2-Phenyl-3-hydroxyimidazolidin-4-one: the regioselective synthesis, structure and enantiomerically enriched crystallization

Igor V. Vystorop,*[a] Konstantin A. Lyssenko[b] and Remir G. Kostyanovsky[c]

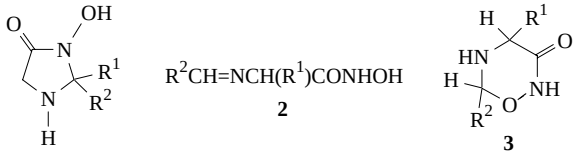
[a] *Institute of Problems of Chemical Physics, Russian Academy of Sciences, 142432 Chernogolovka, Moscow Region, Russian Federation. Fax: +7 096 514 3244; e-mail: vystorop@icp.ac.ru*
[b] *A. N. Nesmeyanov Institute of Organoelement Compounds, Russian Academy of Sciences, 119991 Moscow, Russian Federation. Fax: +7 095 135 5085; e-mail: kostya@xray.ineos.ac.ru*
[c] *N. N. Semenov Institute of Chemical Physics, Russian Academy of Sciences, 119991 Moscow, Russian Federation. Fax: +7 095 938 2156; e-mail: kost@center.chph.ras.ru*

10.1070/MC2003v013n03ABEH001790

The reaction of glycine hydroxamic acid with benzaldehyde regioselectively affords the title racemic cyclic hydroxamic acid, which crystallises as enantiomorphic crystals (space group $P2_12_12_1$) from a methanol solution.

We shown earlier[1(a),(b)] that reactions of glycine hydroxamic acid (GlyHA) with aliphatic ketones proceed as regioselective intramolecular N-aminoalkylation of the hydroxamic group (CONHOH) leading to the formation of five-membered cyclic hydroxamic acids (HAs) **1a–e**. The condensation of GlyHA with acetophenone similarly yields **1f**.[1(b)] According to Charbonnel and Barrans,[2] the reactions of different α-amino HAs with aliphatic and aromatic aldehydes result in the formation of acyclic azomethins **2** or intramolecular (N)-O aminoalkylation products, namely, six-membered cyclic hydroxamates **3**. In particular, the product of GlyHA reaction with benzaldehyde in ethanol (reflux for 1 h) was assigned as azomethine **2a** (R^1 = H, R^2 = Ph; mp 144 °C, 55% yield) based on elemental analysis data and positive test reaction with $FeCl_3$ (in contrast to one with hydroxamates **3**) for the hydroxamic OH group, additionally confirmed by a comparison of the IR spectra (KBr) of **2a** and its monoacylation product.[2]

Because the structure of product **2a** is questionable, taking into account our previous results[1(a),(b)] (*vide supra*), this study was devoted to reinvestigation of product of the reaction of GlyHA with benzaldehyde.

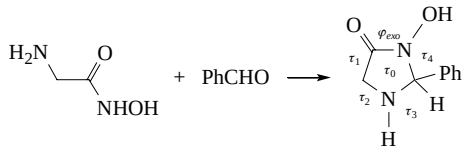


$R^2CH{=}NCH(R^1)CONHOH$ **2**

3

1a $R^1 = R^2$ = Me
1b,**c** $R^1 + R^2 = (CH_2)_4, (CH_2)_5$
(±)-**1d**,**e**,**f** R^1 = Me, R^2 = Et, Bu^t, Ph
R^1 = H, Alk, Ar
R^2 = Alk, Ar

Similarly to **1a–f**, product **5** (Scheme 1)† is a cyclic HA of the imidazolidine series, as established by X-ray diffraction analysis‡ and confirmed by the test reaction with $FeCl_3$ and ^{1}H, ^{13}C NMR data,† which are consistent with published data for **1a–f**.[1(a),(b)]



