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Temperature-dependent racemic compound-conglomerate crystallization of 2,3:6,7-dibenzobicyclo[3.3.1]nona-2,6-diene-4,8-dione

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Abstract—2,3:6,7-dibenzobicyclo[3.3.1]nona-2,6-diene-4,8-dione **1** is a new example of a compound capable of temperature-dependent racemate-conglomerate crystallization: at temperatures below 90°C crystals of the racemic compound (space group $P\bar{1}$, $Z=4$) can be obtained, whereas above 100°C a conglomerate of (+)- and (−)-homochiral crystals (space group $P2_12_12_1$, $Z=4$) forms and therefore it undergoes spontaneous resolution upon crystallization. Enantioselective analytical gas chromatography on a single crystal has been proposed as a simple method for detection of conglomerate formation. The ^{1}H and ^{13}C NMR spectra of **1** are analyzed in detail and the crystal structures of both species (racemic compound and single enantiomer) have been solved by X-ray structural analysis.

1. Introduction

Resolution of conglomerates by preferential crystallization is the easiest and cheapest method available for the generation of enantiomerically pure products.[1–6] However, the percentage of known conglomerate-forming substances in the pool of chiral organic solids[3] is still quite modest and, therefore, the search for new conglomerates among the important synthons or their precursors can prove to be quite fruitful (for examples, see Refs. 1–10).

The difference in the melting points of enantiomerically pure and racemic compounds of more than 30°C (ΔT_{e-r} = melting point of enantiomerically pure compound–melting point of racemic compound) is the only easily available positive test for conglomerate formation.[1–3] The search for new conglomerates has, so far, relied on this test. The downside to the test is that omissions are inevitable because chemists usually carry out crystallization only under standard conditions. Nevertheless, various examples of the temperature-induced conglomerate formation and one example of a dependence on pressure (mandelic acid)[7] have been described. The majority of examples of temperature-dependent racemate-conglomerate crystallization are known for chiral compounds, which have different degrees of solvation for the racemic form compared to the conglomerate. The thermodynamic stability of such compounds is in agreement with Van't Hoff's rule ('the least solvated compound is the most stable at high temperature').[3] For instance, sodium-ammonium tartrate tetrahydrate (Pasteur's conglomerate) forms below 28°C, whereas less hydrated racemic salt (Scacchi monohydrated salt) forms above 28°C.[3] Recently a similar phenomenon has been described for an inclusion compound: conglomer-

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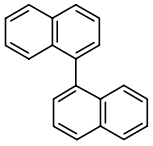
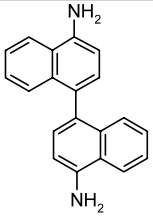
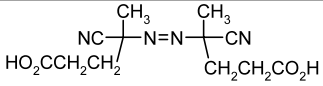
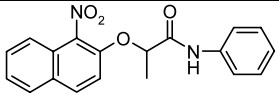
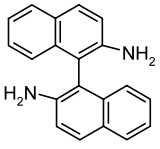
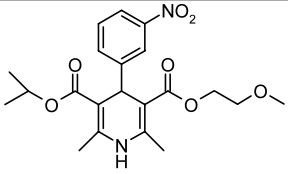
ate is formed at the lower temperature (0°C), and the racemic compound of a different guest/host composition is formed at the room temperature.[11] In the case of solvates the driving force of temperature-dependent racemate-conglomerate crystallization is the enthalpy of solvate formation. Examples of compounds forming both racemic and conglomerate crystals of the same composition are not as common.

All of the compounds, which we found described in the literature as having two crystal forms of the same composition (racemic compound and conglomerate) are listed in the Table 1. The two forms have different melting points Tr and Te, respectively, and there is a transition temperature Ti above which one form is more stable, and below which the other form is more stable. It is known that 1,1′-binaphthyl can form a metastable conglomerate below the thermodynamic transition temperature (76°C).[7] In the case of **4** and **7** it was reported that crystallization from solution at certain temperatures leads to the mixture of two forms. On the other hand, in the case of **1** formation of the racemic compound and the conglomerate is precisely differentiated by the intermediate temperature.

Table 1. Examples of compounds which have two forms (racemic compound and conglomerate) of the same composition; Tr, melting point of racemic compound; Te, melting point of corresponding conglomerate; Ti, intermediate temperature above which one form is more stable and below which the other form is more stable

Name:	Formula:	Tr(°C)	Te(°C)	Ti(°C)	Ref
Racemic compound is more stable below Ti.					
1,1'-binaphthyl **2**		145	158[a]	76	7
Naftidine (4,4'-diamino-1,1'-binaphthyl) **3**		202	204[a]	197	13
4,4'-azobis-4-cyanopentanoic acid **4**		118	130	35	14
Anilide 2-(1-nitro-2-naphthoxy)propionic acid **5**		187	212	173	8,15
Conglomerate is more stable below Ti.					
2,2'-diamino-1,1'-binaphthyl **6**		191	242	186	15
Nimodipine (isopropyl(2-methoxyethyl)-1,4-dihydro-2,6-dimethyl-4-(3-nitrophenyl)-3,5-pyridinedicarboxylate **7**		124	116	88	16

[a] the temperature stated corresponds to the melting of eutectic mixture because of rapid racemization above it and hence melting points of the enantiomers are unknown.

