A (°)
	RCPABA			
N(1)–H(2N) · · · O(1)	[x, y, z]	2.72	1.81	161
N(1)–H(1N) · · · O(2)	[$1-x, y, z$]	2.75	1.85	157
O(3)–H(30) · · · O(1)	[$1-x, y, z$]	2.64	1.64	173
	SCPABA			
N(1)–H(2N) · · · O(1)	[x, y, z]	2.85	1.86	158
N(1)–H(1N) · · · O(1)	[$1-x, y-0.5, 1-z$]	2.73	1.71	169
O(3)–H(30) · · · O(2)	[$1-x, y+0.5, 1-z$]	2.71	1.69	168



Scheme.

Two hydrogen bonds with different strengths connect the O(1) atom and the benzylammonium groups of the two cations, which are situated along a two-fold screw axis.

In this structure the hydroxy group [O(3)] interacts with O(2) of the carboxylate. As a result of the helical hydrogen-bonding system, a polar channel is formed around the central screw axis at [1/2, y, 1/2] (Figure 4).

This channel is surrounded by apolar phenyl, dichlorovinyl, methyl, and ethyl groups. The hydrogen-bonding helix is further supported by symmetry-related hydrogen bonds

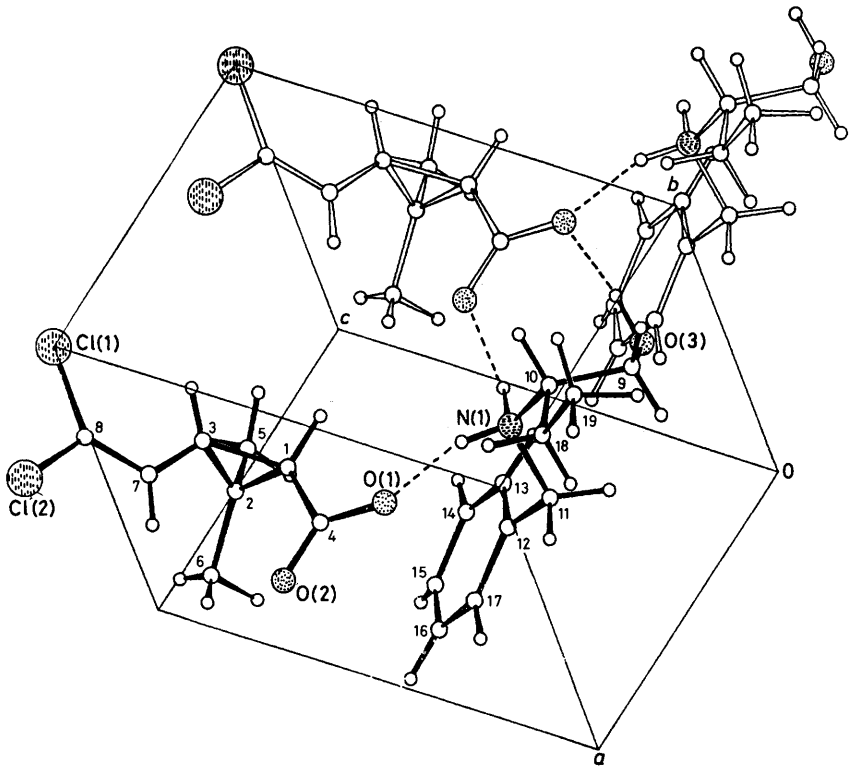


Figure 3. Packing arrangement of SCPABA. The projecting direction is making an angle of 21° with the crystallographic *b* axis