GlyHA **4** (±)-**5**

Scheme 1

The characteristic features of the molecular structure of HA **5** in a crystal (Figure 1) were revealed by a comparison with its analogues **1a**[1(a)] and **1b**.[1(b)] Firstly, according to the calculated phase angle of pseudorotation (*P*)[1(a),(b),3] the chiral N-type ($\tau_2 > 0$) conformation of heterocycle of (*P*,1*R*,2*S*,3*S*)-enantiomer of **5** (Figure 1) is close (P_N = 52.1°) to the pure envelope $_{C(2)}E$ (P_N = 54°) (Scheme 2) and only slightly differs from the heterocycles of **1a** (P_N = 44.0°)[1(a)] and **1b** (P_N = 43.8°)[1(b)] in a crystalline state, which are intermediate between the terminal forms (Scheme 2). Secondly, according to the amplitude of puckering (τ_m),[1(a),(b),3] the heterocycle of **5** in a crystal is substantially more flattened (τ_m = 7.3°), as compared with those of **1a** (τ_m = 31.4°)[1(a)] and **1b** (τ_m = 33.7°).[1(b)] This observation is supported by the displacements of N(1), C(2), O(1) and O(2) atoms from the N(3)C(4)C(5) plane equal to –0.006, 0.100, 0.189 and 0.026 Å, respectively.

The strong flattening of the heterocycle of **5** in a crystal (Figure 1) corresponds to a decrease of the twist value of the hydroxamic

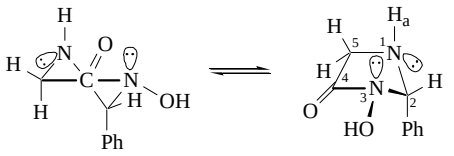
† *Procedure for the synthesis of 2-phenyl-3-hydroxyimidazolidin-4-one* **5**. A suspension of GlyHA **4** (1.80 g, 20 mmol) and benzaldehyde (2.55 g, 24 mmol) in 40 ml of absolute ethanol was refluxed for 1 h. The hot reaction mixture was filtered and cooled to room temperature. The precipitate was filtered off and the solution was evaporated to a small volume. The resulting precipitate was filtered off, then combined with that of earlier obtained and recrystallized from acetonitrile to yield **5** (2.42 g, 68%, mp 147–149 °C) as colourless crystals. Monocrystals of **5** (mp 150–151 °C) for X-ray diffraction analysis‡ and optical activity measurements {$[\alpha]_D^{20}$ +22.2° (*c* 0.68, MeOH), 8.2 mg} were grown from absolute methanol. Compound **4** (GlyHA) was prepared as described previously.[18]

Characteristics and spectroscopic data. The NMR spectra were recorded on Bruker WM-400 and Bruker AC-200 NMR spectrometers at 400.13 (^{1}H) and 50.32 (^{13}C) MHz. The IR spectrum was obtained on a Specord-82M spectrometer. Optical rotation measurements were made on a Perkin–Elmer 341 polarimeter at the D line of sodium (2890 Å).

5, mp 147–149 °C (MeCN). ^{1}H NMR (CD_3OD) δ: 3.44 (d, 1H, CH_AH_B, ^2J 16.1 Hz), 3.62 (d, 1H, CH_AH_B, ^2J 16.1 Hz), 5.36 (s, 1H, C*H*Ph), 7.42 (m, 3H, Ph), 7.47 (m, 2H, Ph). ^{13}C NMR ([$^2H_6$]DMSO) δ: 46.66 (dd, CH_2, ^1J 142.8 Hz, ^1J 143.2 Hz), 77.55 (d, CHPh, ^1J 154.1 Hz), 127.66 (dm, 2C_{Ph}, ^1J 159.1 Hz), 128.60 (dm, 2C_{Ph}, ^1J 160.2 Hz), 129.03 (dm, *p*-C_{Ph}, ^1J 160.9 Hz), 138.87 (m, *i*-C_{Ph}), 171.93 (m, C=O). IR (KBr, ν/cm^{-1}): 3220 (NH), 2908, 2864 (CH_2), 2686 (br.), 2581 (br., OH), 1732 (sh), 1698 (C=O), 1540, 1495, 1460, 1452, 1405, 1384, 1364, 1329, 1284, 1272, 1234, 1208, 1088, 1072, 1050, 1020, 967, 933, 908, 861, 804, 764, 705, 679, 612, 576, 470.