Shiraiwa et al. have found that DL-α-phenylglycine sulfate forms the conglomerate upon crystallization from a 30% solution of H_2SO_4 below 5°C, and the racemic compound is formed above 10°C.[12] This example was not included in the Table 1 because of the absence of data on probable change in composition during transformation from the racemic compound into the conglomerate.

2. Results and discussion

In this study we investigated the temperature-dependent racemate-conglomerate crystallization of 2,3:6,7-dibenzobicyclo[3.3.1]nona-2,6-diene-4,8-dione **1** (Scheme 1). Racemic **1a** was first described by Stetter and Reischl[17] and prepared in enantiomerically pure forms of (1*R*,5*R*)-(+)-**1b** and (1*S*,5*S*)-(−)-**1b** by Naemura et al.[18,19] The enantiomers of **1b** have been used to prepare novel crown ethers and podands.[18–21] The fact that attracted our attention was that the melting point of the enantiomerically pure **1b** was much higher than that of the racemic compound **1a** (Δmp of 46°C!).[18] However, there was not any direct evidence available to prove that **1** was able to form the conglomerate. X-Ray data for **1** had not been obtained at the time.

2.1. Racemate-conglomerate crystallization

In order to find out whether **1** is able to form a conglomerate we synthesized it by the known method[18,22] and studied its properties. Rather large (up to 43.4 mg) and well-formed crystals (colorless needles) of **1a** were obtained by crystallization of **1** at room temperature from various solvents. However despite the above-mentioned difference in the melting point of the enantiomer and the racemic compound it turned out that these crystals were not optically active and their melting point corresponded to that of the racemic compound **1a** (mp, 146–148°C). The racemic nature of the obtained crystals was confirmed by analytical gas chromatography (GC) on chiral stationary phase (CSP) of solutions of separate single crystals (Fig. 1a) and by X-ray data: the compound has the achiral space group $P\bar{1}$, $Z=4$. During the search for conditions of conglomerate formation we attempted crystallization from various solvents at different rates of cooling as well as at lower temperatures and obtained the same racemic compound (the ee of separate single crystals was equal to zero). Only crystallization at elevated temperatures (100°C and above) from a number of solvents led to the expected conglomerate **1b** (ee of single crystal, 75%; mp of single crystal, 188–190°C)—as proven by GC (Fig. 1b) and X-ray analysis (sp. gr. $P2_12_12_1$, $Z=4$). The single crystals obtained using this method have different morphology (colorless plates) and their solutions are optically active. The melting point of **1b** was different for various single crystals and it was within the range of 150–194°C. It means that there is no strong enantioselectivity during crystal growth, i.e. not all the crystals are enantiomerically pure. That confirms the fact that the ee of different single crystals of **1b** significantly differs from zero but only for some crystals does this amount to 100%. Crystallization of **1** at the temperature of 100°C using enantiomerically pure single crystal of **1b** as the seed has not led to the enrichment of the solution which proves the lack of the enantioselectivity during crystal growth.

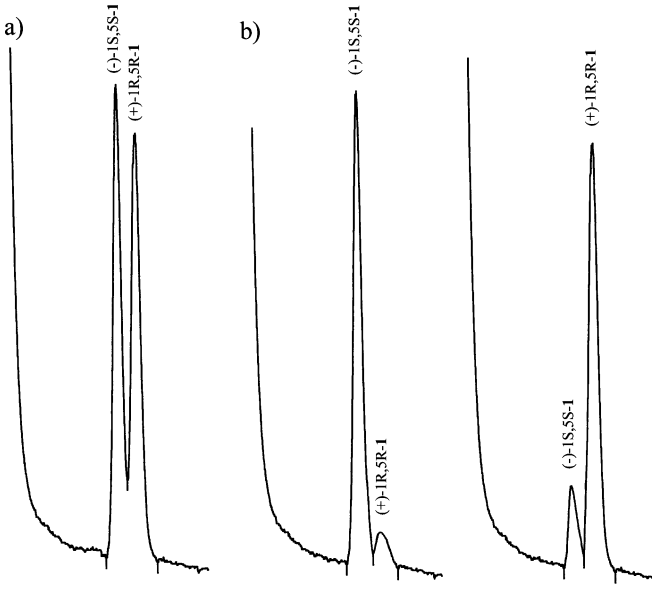
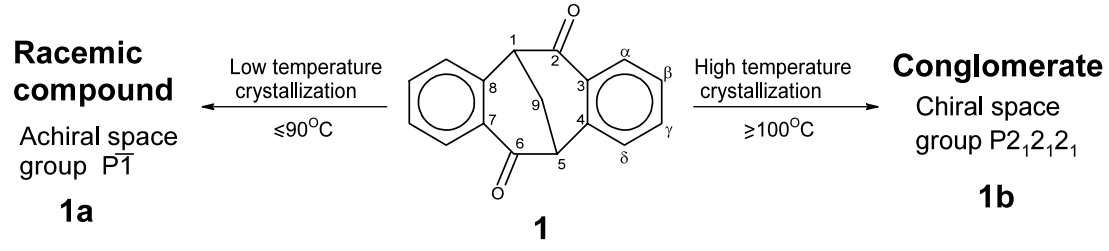


