1997, *36*, 1725; e) K. N. Power, T. L. Hennigar, M. J. Zaworotko, *New J. Chem.* **1998**, 177.
[8] J.-L. Weidmann, J.-M. Kern, J.-P. Sauvage, D. Muscat, S. Mullins, W. Köhler, C. Rosenauer, H. J. Räder, K. Martin, Y. Geerts, *Chem. Eur. J.* **1999**, *5*, 1841, and references therein.
[9] A. J. Blake, N. R. Champness, A. Khlobystow, D. A. Lenenovkii, W.-S. Li, M. Schröder, *Chem. Commun.* **1997**, 2027.
[10] a) M. Fujita, Y. J. Kwon, O. Sasaki, K. Yamaguchi, K. Ogura, *J. Am. Chem. Soc.* **1995**, *117*, 7287; b) L. Carlucci, G. Ciani, D. M. Proserpio, *J. Chem. Soc. Dalton Trans.* **1999**, 1799; c) Y.-B. Dong, R. C. Layland, M. D. Smith, N. G. Pschirer, U. H. F. Bunz, H.-C. zur Loye, *Inorg. Chem.* **1999**, *38*, 3056.
[11] M.-L. Tong, X.-M. Chen, B.-H. Ye, L.-N. Ji, *Angew. Chem.* **1999**, *111*, 2376; *Angew. Chem. Int. Ed.* **1999**, *38*, 2237.
[12] a) F.-Q. Liu, T. D. Tilley, *Inorg. Chem.* **1997**, *36*, 5090; b) L. Carlucci, G. Ciani, P. Macchi, D. M. Proserpio, S. Rizzato, *Chem. Eur. J.* **1999**, *5*, 237.
[13] These topological properties apply also to systems based on the inclined interpenetration of 2D layers (examples are given in ref. [3], sect. 3.2) and even to the remarkable polyrotaxane reported in: B. F. Hoskins, R. Robson, D. A. Slizys, *J. Am. Chem. Soc.* **1997** *119*, 2952.
[14] Crystal data for **1**: $C_{108}H_{185}Cu_5N_{16}O_{52.5}S_5$, monoclinic, space group $P2_1/c$ (no. 14), $a = 27.774(2)$, $b = 17.752(1)$, $c = 30.147(2)$ Å, $\beta = 109.22(1)^\circ$, $V = 14035(2)$ Å^3, $Z = 4$, $\rho_{calcd} = 1.432$ mg m^{-3}, $R = 0.0657$ for 15358 independent reflections [$I > 2\sigma(I)$]. The data collections were performed at 223 K on a Bruker SMART CCD area-detector diffractometer, using $Mo_{K\alpha}$ radiation ($\lambda = 0.71073$ Å) using the ω-scan method within the limits $1 < \theta < 25^\circ$. Empirical absorption corrections (SADABS) were applied. The structure was solved by direct methods (SIR97) and refined by full-matrix least-squares on F^2 (SHELX-97). Anisotropic thermal factors were assigned to all the nonhydrogen atoms except the water molecules with half occupancy. All diagrams were generated using the SCHAKAL 97. Crystallographic data (excluding structure factors) for the structure reported in this paper has been deposited with the Cambridge Crystallographic Data Centre as supplementary publication no. CCDC-136800. Copies of the data can be obtained free of charge on application to CCDC, 12 Union Road, Cambridge CB2 1EZ, UK (fax: (+44) 1223-336-033; e-mail: deposit@ccdc.cam.ac.uk).
[15] Analysis of the holes was performed with the PLATON program (A. L. Spek, PLATON, Utrecht University, **1999**). The representation of the surfaces of the cavities was obtained with SURFNET; R. A. Laskowski, *J. Mol. Graph.* **1995**, *13*, 323.
[16] Refinement of the unit cell parameters on the XRPD spectra at room temperature gave $a = 28.06$, $b = 17.68$, $c = 30.88$ Å, $\beta = 109.1^\circ$, and $V = 14476$ Å^3. The increased dimensions with respect to the single crystal data at 223 K can be attributed mainly to thermal expansion.
[17] Differential scanning calorimetry (DSC) analysis shows a broad exothermic peak (40–120 °C) with its maximum at 90 °C and a minor complex event at 160–190 °C..
[18] Exchange with other polar solvents (methanol, acetonitrile) has also been successful. Samples of **1** dried at 100 °C and left in the presence of vapors of the polar solvent gave rather different XRPD spectra but after desolvation and rehydration with water vapors again show the original spectrum.
[19] This contrasts with that observed in the (reversible) desolvation of a recently reported hydrogen-bonded framework compound of remarkable flexibility that transforms into a second (dehydrated) monocrystalline form:C. J. Kepert, D. Hesek, P. D. Beer, M. J. Rosseinsky, *Angew. Chem.* **1998**, *111*, 3335; *Angew. Chem. Int. Ed.* **1998**, *37*, 3158.
[20] The nonrigidity of catenated networks with flexible ligands is confirmed by a 3D array of interpenetrated ladders that expands by enclathration of *p*-dibromobenzene while maintaining the same topology: M. Fujita, O. Sasaki, K.-Y. Watanabe, K. Ogura, K. Yamaguki, *New J. Chem.* **1998**, 189.