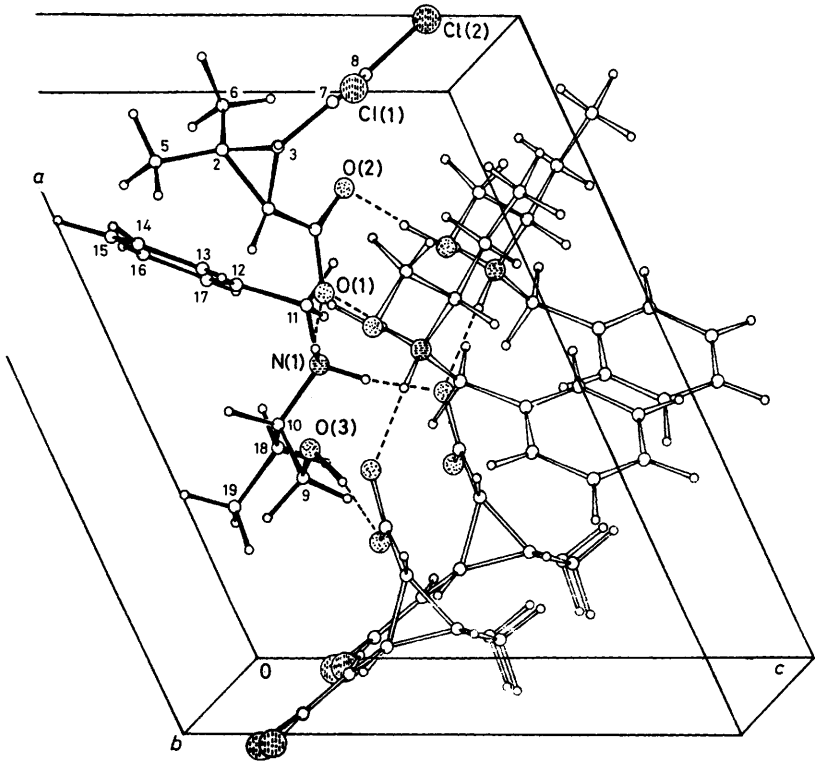


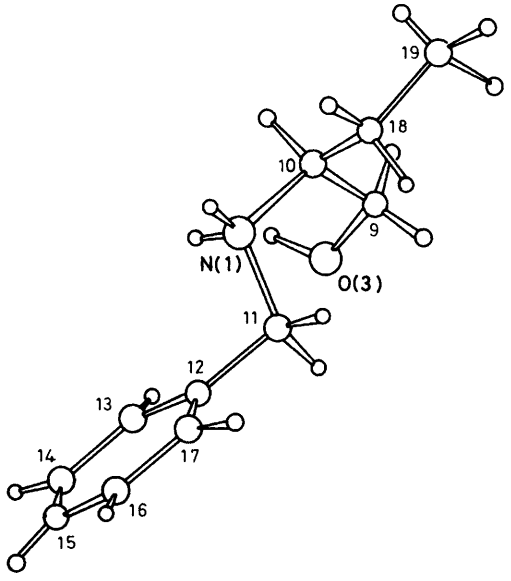
Figure 4. Packing arrangement of RCPABA. The projecting direction is making an angle of 37° with the crystallographic *b* axis

between O(3)–H · · · O(2). Further analysis of the packing patterns has shown that weak second-order interactions may exist between the C–H · · · O and C–H · · · Cl groups, respectively (Table 3). Such types of second-order contacts were found by Taylor and Kennard (C–H · · · X)[20] and Sarma and Desiraju (Cl · · · Cl, C–H · · · O).[21]

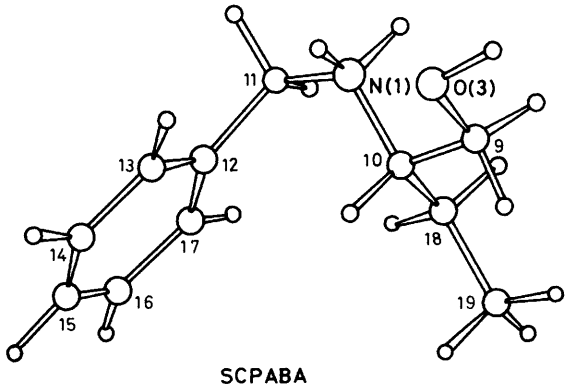
Conformation and packing arrangement. The shape of the *cis*-permethrinic acid anion is similar to that found in the crystal

Table 3. C–H · · · O and C–H · · · Cl contacts in the diastereoisomeric salts

D–H · · · A	Symmetry	D · · · A (Å)	H · · · A (Å)	D–H · · · A (°)
		RCPABA		
C(11)–H(112) · · · O(3)	$[x+1, y, z]$	3.57	2.67	144
C(11)–H(111) · · · Cl(1)	$[x-1, y-1, z-1]$	4.10	3.02	161
		SCPABA		
C(11)–H(111) · · · O(3)	$[x, y-1, z]$	3.46	2.43	160
C(11)–H(112) · · · O(3)	$[1-x, y-0.5, 1-z]$	3.49	2.62	136
C(18)–H(181) · · · O(2)	$[1-x, y-0.5, 1-z]$	3.75	2.69	163