Figure 1. (a) Chromatogram of the solution of single crystal **1a**; (b) chromatograms of solutions of single crystals consisting mainly of (–)-(left) and (+)-(right) enantiomers **1b**. Stationary phase is permethylated-β-cyclodextrin, eluent is hydrogen gas, 130°C, 0.5 bar.



Scheme 1. Compound **1** is the crude 2,3:6,7-dibenzobicyclo[3.3.1]nona-2,6-diene-4,8-dione isolated from the reaction mixture. Compound **1a** is the racemic compound obtained by crystallization of **1** at 20°C. Compound **1b** is the conglomerate obtained by crystallization of **1** at 100°C. Atoms numeration of the molecule is in accordance with NMR data.

ΔT characterizes stability of the racemic compound with respect to the conglomerate ('the rule of stability of racemic compounds' developed by A. Collet),[2,3] i.e. it defines the sign of $\Delta G°$ (the Gibbs free energy of formation of the racemic compound from the two opposite enantiomers). $\Delta G°$ is slightly dependent on temperature,[24] but if it is close to zero then changes in temperature may cause a change in the sign of $\Delta G°$ and consequently alter the relative stability of the racemic compound and the conglomerate—which is exactly what we observe in the case of **1**: below 90°C the racemic compound is formed in spite of such a large difference in melting points of the racemic compound and the enantiomer (46°C).

2.2. Enantioselective gas chromatography as a simple test for conglomerate formation

Racemic **1** was resolved into enantiomers by GC on a chiral stationary phase (permethylated-β-cyclodextrin bonded to polysiloxane), which allowed us to detect conglomerate formation merely by measuring the ee of separate crystals.

Enantioselective chromatographic methods are very convenient and simple techniques for detection of conglomerate formation. In comparison with other methods they possess a number of advantages such as simplicity and precision. In the case of analytical GC only traces of substances are required due to high sensitivity.[23] Furthermore, chromatography is a direct method which does not require a comparison of the spectra of the sample under consideration with that of pure enantiomers in contrast to PXRD, SSNMR and IR methods.[2,24] The advantage of using analytical amounts of substances is only restricted by the possible difficulty of mechanical separation of single crystals.

(−)-**1** has the (1*S*,5*S*)-configuration[18] and elutes first on permethylated-β-cyclodextrin bonded to polysiloxane (H_2-carrier gas) as proven by polarimetry. Using a short two meter column for the resolution of **1** permitted the retention times to be decreased around 4 min, in contrast with 46 and 48 min retention times for (−)-**1** and (+)-**1**, respectively, with a 20 m column of the same type at 170°C and 0.7 bar hydrogen pressure.

2.3. X-Ray analyses of 1a and 1b

The geometries of (±)-**1a** and (+)-**1b** (Fig. 2) are similar both to each other and to those of disubstituted analogues of **1** described in the literature.[22,25,26] Comparisons of the clefts of **1** has shown that for homo- and heterochiral crystals a slight difference exists. The separation between aromatic rings (C(11)···C(16) distance) is increased by more than 0.1 Å in racemic **1a** (7.376(4) and 7.327(4) Å for two independent molecules) in comparison with enantiomeric **1b** (7.208(4) Å). At the same time the torsion angle C(7)C(6)C(5)C(4), which defines the cleft 'bite', varies less and changes only from 89–90° in **1a** to 87° in **1b**. The observed differences indicate that in addition to the substituent influences,[26] the shape of the cleft of this bicyclic molecule is also ruled by peculiarities of crystal packing.

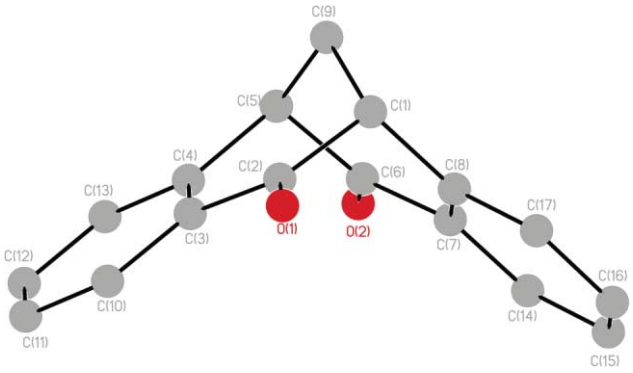


Figure 2. The general view of the 2,3:6,7-dibenzobicyclo-[3.3.1]nona-2,6-diene-4,8-dione.

