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Crystal structure and magnetic properties of novel chiral nitroxides existing as racemic conglomerates

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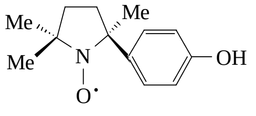
Racemic samples of novel chiral cyclic nitroxides 2-(4-hydroxyphenyl)-2,5,5-trimethylpyrrolidine-1-oxy **1**, *trans*-2-(4-hydroxyphenyl)-2,5-dimethyl-5-phenylpyrrolidine-1-oxy **2** and *trans*-2,5-bis(4-hydroxyphenyl)-2,5-dimethylpyrrolidine-1-oxy **3** having 4-hydroxyphenyl groups on the stereogenic centres adjacent to the NO radical moiety have been found to exist as racemic conglomerates in the crystalline state, and the origin of the conglomerate formation has been studied by X-ray crystallographic analysis and magnetic susceptibility measurements.

The spontaneous resolution of chiral crystals built from achiral compounds or the racemates of chiral compounds in condensed phases is a useful phenomenon especially for the preparation of ordered three-dimensional chiral crystals and liquid crystals.[1]

Here we report that the racemic samples of chiral nitroxides **1**, *trans*-**2** and *trans*-**3** exist as racemic conglomerates in a stable crystalline state, which are very rare for nitroxide radicals.[1–4] Racemic and enantiomerically enriched nitroxides **1**, *trans*-**2** and *trans*-**3** have been prepared analogously to the preparation of *trans*-(±)- and (2*S*,5*S*)-2,5-dimethyl-2,5-diphenylpyrrolidine-1-oxy[5,6] from *trans*-(±)- and (2*R*,5*R*)-2,5-dimethylpyrrolidine, respectively,[7] and recrystallised from Et_2O, $CHCl_3$ and MeOH, respectively. Their thermal, optical and magnetic properties are summarised in Table 1.



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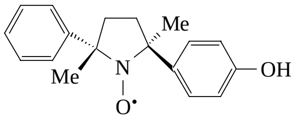
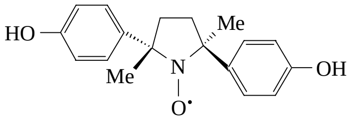


trans-**2**



trans-**3**

Interestingly, as expected from the identity of IR spectra between the enantiomerically enriched material and the racemate, all the racemic samples of **1**, *trans*-**2** and *trans*-**3** have found to exist as not a racemic compound but a rare racemic conglomerate consisting of chiral crystals by X-ray crystallographic ananlysis.[†] They have commonly a head-to-tail type of homochiral supramolecular 1D zigzag chains characterised by strong intermolecular hydrogen bonds between the NO radical and the phenolic OH groups [O···O distances of 2.725(6), 2.752(3) and 2.665(5) Å for **1**, *trans*-**2** and *trans*-**3**, respectively] [Figures 1(*a*), 2(*a*) and 3]. It is easily envisaged that the formation of such a homochiral supramolecular zigzag arrangement along a two-fold screw axis in preference to a centrosymmetric dimer structure in the crystalline state should be due to the *para* disposition of the phenolic OH group.[8]

Since at first glance it was difficult to find out the primary interactions, which control the homochiral packing of the homochiral 1D zigzag chains, *i.e*., the origin of the formation of the racemic conglomerates, the molar magnetic susceptibility χ_{mol} was measured for **1**, *trans*-**2** and *trans*-**3** at the temperatures ranging between 2 and 300 K using a SQUID susceptometer at a field of 0.5 T (Figure 4). This is because the measurement of the temperature dependence of the magnetic susceptibility of molecular magnetic materials often affords useful information