RCPABA

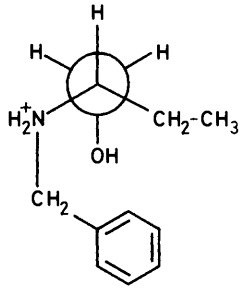


SCPABA

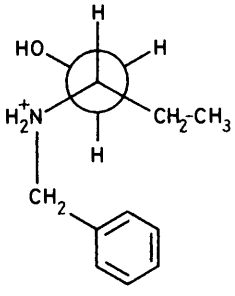
Figure 5. The cation conformations in the RCPABA and SCPABA, respectively

Table 4. Selected torsion angles (°) with their e.s.d.s in parentheses

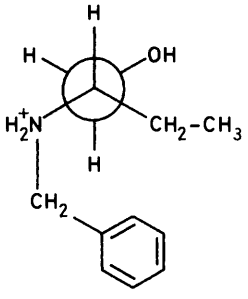
	RCPABA	SCPABA
	2-*N*-Benzylaminobutanol	
C(13)–C(12)–C(11)–N(1)	66.9(6)	58(1)
C(12)–C(11)–N(1)–C(10)	−175.9(5)	48(1)
C(11)–N(1)–C(10)–C(9)	51.5(4)	178(1)
N(1)–C(10)–C(9)–O(3)	38.0(4)	49(1)
C(11)–N(1)–C(10)–C(18)	−74.0(5)	54(1)
N(1)–C(10)–C(18)–C(19)	−174.7(6)	−179(1)
	cis-Permethrinic acid	
C(8)–C(7)–C(3)–C(1)	153.0(7)	−138(2)
C(7)–C(3)–C(1)–C(4)	−3.5(5)	5(1)
C(3)–C(1)–C(4)–O(1)	−136.2(6)	141(1)



A



B



C

Figure 6. Stable rotamers of SCPABA and RCPABA in solution [relative to the C(10)–C(9) bond]

structure of racemic and optically active *cis*-permethrinic acids (to be published). In contrast to the relative rigidity of the anion, the conformations of the cations in the diastereoisomeric salts differ with respect to the C(11)–N(1) and N(1)–C(10) single bonds, as can be seen in Figure 5. (Characteristic torsion angles for the cations and the anions are given in Table 4).

A common feature of the two conformers is the *gauche* position of the N(1) and O(3) atoms relative to the C(10)–C(9) bond. This rotamer is present in the solid state, probably due to intermolecular hydrogen bonds between a pair of counterions (see Table 2).

The resolving base seems to be more flexible than the anion (see the torsional angles for the cations in Table 4). In both cases, the conformers contain the polar groups (*i.e.* the protonated amino and primary hydroxy groups) in appropriate positions for interactions with the electron-donor carboxylate

Table 5. Characteristic ^{1}H n.m.r. data (δ_{Me_4Si} 0.0) for RCPABA (the values for SCPABA are identical within the experimental errors)

δ	Multiplicity	Intensity (H)	Assignation	Coupling constant (Hz)
0.84	t	3	19-H_3	
1.02, 1.07	s, s	6	5-H_3, 6-H_3	
1.5—1.75	m	4	1-H, 3-H, 18-H_2	
3.08	m	1	10-H	
3.65	dd	1	9-H_a	*J* (9a, 9b) 12.8; *J* (9a, 10) 5.4
3.79	dd	1	9-H_b	*J* (9b, 10) 3.6
4.15	s	2	11-H_2	
6.17	m	1	7-H	
7.34	s	5	13-, 14-, 15-, 16-, 17-H	

group. In the chiral holes the apolar alkyl and aralkyl groups can assume favourable positions only in two different conformations.

Consequently the cation in RCPABA is more elongated [C(Phe)–C(19) distance 7.34(1) Å] and only weak C–H • • • A interactions connect the neighbouring ion-pairs related only by translational symmetry in the directions *b* and *c*.

The unit cell in SCPABA is formed by two ion-pairs linked by a two-fold screw axis. The cation has a sickle shape [C(Phe)–C(19) distance 5.17(1) Å]. This shape permits a more compact arrangement (Figure 4).