‡ *Crystallographic data for* **5**: at 298 K, the crystals of $C_9H_{10}N_2O_2$ are orthorhombic, space group $P2_12_12_1$, a = 5.734(1) Å, b = 8.987(2) Å, c = = 15.909(3) Å, V = 819.8(3) Å^3, Z = 4, M = 178.19, d_{calc} = 1.444 g cm^{-3}, μ(MoKα) = 1.04 cm^{-1}, F(000) = 376. Intensities of 1403 reflections were measured with a Nonius CAD4 diffractometer at 298 K [λ(MoKa) = = 0.71072 Å, $\theta/2\theta$-scan mode, $2\theta < 60°$], and 1392 independent reflections (R_{int} = 0.0094) were used in a further refinement. The structure was solved by a direct method and refined by the full-matrix least-squares technique against F^2 in the anisotropic–isotropic approximation. Hydrogen atoms were located from the Fourier synthesis and refined in the isotropic approximation. The refinement converged to wR_2 = 0.0929 and GOF = 1.076 for all independent reflections [R_1 = 0.0305 was calculated against F for 1282 observed reflections with $I > 2\sigma(I)$]. All calculations were performed using SHELXTL PLUS 5.0 on IBM PC AT.

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.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 number 214875. For details, see 'Notice to Authors', *Mendeleev Commun.*, Issue 1, 2003.



$^{N(1)}_{C(2)}T$, P_N = 36° $\quad$ $_{C(2)}E$, P_N = 54°

(*P*,1*R*,2*S*,3*S*)-**5**

Scheme 2 Some terminal forms of the heterocycle of **5**.

fragment (φ_{exo} = 7.8°) in comparison with the molecules of **1a** (φ_{exo} = 19.3°)[1(*a*)] and **1b** (φ_{exo} = 17.9°)[1(*b*)] but retains the sign of this skew ($\varphi_{exo} > 0$) observed[1(*a*),(*b*)] for the P_N-type of enantiomeric form of heterocycle. Together with the simultaneous decrease of the opposite sign endocyclic dihedral angle (τ_0 = = –4.4°) of **5**, as compared with its analogues **1a** (τ_0 = –14.9°)[1(*a*)] and **1b** (τ_0 = –15.6°),[1(*b*)] this leads to the almost full planarity of the amide N(3) atom [$\Sigma\omega$ N(3) = 358.6°; the height of its very shallow pyramid is equal to 0.097 Å] in contrast to the expressed non-planarity of N(3) atoms in the molecules of **1a** (350.8°, 0.250 Å)[1(*a*)] and **1b** (350.9°, 0.247 Å)[1(*b*)] in crystals. The planarization of the amide group in **5** is accompanied by the enforcing of the amide n_N–π*(C=O) conjugation that results in a change in the N(3)–C(4), C(2)–N(3) and C(2)=O(4) bond lenghts (Figure 1, *cf.* for **1a**,**b**[1(*a*),(*b*)]), which are almost equal to the averaged lengths of the corresponding bonds [1.335 Å (C_{sp^2}–N), 1.455 Å (C_{sp^3}–N) and 1.232 Å (C=O)][4] of γ-lactams in a crystalline state. Moreover, the noticeable shortening of the C(2)–N(3) bond (1.455 Å) in the molecule of **5** in comparison with the molecules of **1a** (1.484 Å)[1(*a*)] and **1b** (1.474 Å)[1(*b*)] corresponds to a diminution of the $n_{N(1)}$–σ*[C(2)–N(3)] interaction[5] {φ[LP$_{N(1)}$N(1)C(2)N(3)] = –128.5°}, as compared to **1a** (–152.5°)[1(*a*)] and **1b** (–157°).[1(*b*)] The decrease of the piramidality of the amine N(1) atom [$\Sigma\omega$ N(1) = 324.5°] of HA **5** is also observed in comparison with HAs **1a** (317.2°)[1(*a*)] and **1b** (315°).[1(*b*)]

In all the three crystal structures of compounds **1a**,[1(*a*)] **1b**[1(*b*)] and **5** (Figure 2), strong O(1)–H(10)···N(1) and weak[6] N(1)–H(1N)···O(2) intermolecular hydrogen bondings are formed. Another hydrogen bonding of the C(10)–H(10)···O(2) type[7] is also formed between the molecules of **5** (Figure 2).