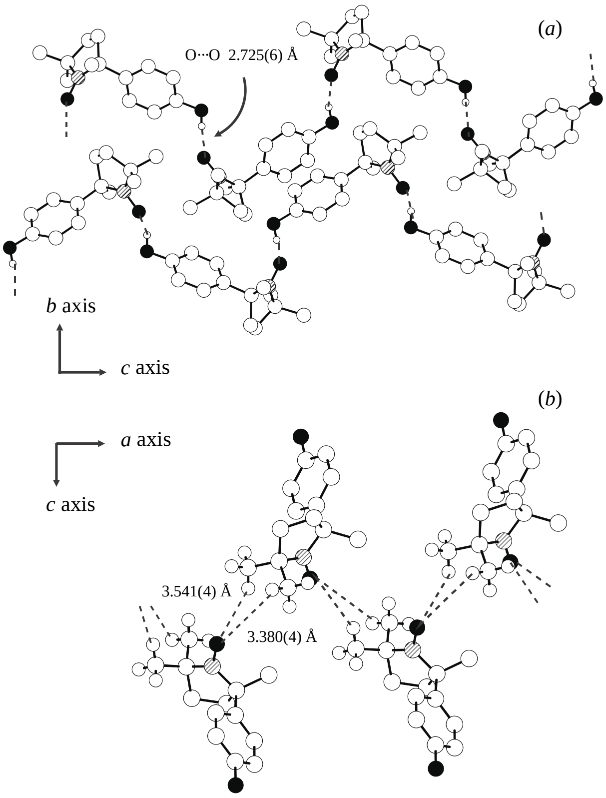


Figure 1 Crystal structure of (±)-**1** viewed down the (*a*) *a* axis and (*b*) *b* axis. The carbon, hydrogen, nitrogen, and oxygen atoms are represented by large open, small open, crosshatched, and closed circles, respectively. Hydrogen atoms except the OH and two methyl groups on the pyrrolidinyl C(5) are omitted.

Table 1 Melting points, specific rotations, EPR *g*-factors and hyperfine coupling constants and magnetic data for nitroxides **1**–**3**.

Compound	mp/°C[a]	ee (%)[b]	$[\alpha]_D^{25\,c}$	EPR[d] *g*	EPR[d] a_N/mT	C^e/emu K mol^{-1}	θ^f/K
(*S*)-**1**	161.7 (decomp.)	88	–118.66	2.0067	1.38	0.38	+0.20
(±)-**1**	151.0 (decomp.)	—	—	2.0073	1.38	0.37	+0.15
(2*S*,5*S*)-**2**	180.8 (decomp.)	97	–202.18	2.0070	1.33	0.37	–0.33
(±)-**2**	168.5 (decomp.)	—	—	2.0070	1.33	0.37	–0.30
(2*S*,5*S*)-**3**	177.2 (decomp.)	97	–187.30	2.0067	1.34	0.38	–0.01
(±)-**3**	173.8 (decomp.)	—	—	2.0080	1.35	0.38	–0.02

[a]Measured by DSC. [b]Determined by HPLC analysis using a chiral stationary phase column (Daicel Chiralcel OD-H, 0.4×25 cm) and a mixture of hexane and propan-2-ol (9:1) as the mobile phase. [c]Measured in THF, *c* 1.00. [d]Measured in THF at 25 °C. [e]Curie constants. [f]Weiss temperature.

on weak intermolecular interactions in the crystal lattice.[9] The racemic sample showed the same magnetic behaviour as the enantiomerically enriched one for each of **1**, *trans*-**2** and *trans*-**3** because of their existence as conglomerates. Three typical magnetic behaviours, such as ferro-, antiferro- and paramagnetic interactions, were observed for **1**, *trans*-**2** and *trans*-**3**, respectively, although the former two were weak (Table 1).

Appearance of a weak ferromagnetic interaction for **1** is consistent with its crystal structure in which the intra- and intermolecular spin polarization exchange coupling can be transmitted ferromagnetically in accord with the McConnell mechanism;[10] *i.e.*, the sandwich-type weak C–H···O···H–C interactions [H···O distances of 3.380(4) and 3.541(4) Å] between the oxygen atom of a NO group and the two methyl groups on the pyrrolidinyl C(5) of the neighbouring molecule giving another homochiral 1D zigzag chain along the *a* axis seems responsible for the weak ferromagnetic interaction [Figure 1(*b*)].[9,11] This zigzag chain along the *a* axis and the foregoing homochiral 1D zigzag chain along the *c* axis formed by strong OH···ON hydrogen bonds are alternately weaved along the *b* axis into the homochiral 3D network structure.[‡]

The observed weak antiferromagnetic behaviour of *trans*-**2** is explained by the dipole–dipole interactions between the NO groups [the shortest O···O distance is 6.399(3) Å] along the *c* axis [Figure 2(*b*)]. The 1D zigzag chains along the *b* axis, which were formed by the O–H···O–N hydrogen bonds, were further connected with one another on the *ab* plane by the C(sp^3)–H···O–N interactions [H···O distance of 2.875(2) Å] between the pyrrolidinyl C(4)Hs of a homochiral chain and the N–O groups of the neighbouring chain to give a sheet structure [Figure 2(*a*)]. Thus, the above dipole–dipole interactions between the NO groups along the *c* axis may be responsible for the homochiral stacking of the homochiral *ab* sheets along the *c* axis.

In the paramagnetic crystals of *trans*-**3**, in which the O···O distance (7.547 Å) between the nearest NO groups was too long to show an antiferromagnetic behaviour, a combination of hydrogen bonds between the neighbouring phenolic OH groups [O···O distance of 2.761(5) Å] with the O–H···O–N hydrogen bonds provides a homochiral 1D ribbon structure along the *c* axis (Figure 3). No appreciable interribbon interaction other than van der Waals interactions was seen. Probably, in this case such a homochiral crystal packing should be energetically favoured over any heterochiral packing of the homochiral 1D zigzag chains.