Taking into account the quite rare spontaneous resolution upon crystallization observed for **1** and Δmp (**1b**–**1a**), it was interesting to compare the crystal packing of homo- and heterochiral crystals. First of all, it is important to mention that according to X-ray investigation the densities of **1a** and **1b** crystals at 120 K are practically the same in spite of Wallach's rule.[27] Since the densities of **1a** and **1b** are equal it would be expected that the observed difference in melting point is the result of some specific interactions in the structure of **1b**. The analysis of the crystal packing in **1a** and **1b** has revealed that there are two types of secondary interactions, namely C–H···(π-system) and C–H···O contacts. While the latter contacts are rather weak both in **1a** and **1b**, in the case of the homochiral crystal **1b** the corresponding C···O distances are slightly shorter (3.323(3)–3.338(3) and 3.527(3)–3.88(2) Å in **1b** and **1a**, respectively), which can be interpreted as strengthening of the C–H···O interactions in **1b**. The role of these contacts in the two types of crystals is also different. Indeed, in the homochiral crystal **1b** C–H···O contacts assemble molecules in the CH···O bonded corrugated layers (Fig. 3), while in the heterochiral crystal **1a** the

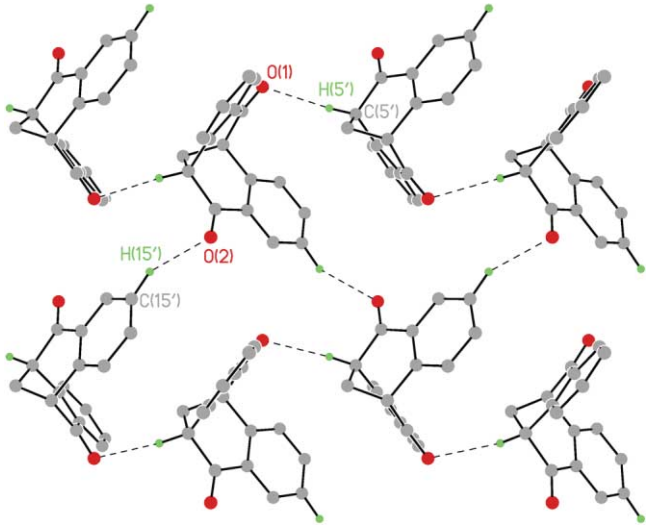


Figure 3. The scheme illustrating the formation of C–H···O bonded layers in the crystal of **1b**.

similar contacts assemble molecules into the tetramers composed from both independent molecules (Fig. 4).

As for the C–H···(π-system) interactions, in contrast to C–H···O bonds, they were found only in the homochiral crystal **1b**. These contacts assemble molecules into a helix directed along the **c** crystallographic axis (Fig. 5). The parameters characterizing this contact are H···X 2.55 Å, C(13)···X 3.590(2) Å, C–H···X 162°, where X is the center of the aromatic ring (C(7), C(8), C(14), C(15), C(16), C(17) atoms).

Thus, as the analysis of crystal packing unambiguously shows, in the case of **1a** and **1b** the observed difference in the melting point is a result of weak interactions. It is noteworthy that recent investigations of structural and thermodynamic relationships between optically active and racemic halogen substituted 3-hydroxy-3-phenylpropionic acids have shown that weaker secondary interactions influence the difference in relative stability of racemic compounds and conglomerates in addition to differences in H-bonding.[28] In the case of **1a**,**b** only weak interactions are present in the crystal structures and these interactions must be responsible for the difference in the stability of the racemic compound and the conglomerate.

2.4. NMR investigation

Previously, the ^{1}H and ^{13}C NMR spectra of diazabicyclo[3.3.1]nonanes, for which the so-called virtual spin–spin coupling constants are typical, were studied in our laboratory.[29–31] We have performed a thorough analysis of ^{1}H and ^{13}C NMR spectra of **1a** and all the signals of protons and carbons were assigned by means of 2D NMR (Fig. 6).

Under the conditions of selective decoupling from α-protons we have observed the expected picture in the ^{13}C spectrum of the carbonyl carbons (Fig. 7). The carbonyl carbons must have different spin–spin coupling constants because of different dihedral angles of $C_{2,6}$ with *anti*- and *syn*- methylene protons (179 and 60°, respectively, according to X-ray data). The values of spin–spin coupling constants calculated for these angles by means of the Karplus equation are approximately 9 and 1 Hz, respectively. Thus, the observed virtual spin–spin coupling constant is equal to the half of the sum of the regular coupling constants. This is in accordance with the theoretical considerations on the nature of virtual spin–spin coupling and experimental data.[29–31]