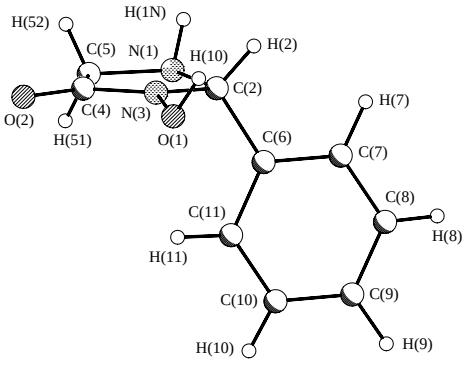


Figure 1 Molecular structure of hydroxamic acid **5** [the absolute configuration is unknown and illustrated by (*P*,1*R*,2*S*,3*S*)-enantiomer]. Selected bond lengths (Å): O(1)–N(3) 1.381(2), N(1)–C(2) 1.479(2), N(1)–C(5) 1.475(2), O(2)–C(4) 1.225(2), C(2)–N(3) 1.455(2), C(2)–C(6) 1.512(2), N(3)–C(4) 1.335(2), C(4)–C(5) 1.503(2); selected bond and dihedral angles (°): C(2)–N(1)–C(5) 108.7(1), N(1)–C(2)–N(3) 102.6(1), N(1)–C(2)–C(6) 112.5(1), N(3)–C(2)–C(6) 113.4(1), O(1)–N(3)–C(2) 120.5(1), O(1)–N(3)–C(4) 122.1(1), C(2)–N(3)–C(4) 116.0(1), O(2)–C(4)–N(3) 127.2(1), O(2)–C(4)–C(5) 126.5(1), N(3)–C(4)–C(5) 106.3(1), N(1)–C(5)–C(4) 106.1(1), C(2)–C(6)–C(7) 117.9(1), C(2)–C(6)–C(11) 122.3(1); H(10)–O(1)–N(3)–C(2) 74.0, H(10)–O(1)–N(3)–C(4) –120.3, H(1N)–N(1)–C(2)–N(3) 109.8, C(5)–N(1)–C(2)–N(3) (τ_3) –6.6(1), C(5)–N(1)–C(2)–C(6) 115.7(1), H(1N)–N(1)–C(5)–H(51) 132.3, H(1N)–N(1)–C(5)–H(52) 8.3, C(2)–N(1)–C(5)–C(4) (τ_2) 4.5(1), N(1)–C(2)–N(3)–O(1) 173.6(1), N(1)–C(2)–N(3)–C(4) (τ_4) 7.0(1), C(6)–C(2)–N(3)–O(1) 51.9(1), C(6)–C(2)–N(3)–C(4) –114.6(1), N(1)–C(2)–C(6)–C(7) 94.3(1), N(1)–C(2)–C(6)–C(11) –82.0(2), N(3)–C(2)–C(6)–C(7) –149.8(1), N(3)–C(2)–C(6)–C(11) 33.9(2), O(1)–N(3)–C(4)–O(2) (φ_{exo}) 7.8(2), O(1)–N(3)–C(4)–C(5) –170.7(1), C(2)–N(3)–C(4)–O(2) 174.1(1), C(2)–N(3)–C(4)–C(5) (τ_0) –4.4(2), O(2)–C(4)–C(5)–N(1) –178.8(1), N(3)–C(4)–C(5)–N(1) (τ_1) –0.2(1), C(2)–C(6)–C(7)–C(8) –176.1(1), C(2)–C(6)–C(11)–C(10) 175.4(1).