N.m.r. Studies.—In order to acquire information on the conformations in solution, the ^{1}H n.m.r. spectra of SCPABA and RCPABA were studied in detail. The spectra of the diastereoisomeric salts (0.01 mol dm^{-3}) recorded in deuterioacetone–deuterium oxide were identical, indicating that at this concentration the counterions are solvated separately. The assignments are given in Table 5. The vicinal coupling constants provide information about the conformational distribution relative to the C(10)–C(9) bond. The three stable rotamers A–C around this bond are shown in Figure 6. The Karplus relationship[22] and the electronegativities of the substituents were utilized to calculate the rotamer distribution: A/(B + C) = 60/40. Rotamer B is the one found in the solid.

Conclusions.—The structural analysis of the present diastereoisomeric salts provided further evidence of the reliability of the stereochemical model of optical resolution.[6] The success or failure of a resolution is determined by the presence or lack of differences between the second-order interactions in the diastereoisomers.

In our case the experimental resolution data revealed a special pH dependence and in connection with this the pure salts have different dissociation constants, drawing attention to the fact that the second-order interactions can strongly influence the salt bridge dissociation. In the more soluble RCPABA the salt bridge is not shielded, and the hydrogen-bonding system can easily be destroyed: one strong base molecule, such as the sodium hydroxide, can cause the immediate destruction of the two equivalent salt bridges in the monomeric salt, while in SCPABA the further hydrogen bond-supported helical system of the salt bridge provides some stability and shields the salt bridges against attack by base.

The main question to be answered is how to interpret the mechanism of the given optical resolution. In the relatively well studied bitartrate salts[9] a tartrate chain selects between the enantiomeric bases, whereas in this case the resolving agent cannot form an extended chiral recognition unit, but 'tries' to accommodate (as a monomer) to different acid enantiomers. This accommodating ability is proved by the transformation of rotamer A in excess in solution to rotamer B; hence, in rotamer B the groups of importance for chiral recognition are in the most favourable position. Chiral discrimination is afforded by the central part of the resolving agent, the N(1)–C(8)–C(9)–O(3) fragment; this part of the molecule interacts with the carboxylate group of *cis*-permethrinic acid, forming three hydrogen bonds in each case.

Experimental

Thermal data were recorded by the DSC cell of Dupont 1090 TA system. Potentiometric titration was accomplished with a Radelkis precision pH-meter with combined glass electrode. Optical rotational power was measured by a Perkin-Elmer 241 polarimeter. N.m.r. spectra were recorded by a Brucker 360 spectrometer.

Optical Resolution of cis-*Permethrinic Acid.*—Racemic *cis*-permethrinic acid (5.2 g, 0.025 mol) was dissolved at 68 °C in water (31 cm^3) containing sodium hydroxide (0.0306 mol). The clear solution was treated with (*S*)-2-benzylaminobutanol (2.25 g, 0.0125 mol) dissolved in a mixture of 2N-hydrochloric acid (6.25 cm^3) and acetone (5 cm^3). The mixture was allowed to cool to room temperature. The resulting precipitate was the (*S*)-2-benzylaminobutanol salt of (1*S*)-*cis*-permethrinic acid (SCPABA) (2.4 g), m.p. 122 °C.

The mother liquor was warmed to 68 °C and, with stirring, neutralized through the addition of 2N-hydrochloric acid (2.66 cm^3). After cooling the (*S*)-2-benzylaminobutanol salt of (1*R*)-*cis*-permethrinic acid (RCPABA) precipitated out (2.15 g), m.p. 112 °C.

The optically active permethrinic acids could be obtained by decomposing the diastereoisomeric salts with 2N-hydrochloric acid. The free acids were extracted with chloroform. Evaporation of the solvent resulted in the pure acids (1.24 and 1.1 g), respectively, $[\alpha]_D^{22}$ −31° (*c* 1 in $CHCl_3$) (for the *S*-isomer).

X-*Ray Investigations.*—Crystals of SCPABA and RCPABA were grown from methanol and acetone, respectively. Crystal data are listed in Table 1. Data on RCPABA were collected on an Enraf–Nonius CAD-4 diffractometer with monochromated Cu-K_α radiation (at the Central Research Institute for Chemistry of the Hungarian Academy of Sciences, Budapest). 2 101 Independent reflections ($2\theta_{max.}$ 160°) were collected. The intensity reduction of 6.2% was corrected by means of intensity standard reflections. The structure was solved through application of the MULTAN 84 program.