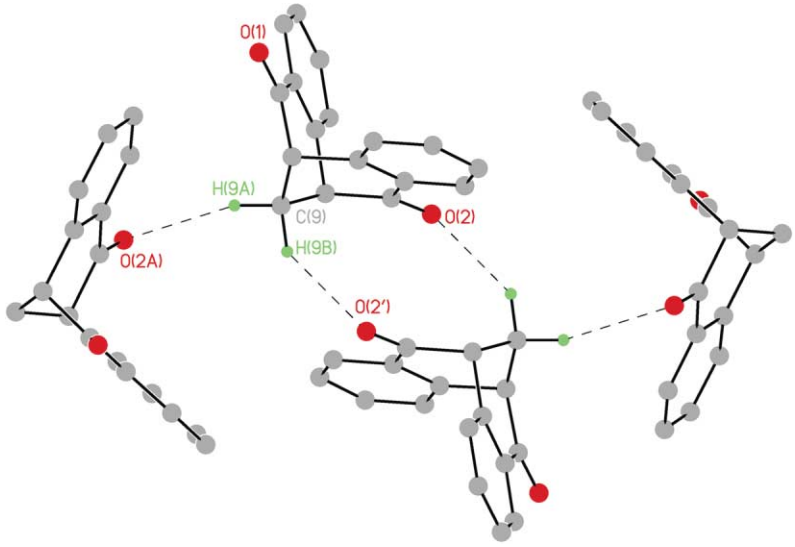


Figure 4. The scheme illustrating the formation of C–H···O bonded tetramers in the crystal of **1a**.

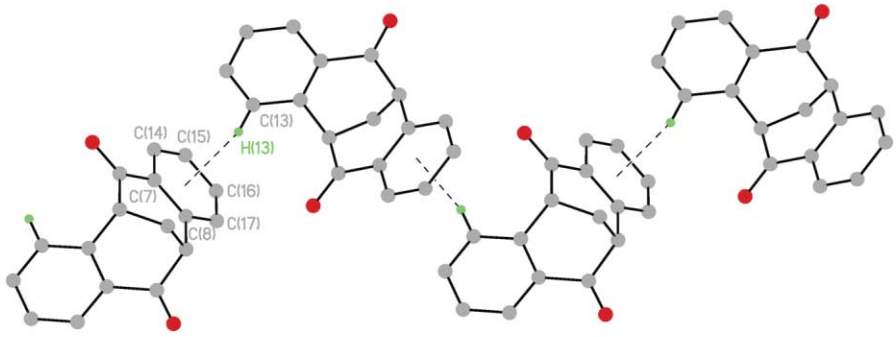


Figure 5. The scheme illustrating the formation of the C–H···π bonded helixes in the crystal of **1b**.