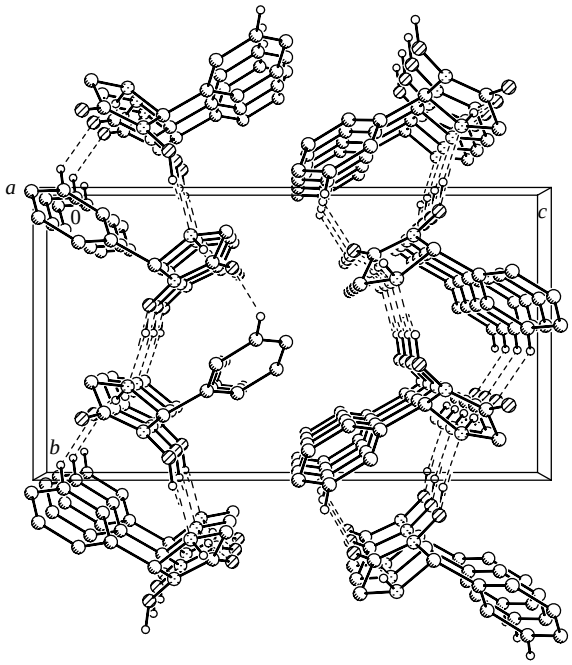


Figure 2 Fragment of homochiral layers consisting of alternate antiparallel translational columns in the crystal structure of **5**. Hydrogen atoms without H-bondings are omitted for clarity. H-bondings are shown by dashed lines. The geometric parameters of H-bondings are as follows: H(1O)···N(1) 1.835 Å, O(1)···N(1) 2.726 Å, O(1)–H(1O)···N(1) 169.3°; H(1N)···O(2) 1.977 Å, N(1)···O(2) 2.883 Å, N(1)–H(1N)···O(2) 165.0°; H(10)···O(2) 2.352 Å, C(10)···O(2) 3.325 Å, N(1)–H(1N)···O(2) 149.1. [The symmetry transformation used to generate the atoms N(1) (–*x* + 1, *y* + 1/2, –*z* + 1/2), O(2) (*x* + 1, *y*, *z*) and O(2) (–*x*, –0.5 + *y*, –*z*)].

The space group of **5** is chiral ($P2_12_12_1$, Z = 4)‡ to reveal the enantiomorphic nature of crystals similarly to formally achiral monocyclic HA **1a** ($P2_12_12_1$, Z = 4)[1(*a*)] but as opposed to spiro cyclic HA **1b** ($P2_1/n$, Z = 4).[1(*b*)]

Moreover, according to the polarimetric monitoring of the optical activity of a monocrystal† of a dextrorotatory enantiomer of **5**, the reaction rate of its racemization in methanol at 20 °C is high ($t_{1/2} \approx$ 1 h). Together with the chiral nature of crystals of **5**, this another 'necessary' condition of 'spontaneous asymmetric synthesis'[8(*a*)] enabled us to attempt the spontaneous enantiomerically enriched crystallization of **5** from a methanol solution.

Really, in both of the trials,§ the precipitates were optically active as a whole and 17% and 37% enantiomerically enriched. Their optical yields correspond to the well-known dependence on the duration of nucleation or crystal growth.[8,9] The solids obtained by quick evaporation of both mother liquors show the absence of optical activity confirming that the above crystallizations of **5** occurred under conditions of more rapid racemization than crystal growth.

Note that the way in which the solutions of **5** for crystallization have been performed,§ namely careful filtering followed