The reliability factor for the positions of non-hydrogen atoms applying isotropic refinement was decreased to *R* 0.14. An empirical absorption correction was applied to all reflections, using the DIFABS[23] program (*R* 0.12). After anisotropic refinement, the reliability factor was $R = 0.058$, $R_w = 0.079$ for 2 068 reflections [$I > 3\theta(I)$, $p = 0.03$]. Hydrogen atoms with known positions were generated, except for N–H and

Table 6. Fractional co-ordinates for RCPABA with e.s.d. values in parantheses

Atom	*x*	*y*	*z*
Cl(1)	1.000 0(0)	1.000 0(0)	1.000 0(0)
Cl(2)	1.415 7(1)	1.001 0(1)	0.897 5(1)
O(1)	0.824 2(4)	0.522 4(3)	0.440 2(2)
O(2)	1.139 4(4)	0.506 0(4)	0.543 1(2)
O(3)	−0.001 5(4)	0.354 8(4)	0.229 3(2)
N(1)	0.411 6(4)	0.424 2(3)	0.347 0(2)
C(1)	0.817 2(5)	0.533 9(4)	0.658 2(3)
C(2)	0.884 2(5)	0.455 3(4)	0.767 1(2)
C(3)	0.903 0(5)	0.651 9(4)	0.787 4(3)
C(4)	0.938 0(5)	0.518 1(3)	0.539 2(2)
C(5)	0.701 9(7)	0.387 5(6)	0.830 1(3)
C(6)	1.082 8(7)	0.347 3(5)	0.763 9(4)
C(7)	1.114 4(6)	0.746 3(4)	0.800 4(3)
C(8)	1.166 3(6)	0.895 0(4)	0.886 8(3)
C(9)	0.143 1(6)	0.448 0(5)	0.172 7(3)
C(10)	0.335 1(5)	0.538 1(3)	0.262 3(2)
C(11)	0.456 6(6)	0.238 1(4)	0.280 8(3)
C(12)	0.516 1(6)	0.135 6(4)	0.376 6(3)
C(17)	0.719 8(7)	0.068 4(5)	0.382 5(4)
C(16)	0.769 9(9)	−0.032 2(6)	0.466 2(6)
C(15)	0.618(1)	−0.067 6(5)	0.545 2(5)
C(14)	0.416(1)	−0.000 4(6)	0.541 6(4)
C(13)	0.365 1(7)	0.099 8(5)	0.457 1(4)
C(18)	0.520 8(7)	0.588 8(5)	0.190 9(3)
C(19)	0.461(1)	0.717 0(6)	0.113 0(4)
H(51)	0.58(1)	0.467(9)	0.837(7)
H(52)	0.71(1)	0.385(9)	0.932(7)
H(53)	0.66(1)	0.275(9)	0.777(6)
H(61)	0.19(1)	0.381(9)	0.722(6)
H(62)	1.02(1)	0.214(9)	0.718(7)
H(63)	1.11(1)	0.33(1)	0.828(7)
H(7)	1.23(1)	0.708(9)	0.753(6)
H(91)	0.08(1)	0.541(9)	0.157(6)
H(92)	0.20(1)	0.372(9)	0.100(6)
H(10)	0.28(1)	0.635(8)	0.331(6)
H(111)	0.32(1)	0.153(8)	0.220(6)
H(112)	0.59(1)	0.250(8)	0.224(6)
H(17)	0.83(1)	0.070(8)	0.323(5)
H(16)	0.92(1)	−0.071(8)	0.478(6)
H(15)	0.63(1)	−0.144(8)	0.590(6)
H(14)	0.32(1)	−0.014(8)	0.603(6)
H(13)	0.22(1)	0.137(8)	0.436(6)
H(181)	0.64(1)	0.644(9)	0.252(7)
H(182)	0.56(1)	0.478(9)	0.134(6)
H(191)	0.59(1)	0.75(1)	0.055(7)
H(192)	0.37(1)	0.80(1)	0.168(8)
H(193)	0.35(1)	0.64(1)	0.033(7)
H(1)	0.65(1)	0.552(8)	0.648(6)
H(3)	0.80(1)	0.715(8)	0.839(6)
H(3o)	−0.08(1)	0.412(8)	0.308(6)
H(1n)	0.304(0)	0.421(0)	0.405(0)
H(2n)	0.541(0)	0.477(0)	0.392(0)