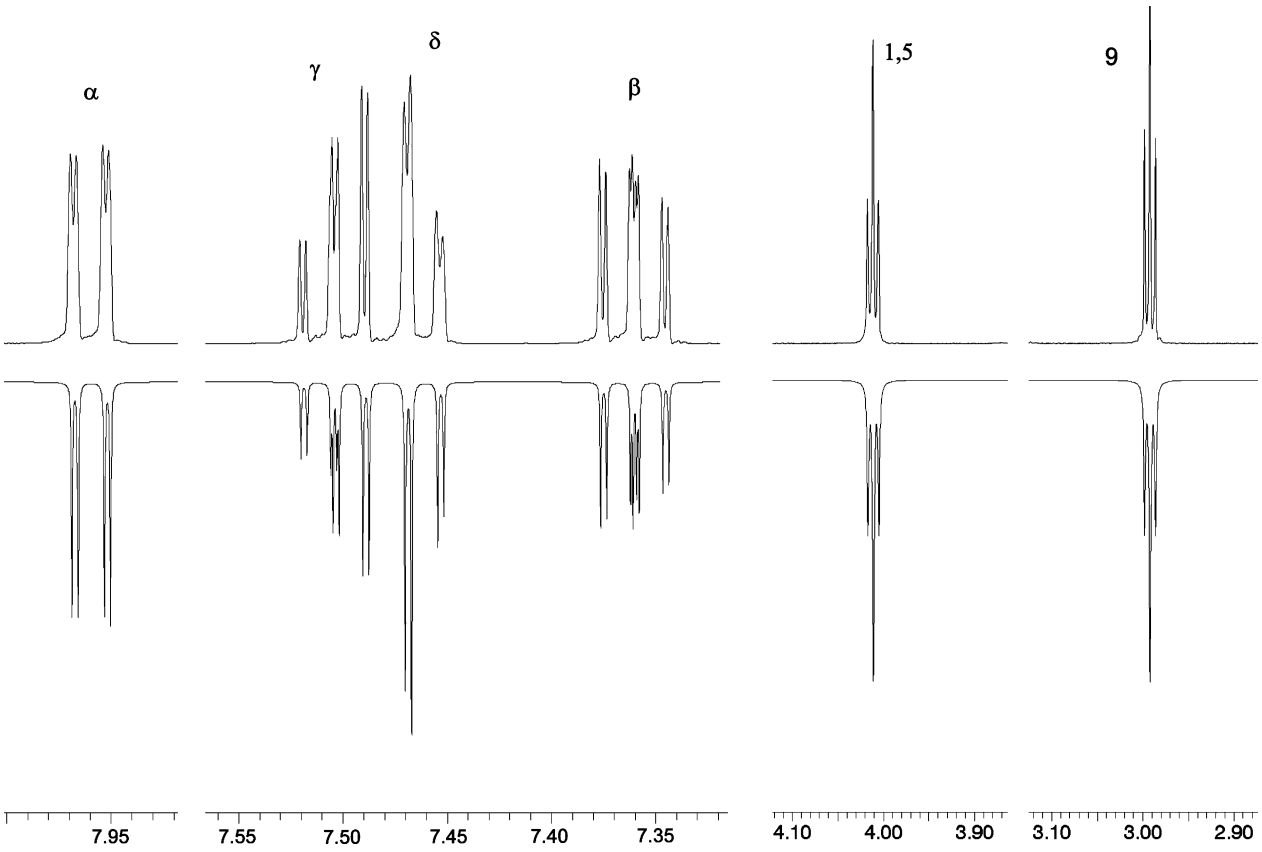


Figure 6. ^{1}H NMR spectra of **1a** in $CDCl_3$ (500 MHz), experimental (above) and calculated by CALM (below).

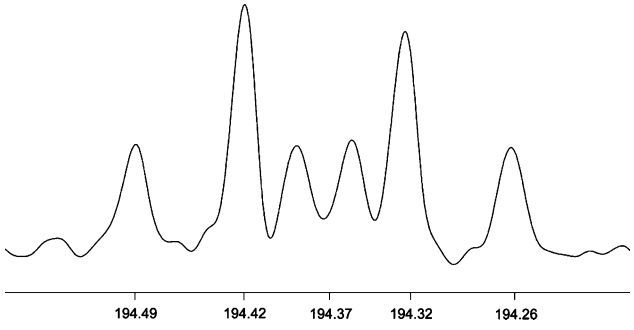


Figure 7. Carbonyl carbon ^{13}C {α-^{1}H} NMR spectrum of **1** ($CDCl_3$): $^{2}J_{C(2,6)H(1,5)}=7.5$ Hz, $^{3}J^{vis}_{C(2,6)H2(9)}=5.0$ Hz ($^{3}J_{CH\text{-}anti}=9$ Hz, $^{3}J_{CH\text{-}syn}=1$ Hz).

3. Conclusion

The rare example of a compound that forms either a racemic compound or a conglomerate of the same composition depending on crystallization conditions has been found. Crystals of the racemic compound can be obtained below 95°C, but higher temperatures induce the formation of the conglomerate. This example presents a possible violation of the 'rule of stability of racemic compounds' developed by A. Collet[2,3] in the temperature range far from the melting points of racemic compounds and enantiomers.

Enantioselective gas chromatography has been successfully used as a test on conglomerate formation for the first time.

The crystal structures of both racemic compound **1a** and conglomerate **1b** have been investigated. It was concluded that small variations in the weak interactions are responsible for such a large difference between melting points of the enantiomerically pure and the racemic crystals ($T_{e-r}=46$°C), whereas crystal densities are practically the same and can not be the determining factor.

4. Experimental

4.1. Synthesis and NMR

4.1.1. 2,3:6,7-dibenzobicyclo[3.3.1]nona-2,6-diene-4,8-dione 1. Compound **1a** was prepared by the modified procedure[18,22] as follows: benzyl cyanide (0.4 mol), diiodomethane (0.2 mol) and powdered sodium hydroxide (0.4 mol) were mixed and heated to 170°C under stirring for 30 min. To the cooled mixture of crude 1,3-diphenylglutarodinitrile (dark oil) dissolved in ethanol (250 ml) was added a solution of potassium hydroxide (105 g) in water (300 ml) and the resulting mixture was heated at 70°C for 20 h. The reaction mixture was

diluted with water (500 ml) and washed with diethyl ether. The aqueous layer was acidified with concentrated hydrochloric acid and extracted with ethyl acetate. The extract was washed with brine, dried over sodium sulfate, and the solvent was removed under reduced pressure. The crude mixture of (±)- and *meso*-1,3-diphenylglutaric acids was obtained as a dark oil. The mixture of acids was dissolved in concentrated sulfuric acid and heated to 85°C with stirring for 1 h. The reaction mixture was poured onto ice and extracted with ethyl acetate. Undissolved solid residue was washed with water and re-crystallized from methanol several times to give pure **1a** as colorless needles. On vacuum-assisted evaporation of ethyl acetate from the extract a colorless solid was obtained which was re-crystallized twice from methanol to yield the second portion of **1a**. The two portions were combined to give 19.3 g of **1a** (mp 146–148°C) NMR spectra were recorded in $CDCl_3$ solutions using Bruker DRX-500 spectrometer. ^{1}H NMR 500 MHz ($CDCl_3$) δ: 2.99 (t, 2H, 9-CH_2, ^3J=3.00 Hz), 4.01 (t, 2H, 1,5-CH, ^3J=3,00 Hz), 7.36 (m, 2H, 2β-H, $^3J_{\alpha\beta}$=7.80 Hz, $^3J_{\beta\gamma}$=7.39, $^4J_{\beta\delta}$=1.24 Hz), 7.46 (m, 2H, 2δ-H, $^3J_{\gamma\delta}$=7.74, $^5J_{\alpha\delta}$<0.4 Hz), 7.50 (m, 2H, 2γ-H, $^4J_{\alpha\gamma}$=1.51 Hz), 7.96 (m, 2H, 2α-H); ^{13}C NMR 125 MHz {^{1}H} ($CDCl_3$) δ: 32.27 (9-C), 48.77 (1,5-C), 128.23 (α-C), 128.72 (β-C), 128.76 (δ-C), 128.80 (3,7-C), 134.44 (γ-C), 140.01 (4,8-C), 194.37 (2,6-C).