§ *The crystallization of* **5** *was performed as follows*: a hot solution of a racemic modification of **5** in absolute methanol [400 mg/5 ml (trial *a*) or 400 mg/10 ml (trial *b*)] was filtered through synthetic cotton wool into a round-bottom flask. The filtrate was heated to boiling; the flask was closed with a stopper and allowed to stand without stirring at room temperature (18–20 °C) to give the crystals of **5** from the supersaturated solution. The time during which the first crystals appeared [10 h (*a*) or 4 days (*b*)] was marked. After a time [7 h (*a*) or 3 days (*b*)], the precipitate was filtered off, washed with a small volume of cold acetonitrile and dried *in vacuo* at room temperature. The solid obtained [245 mg, 61.3% conversion (*a*) or 170 mg, 42.5% (*b*)] was carefully ground and mixed up. Then, it was studied polarimetrically {$[\alpha]_D^{20}$ +3.8° (*c* 1.0, MeOH) or $[\alpha]_D^{20}$ –8.2° (*c* 1.0, MeOH), respectively}. The optical yield of the precipitate [17.1% (*a*) or 36.9% (*b*)] was calculated by comparing its specific rotation with that of the monocrystal.†

by heating the solution to boiling prevents from inadvertent seeding or crystalline dust. In addition, the opposite signs of the optically active precipitates§ obtained show the random generation of their handedness.

Owing to the enantiomeric enrichment of crystalline **5** produced in unstirred crystallization,§ the human intervention to the crystallization procedure, namely, as stirring[8(*b*),9] or seeding,[10] may presumably substantially increase the optical purity of the solid.

This type of preferential crystallization of one enantiomer from a racemic mixture under conditions of simultaneous asymmetric transformation of the other enantiomer in the solution is known as a second order[11,12] (crystallization-induced[10–12]) asymmetric transformation. This process has frequently taken place for diastereomers[10,11] but was represented by rare cases of non-provoked crystallization of enantiomers.[8,12,13] In our case, the synthesis of racemate **5** from achiral substrates and its enantiomerically enriched crystallization occur without the deterministic influence of any chiral agent. Therefore, this process is an example of an absolute asymmetric synthesis.[15]

Taking into account the existence of several types[16] of chirality in the molecule of **5**, namely, the N(1), C(2) and N(3) asymmetric centres, the spiral chirality of the hydroxamic fragment, and the handedness of heterocycle conformation, compound **5** can theoretically exist as at least 16 diastereomeric pairs of enantiomers. However, the spiral chirality of the hydroxamic group and the configuration of the N(3) amide atom are related to the heterocycle conformation chirality, whose interconversion and the inversion of the configuration of the N(1) centre proceed in solution much faster than the epimerization of the C(2) centre. Thus, the possible presence of several diastereomers of **5** in solution has no influence upon kinetically controlled crystallization as pairs of (*P*,1*R*,2*S*,3*S*)- and (*M*,1*S*,2*R*,3*R*)-enantiomers.

The enantiomeric enrichment during the spontaneous crystallization of **5** under conditions of simultaneous racemization in methanol can be best interpreted by the stereospecific autocatalysis model.[8(*a*),14,15(*a*),17]

Thus, we found that the condensation of GlyHA with benzaldehyde similarly to that with ketones,[1(*a*),(*b*)] yields a cyclic hydroxamic acid of the imidazolidine series rather than an acyclic azomethine.[2] It can be assumed that the regioselective N,N′-cyclocondensation is common to the reactions of GlyHA with ketones and aldehydes.

Moreover, we expanded the range[8,12,13] of racemic compounds capable of chiral symmetry breaking by spontaneous crystallization and present a further example of a heterogeneous absolute asymmetric synthesis having an implication toward the origin of homochirality in the biosphere.[14,15,17]

This work was supported by the Russian Foundation for Basic Research (grant nos. 03-03-32019 and 00-03-81187 BEL) and INTAS (grant no. 99-0157).

References

1 (*a*) I. V. Vystorop, K. A. Lyssenko and R. G. Kostyanovsky, *Mendeleev Commun*., 2002, 85; (*b*) I. V. Vystorop, K. A. Lyssenko, V. N. Voznesensky, V. P. Lodygina and R. G. Kostyanovsky, *Mendeleev Commun*., 2002, 193.