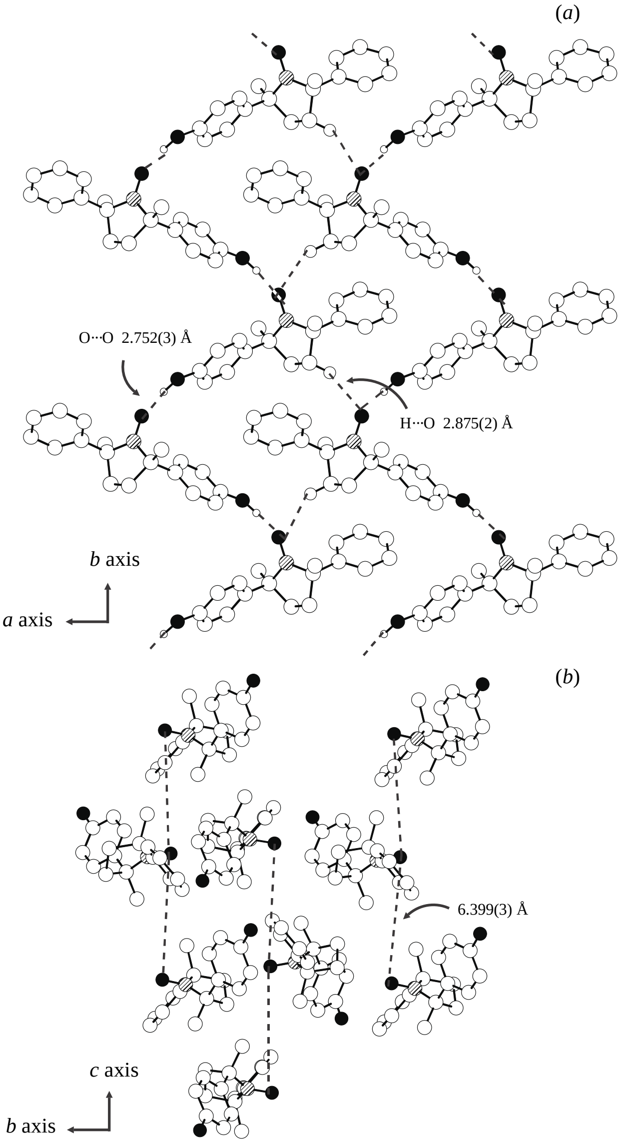


Figure 2 Crystal structure of *trans*-(±)-**2** viewed down the (*a*) *c* axis and (*b*) *a* axis. The carbon, hydrogen, nitrogen, and oxygen atoms are represented by large open, small open, crosshatched, and closed circles, respectively. Hydrogen atoms except the OH group and one hydrogen atom on the pyrrolidinyl C(4) are omitted in (*a*), while all hydrogen atoms are done in (*b*).

Thus, the origin of the conglomerate formation with respect to **1**, *trans*-**2** and *trans*-**3** can be interpreted in terms of strong

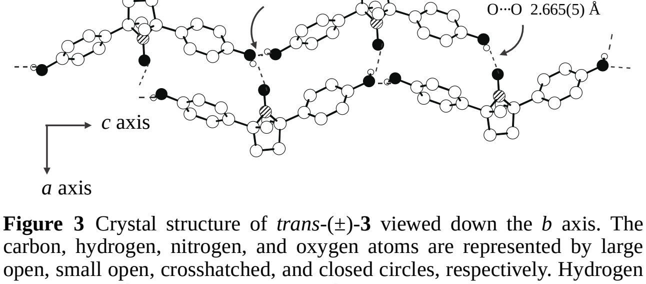


Figure 3 Crystal structure of *trans*-(±)-**3** viewed down the *b* axis. The carbon, hydrogen, nitrogen, and oxygen atoms are represented by large open, small open, crosshatched, and closed circles, respectively. Hydrogen atoms except the OH group are omitted.

[†] The X-ray data were collected at 294 K on an Enraf-Nonius Kapp CCD diffractometer. The crystal structure was solved by the direct methods and refined by full-matrix least squares. All non-hydrogen atoms were refined anisotropically. All of the crystallographic calculations were performed using the maXus software package.[12]

Crystal data for (±)-**1** (conglomerate): $C_{13}H_{18}NO_2$, $M_r = 220.292$, 0.30×0.20×0.13 mm, orthorhombic, space group $P2_12_12_1$, $a = 8.6141(4)$ Å, $b = 10.7211(6)$ Å, $c = 13.4213(6)$ Å, $V = 1239.5(1)$Å^3, $Z = 4$, $d_{calc} =$ = 1.391 g cm^{-3}, $2\theta_{max} = 53.4°$, MoKα ($\lambda = 0.71073$ Å), $\mu = 0.79$ cm^{-1}, ϕ–ω scans, $T = 298$ K, 1517 independent reflections, 945 observed reflections [$I > 2.0\sigma(I)$], 148 refined parameters, $R = 0.066$, $R_w = 0.181$, $\Delta\rho_{max} = 0.239$ eÅ^{-3}, $\Delta\rho_{min} = -0.401$ eÅ^{-3}.