4.2. Crystallization and gas chromatography

Optical activities were determined by polarimetry (polarimeter Polamat A). Optical rotations were measured for EtOH solutions at 21–24°C in a 1 dm tube, the observed α_λ varied from 0.03 to 1.2°.

A HRGC 5160 gas chromatograph, equipped with split injector and flame-ionization detector, was used. Hydrogen served as a carrier gas (0.5 bar), in isothermal elution at 130°C. Fused silica capillary column of 0.25 μm film thickness, 2 m×0.25 mm was used (Chrompack, Middelburg, NL). The stationary phase was based on permethylated β-cyclodextrin-6-oct-1-enyl-polydimethylsiloxane (CP-Chirasil-Dex-CB).

The single crystals of **1a** (colorless needles, mp 146–148°C) were obtained by slow evaporation of its near-saturated solutions in various organic solvents at −6, 4, 23°C and from *n*-octane up to 90°C. The best single crystals of **1a** (up to 43.4 mg) were obtained by slow evaporation of an acetone solution of **1** at rt.

The single crystals of **1b** (colorless plates, mp 160–190°C) were obtained by slow evaporation of its near-saturated *n*-octane solution at 100°C and higher. The best single crystals of **1b** (the largest and having the best ee, 98%) were obtained from *n*-octane at 100°C.

4.3. X-Ray analysis

Crystallographic data for **1a** and **1b** were measured on Bruker-AXS SMART 1000 CCD are summarized in Table 2. The data were collected using graphite-monochromated Mo Kα (λ=0.71072 Å, ω-scans with 0.3 step in ω and 10 s exposure per frame). The structures were solved by direct methods and refined in

Table 2. Crystallographic data for **1a** and **1b**

	1a		**1b**
Formula		$C_{17}H_{12}O_2$	
M		248.27	
Crystal system	Triclinic		Orthorhombic
Space group	$P\bar{1}$		$P2_12_12_1$
T (K)	293	120[a]	120
a (Å)	8.068(3)	8.038(5)	8.601(5)
b (Å)	11.309(5)	11.227(5)	11.049(6)
c (Å)	14.891(7)	14.769(7)	12.663(8)
α (°)	102.993(6)	103.47(1)	
β (°)	104.40(1)	105.05(1)	
γ (°)	100.84(1)	101.09(1)	
V (Å)	1238.7(9)	1205.4(11)	1203.3(12)
Z	4/2	4/2	4
F(000)		520	
ρ_{calcd} (g cm^{-1})	1.331	1.368	1.370
Linear absorption μ(cm^{-1})	0.87	0.89	0.89
θ range (°)	1.91–25.55		2.45–26.03
Measured	7488		3436
Unique	4595 (R_{int}=0.0419)		1902 (R_{int}=0.0346)
With [$I>2\sigma(I)$]	2167		1345
$R(F_{hkl})$:R_1	0.0668		0.0402
wR_2	0.1697		0.0924
GOF	0.951		0.891
ρ_{max}/ρ_{min} (e Å^{-3})	0.253/−0.214		0.193/−0.158

[a] Cell dimensions for **1b** at 120 K were measured using 995 reflections with $I>10\sigma(I)$ on SMART 1000 CCD for the purposes of comparison of the density of the homochiral and heterochiral crystals.

anisotropic approximation. The hydrogen atoms were located using Fourier density synthesis and were all included in refinement in isotropic approximation. All calculations were carried out using SHELXTL PLUS 5.1. CCDC 204500 **1a** and 204499 **1b** contain the supplementary crystallographic data for this paper. These data can be obtained free of charge at http://www.ccdc.cam.ac.uk/conts/retrieving.html [or from the Cambridge Crystallographic Data Centre, 12, Union Road, Cambridge CB2 1EZ, UK; fax: (int.) +44-1223/336-033; e-mail: deposit@ccdc.cam.ac.uk].