2 J. Charbonnel and J. Barrans, *Compt. Rend*., 1966, **263C**, 824.

3 C. Altona and M. Sundaralingam, *J. Am. Chem. Soc*., 1972, **94**, 8205.

4 (*a*) F. H. Allen, O. Kennard, D. G. Watson, L. Brammer, A. G. Orpen and R. Taylor, *J. Chem. Soc., Perkin Trans. 2*, 1987, no. 12, Suppl. 1; (*b*) L. Nórskov-Lauritsen, H.-B. Bürgi, P. Hofmann and H. R. Schmidt, *Helv. Chim. Acta*, 1985, **68**, 76.

5 (*a*) S. A. Glover and A. Rauk, *J. Org. Chem*., 1999, **64**, 2340; (*b*) G. Cuevas and E. Juaristi, *J. Am. Chem. Soc*., 2002, **124**, 13088.

6 (*a*) R. Taylor and O. Kennard, *Acc. Chem. Res*., 1984, **17**, 320; (*b*) A. Lautie, F. Froment and A. Novak, *Spectrosc. Lett*., 1976, **9**, 289.

7 (*a*) G. R. Desiraju, *Acc. Chem. Res*., 1996, **29**, 441; (*b*) T. Steiner, *Chem. Commun*., 1997, 727.

8 (*a*) E. Havinga, *Biochim. Biophys. Acta*, 1954, **13**, 171; (*b*) R. G. Kostyanovsky, V. R. Kostyanovsky, G. K. Kadorkina and K. A. Lyssenko, *Mendeleev Commun.*, 2001, 1.

9 (*a*) D. K. Kondepudi, R. J. Kaufman and N. Singh, *Science*, 1990, **250**, 975; (*b*) D. K. Kondepudi, K. L. Bullock, J. A. Digits and P. D. Yarborough, *J. Am. Chem. Soc*., 1995, **117**, 401; (*c*) J. M. McBrige and R. L. Carter, *Angew. Chem., Int. Ed. Engl*., 1991, **30**, 293.

10 J. Jacques, A. Collet and S. H. Wilen, *Enantiomers, Racemates, and Resolutions*, Krieger, Malabar, Florida, 1994, pp. 369–377.

11 (*a*) M. M. Harris, *Prog. Stereochem*., 1958, **2**, 157; (*b*) E. E. Turner and M. M. Harris, *Q. Rev. Chem. Soc.*, 1947, 299; (*c*) R. Kuhn, *Ber*., 1932, **65**, 49.

12 E. L. Eliel, S. H. Wilen and L. N. Mander, *Stereochemistry of Organic Compounds*, Wiley, New York, 1994, pp. 315–322.

13 Y. Okada, T. Takebayashi, M. Hashimoto, S. Kasuga, S. Sato and C. Tamura, *J. Chem. Soc., Chem. Commun*., 1983, 784.

14 (*a*) W. A. Bonner, *Top. Stereochem*., 1988, **18**, 1; (*b*) S. R. Mason, *Chem. Soc. Rev*., 1988, **17**, 347.

15 (*a*) B. L. Feringa and R. A. van Delden, *Angew. Chem., Int. Ed. Engl*., 1999, **38**, 3418; (*b*) M. Avalos, R. Babino, P. Cintas, J. L. Jiménez, J. C. Palacios and L. D. Barron, *Chem. Rev*., 1998, **98**, 2391; (*c*) M. Sakamoto, *Chem. Eur. J*., 1997, **3**, 684; (*d*) B. S. Green, M. Lahav and D. Rabinovich, *Acc. Chem. Res*., 1979, **12**, 191.

16 R. S. Chan, C. K. Ingold and V. Prelog, *Angew. Chem., Int. Ed. Engl*., 1966, **5**, 385.

17 (*a*) H. Buschmann, R. Thede and D. Heller, *Angew. Chem., Int. Ed. Engl*., 2000, **39**, 4033; (*b*) V. Avetisov and V. Goldanskii, *Proc. Natl. Acad. Sci. USA*, 1996, **93**, 11435; (*c*) B. S. Green and L. Heller, *Science*, 1974, **185**, 525.

18 K. G. Cunningham, G. T. Newbold, F. S. Spring and J. Stark, *J. Chem. Soc*., 1949, 2091.

Received: 30th April 2003; Com. 03/2116