Crystal data for (±)-**2** (conglomerate): $C_{18}H_{20}NO_2$, $M_r = 282.363$, 0.25×0.16×0.10 mm, orthorhombic, space group $P2_12_12_1$, $a = 10.4826(3)$ Å, $b = 11.5410(4)$ Å, $c = 12.5330(4)$ Å, $V = 1516.2(1)$ Å^3, $Z = 4$, $d_{calc} =$ = 1.237 g cm^{-3}, $2\theta_{max} = 55.74°$, MoKα ($\lambda = 0.71073$ Å), $\mu = 0.80$ cm^{-1}, ϕ–ω scans, $T = 298$ K, 2072 independent reflections, 1572 observed reflections [$I > 2.0\sigma(I)$], 193 refined parameters, $R = 0.042$, $R_w = 0.104$, $\Delta\rho_{max} = 0.247$ eÅ^{-3}, $\Delta\rho_{min} = -0.264$ eÅ^{-3}.

Crystal data for (±)-**3** (conglomerate): $C_{18}H_{20}NO_3$, $M_r = 298.362$, 0.25×0.18×0.15 mm, orthorhombic, space groups $P2_12_12_1$, $a = 10.4680(3)$ Å, $b = 10.5485(3)$ Å, $c = 13.5817(5)$ Å, $V = 1499.7(1)$ Å^3, $Z = 4$, $d_{calc} =$ = 1.321 g cm^{-3}, $2\theta_{max} = = 53.41°$, MoKα ($\lambda = 0.71073$ Å), $\mu = 0.90$ cm^{-1}, ϕ–ω scans, $T = 298$ K, 1825 independent reflections, 1070 observed reflections [$I > 2.0\sigma(I)$], 203 refined parameters, $R = 0.046$, $R_w = 0.105$, $\Delta\rho_{max} = 0.247$ eÅ^{-3}, $\Delta\rho_{min} = -0.292$ eÅ^{-3}.

Atomic coordinates, bond lengths, bond angles and thermal parameters have been deposited at the Cambridge Crystallographic Data Centre (CCDC). These data can be obtained free of charge *via* www.ccdc.cam.ac.uk/conts/retrieving.html (or from the CCDC, 12 Union Road, Cambridge CB2 1EZ, UK; fax: +44 1223 336 033; or deposit@ccdc.cam.ac.uk). Any request to the CCDC for data should quote the full literature citation and CCDC reference numbers 204742–204744. For details, see ‘Notice to Authors’, *Mendeleev Commun.*, Issue 1, 2003.

[‡] Contribution of the OH···ON hydrogen bond to the intermolecular spin polarization exchange coupling is considered to be negligible with respect to **1**, *trans*-**2** and *trans*-**3** because the spin densities on the phenolic oxygen and hydrogen atoms have been found to be very low by MO calculations (UHF/6-31G* level using Spartan 02).

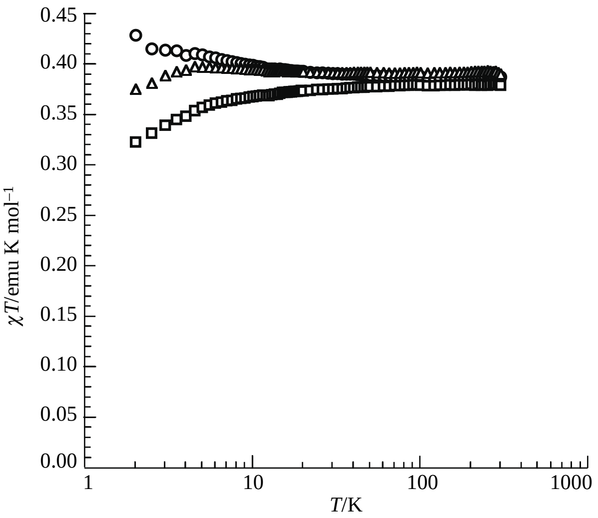


Figure 4 Temperature dependence of the magnetic susceptibility of (*S*)-**1** (represented by circles), *trans*-(2*S*,5*S*)-**2** (squares) and *trans*-(2*S*,5*S*)-**3** (triangles).

intermolecular OH···ON hydrogen bonds together with weak attractive forces such as C(sp^n)H···ON interactions and dipole–dipole interactions between the NO groups.

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