Table 7. Fractional co-ordinates for SCPABA with e.s.d. values in parentheses

Atom	*x*	*y*	*z*
Cl(1)	0.979 4(1)	0.783 0(0)	0.793 4(2)
Cl(2)	1.035 9(2)	0.356 5(6)	0.896 8(2)
O(1)	0.606 2(2)	0.307(1)	0.481 5(4)
O(2)	0.743 8(3)	0.107(1)	0.562 2(4)
O(3)	0.374 8(3)	0.389(1)	0.345 1(4)
N(1)	0.457 8(3)	−0.004(1)	0.353 5(4)
C(1)	0.753 8(4)	0.452(1)	0.476 0(5)
C(2)	0.842 3(4)	0.425(1)	0.438 0(5)
C(3)	0.857 7(4)	0.523(1)	0.557 6(6)
C(4)	0.700 1(4)	0.275(1)	0.509 3(5)
C(5)	0.842 0(5)	0.580(1)	0.339 5(6)
C(6)	0.882 7(5)	0.201(1)	0.429 7(6)
C(7)	0.914 1(4)	0.410(1)	0.669 6(6)
C(8)	0.967 1(5)	0.501(1)	0.770 6(6)
C(9)	0.310 0(4)	0.223(1)	0.275 2(6)
C(10)	0.371 6(4)	0.056(1)	0.241 3(5)
C(11)	0.528 5(4)	−0.175(1)	0.344 4(5)
C(12)	0.563 8(4)	−0.146(1)	0.241 7(5)
C(13)	0.611 8(4)	0.042(1)	0.230 8(5)
C(14)	0.651 3(5)	0.054(1)	0.140 0(7)
C(15)	0.641 5(5)	−0.115(1)	0.063 9(7)
C(16)	0.594 1(5)	−0.299(1)	0.073 2(6)
C(17)	0.553 2(5)	−0.318(1)	0.163 2(6)
C(18)	0.311 8(5)	−0.144(1)	0.183 1(6)
C(19)	0.225 1(6)	−0.092(1)	0.067 2(7)
H(1)	0.707	0.588	0.439
H(3)	0.879	0.676	0.590
H(51)	0.811	0.739	0.350
H(52)	0.918	0.605	0.345
H(53)	0.798	0.514	0.253
H(61)	0.880	0.096	0.502
H(62)	0.840	0.124	0.345
H(63)	0.960	0.216	0.437
H(7)	0.906	0.235	0.668
H(1n)	0.429	−0.058	0.416
H(2n)	0.499	0.137	0.387
H(91)	0.256	0.298	0.194
H(92)	0.268	0.145	0.323
H(10)	0.402	0.126	0.179
H(111)	0.492	−0.332	0.336
H(112)	0.594	−0.173	0.428
H(13)	0.615	0.187	0.287
H(14)	0.697	0.206	0.140
H(15)	0.669	−0.100	−0.013
H(16)	0.588	−0.438	0.015
H(17)	0.515	−0.466	0.173
H(181)	0.279	−0.216	0.244
H(182)	0.358	−0.265	0.164
H(191)	0.183	−0.242	0.027
H(192)	0.174	0.024	0.081
H(193)	0.253	−0.025	0.001
H(3o)	0.332	0.457	0.389

O–H, which were taken from difference Fourier calculations. The fractional co-ordinates and the isotropic temperature factors with their e.s.d.s are given in Table 6.

Data on SCPABA were also collected on a CAD-4 diffractometer with monochromated Mo-K_α radiation (at the Institute of Physical Chemistry of the Academy of Science, Berlin). 1 343 Independent reflections were obtained. Application of the MULTAN 84 program did not afford an acceptable solution. The positions of the chlorine atoms were obtained through simultaneous application of Patterson synthesis and translation function analysis. With the Karl recyclization method,[24] all but one atomic positions were obtained. The reliability factor after isotropic refinement was $R = 0.10$. An empirical absorption correction was applied with the DIFABS program. Hydrogen atoms with known positions were generated; hydrogen atoms attached to N and O atoms and to the ring were taken from the electron density difference maps. After further anisotropic refinement $R = 0.059$ was reduced to $R_w = 0.059$ for 1 199 reflexions [$I > \theta(I)$, $p = 0.01$]. (The fractional co-ordinates and the isotropic temperature factors with their e.s.d. values are listed in Table 7.)

All calculations were carried out on a PDP 11/34 minicomputer by means of the ENRAF-NONIUS SDP program package, with local modifications.

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