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References

1. Perez-Garcia, L.; Amabilino, D. B. *Chem. Soc. Rev*. **2002**, *31*, 342–356.
2. Eliel, E. L.; Wilen, S. H.; Mander, L. N. *Stereochemistry of Organic Compounds*; John Wiley and Sons: New York, 1994; pp. 297–464.
3. Jacques, J.; Collet, A.; Wilen, S. H. *Enantiomers, Racemates and Resolutions*; Krieger Publishing Company: Malabar, Florida, 1994.
4. Collet, A.; Ziminski, L.; Garcia, C.; Vigne-Maeder, F. In *Chiral discrimination in Crystalline Enantiomer Systems: Facts, Interpretations and Speculations*; Siegel, J. C., Ed. Supramolecular stereochemistry; NATO ASI Series, Kluwer Academic Publishers: Dordrecht, 1995; pp. 91–110.
5. Collet, A. In *Optical Resolution*; Reinhoudt, D. N., Ed. Comprehensive supramolecular chemistry; Pergamon, 1996; Vol. 10, Chapter 5, pp. 113–149.
6. Collet, A. *Enantiomer* **1999**, *4*, 157.
7. Collet, A.; Vigne-Maeder, F. *New J. Chem*. **1995**, *19*, 877.
8. Collet, A.; Brienne, M.-J.; Jacques, J. *Bull. Soc. Chim. Fr*. **1972**, 127.
9. Kostyanovsky, R. G.; Kadorkina, G. K.; Lyssenko, K. A.; Torbeev, V. Yu.; Kravchenko, A. N.; Lebedev, O. V.; Grintselev-Knyazev, G. V.; Kostyanovsky, V. R. *Mendeleev Commun*. **2002**, *1*, 6–8.
10. Kostyanovsky, R. G.; Lakhvich, F. A.; Philipchenko, P. M.; Lenev, D. A.; Torbeev, V. Yu.; Lyssenko, K. A. *Mendeleev Commun*. **2002**, *4*, 147–149.
11. Ung, A. T.; Bishop, R.; Craig, D. C.; Dance, I. G.; Scudder, M. L. *Tetrahedron* **1993**, *49*, 639.
12. Shiraiwa, T.; Ikawa, A.; Fujimoto, K.; Iwafuji, K.; Kurokawa, H. *Nippon Kagaku Kaishi* **1984**, *5*, 764.
13. May, D.-M. Lu.; Pincock, R. E. *J. Org. Chem*. **1978**, *43*, 601.
14. Labianca, D. A. *J. Chem. Ed*. **1975**, *52*, 156.
15. Jacques, J.; Fouquey, C.; Gabard, J.; Douglas, W. *C. R. Acad. Sci*. **1967**, *265*, 260–262.
16. Grundenberg, A.; Keil, B.; Henck, J. O. *Int. J. Pharm*. **1995**, *118*, 11–21.
17. Stetter, H.; Reischl, A. *Chem. Ber*. **1960**, *93*, 791.
18. Tatemitsu, H.; Ogura, F.; Nakagawa, Y.; Nakagawa, M.; Naemura, K.; Nakazaki, M. *Bull. Chem. Soc. Jpn*. **1975**, *48*, 2473.
19. Naemura, K.; Fukunaga, R. *Chem. Lett*. **1985**, 1651.
20. Naemura, K.; Fukunaga, R.; Yamanaka, M. *J. Chem. Soc., Chem. Commun*. **1985**, 1560.
21. Naemura, K.; Fukunaga, R.; Komatsu, M.; Yamanaka, M.; Chikamatsu, H. *Bull. Chem. Soc. Jpn*. **1989**, *62*, 83.
22. Kostyanovsky, R. G.; Levkin, P. A.; Lyssenko, K. A.; Strelenko, Yu. A.; Golovanov, D. G. *Mendeleev Commun*. **2002**, *6*, 220–222.
23. Schurig, V. *J. Chromatogr. A* **2002**, *965*, 315–356.
24. Li, Z. J.; Zell, M. T.; Munson, E. J.; Grant, D. J. W. *J. Pharm. Sci*. **1999**, *3*, 337–346.
25. Try, A. C.; Painter, L.; Harding, M. M. *Tetrahedron Lett*. **1998**, *39*, 9809.
26. Kimber, M. C.; Try, A. C.; Painter, L.; Harding, M. M.; Turner, P. *J. Org. Chem*. **2000**, *65*, 3042.
27. Wallach, O. *Liebigs Ann. Chem*. **1895**, *286*, 90–143.
28. Larsen, S.; Marthi, K. *Acta Crystallogr*. **1997**, *B53*, 803–811.
29. Kostyanovsky, R. G.; El'natanov, Yu. I.; Chervin, I. I.; Voznesenskii, V. N. *Russ. Chem. Bull*. **1996**, *45*, 991 [*Izv. Akad. Nauk. Ser. Khim*. **1996**, 1037 (in Russian)].
30. Kostyanovsky, R. G.; Lyssenko, K. A.; El'natanov, Yu. I.; Krutius, O. N.; Bronzova, I. A.; Strelenko, Yu. A.; Kostyanovsky, V. R. *Mendeleev Commun*. **1999**, 106.
31. Lenev, D. A.; Lyssenko, K. A.; Kostyanovsky, R. G. *Russ. Chem. Bull*. **2000**, *49*, 1241 [*Izv. Akad. Nauk, Ser. Khim*. **2000**, 1244 (in Russian)].