Asymmetric Synthesis of an Organic Compound with High Enantiomeric Excess Induced by Inorganic Ionic Sodium Chlorate**

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Recent progress in asymmetric synthesis has been made by the developments of both organic asymmetric catalysts and stoichiometric organic chiral auxiliaries.[1] The origin of significant enantiomeric enrichments in organic compounds such as L-amino acids on the earth has been an intriguing puzzle.[2] One of the proposed mechanisms for the enantiomeric enrichments of organic compounds is through asymmetric synthesis and/or subsequent asymmetric adsorption[3] on the surface of inorganic enantiomorphic crystals. We recently reported an enantioselective synthesis of an organic compound promoted by chiral quartz,[4] which is an enantiomorphic inorganic molecule with covalent bonds between the silicon and oxygen atoms.

On the other hand, sodium chlorate ($NaClO_3$) is an enantiomorphic inorganic ionic crystal.[5] Kondepudi et al. reported that almost all of the $NaClO_3$ crystals precipitated from a stirred particular solution have the same chirality.[6, 7] However, the relevance of the chirality of $NaClO_3$ to that of an organic compound was not established. An earlier report[8] on the enantioselective adsorption of racemic compounds by $NaClO_3$ was disproved by the later examination of Gillard and da Luz de Jesus.[9] Thus, the question has remained as to whether significantly enantiomerically enriched organic compound can be formed using chiral $NaClO_3$, an inorganic ionic crystal.

Herein we report an unprecedented highly enantioselective synthesis of an organic compound which is induced by *d*- or *l*-$NaClO_3$ crystals. The enantioselective addition of diisopropylzinc (*i*Pr_2Zn) to 2-(*tert*-butylethynyl)pyrimidine-5-carbaldehyde (**1**) in the presence of *d*- or *l*-$NaClO_3$ powder gave pyrimidylalkanol **2** with high *ee* values (96–98% *ee*) in high yields (90–99%; Scheme 1, Table 1).

The (*S*)-pyrimidylalkanol (*S*)-**2** was obtained with 98% *ee* in 93% yield when *i*Pr_2Zn was added to the mixture of *d*-$NaClO_3$ and aldehyde **1** (Entry 1). The reaction is reproducible (Entries 2 and 3). On the other hand, reactions between aldehyde **1** and *i*Pr_2Zn in the presence of *l*-$NaClO_3$, instead of *d*-$NaClO_3$, always gave (*R*)-**2** with 98% *ee* in yields of 91–98% (Entries 4–6). When the reactions were run sequentially in the presence of *d*-, *l*-, *d*-, and *l*-$NaClO_3$, using exactly the same reaction equipments, (*S*)-, (*R*)-, (*S*)-, and (*R*)-**2** with

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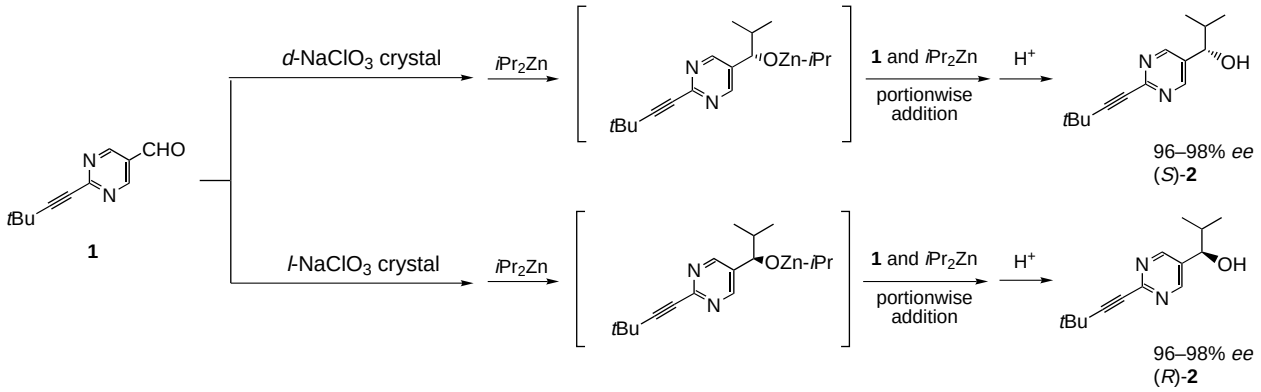

Scheme 1. Enantioselective synthesis of **2** in the presence of $NaClO_3$.

Table 1. Enantioselective synthesis of pyrimidylalkanol **2** in the presence of *d*- and *l*-$NaClO_3$.

Entry[a]	$NaClO_3$	Pyrimidylalkanol **2**	
		yield [%]	ee [%] (config.)[b]
1	*d*	93	98 (*S*)
2	*d*	99	98 (*S*)
3	*d*	90	97 (*S*)
4	*l*	91	98 (*R*)
5	*l*	95	98 (*R*)
6	*l*	98	98 (*R*)
7[c]	*d*	93	96 (*S*)
8[c]	*l*	94	96 (*R*)
9[c]	*d*	93	96 (*S*)
10[c]	*l*	94	96 (*R*)
11	*d*/*l* (3/1)	92	97 (*S*)
12	*l*/*d* (3/1)	90	97 (*R*)

[a] $NaClO_3$/**1**/iPr_2Zn = 1.9/1.0/2.0. See also Experimental Section. [b] The *ee* value was determined by HPLC analysis on a column fitted with a chiral stationary phase (Chiralcel OD). [c] Reactions were carried out sequentially in the order of the entry numbers using the same equipment.

96% *ee* were obtained, respectively, in 93–94% yields (Entries 7–10). These results clearly show that the chirality of $NaClO_3$ controls the absolute configuration of the newly formed alkanol **2**.

The corresponding reactions in the presence of the mixture of *d*- and *l*-$NaClO_3$ were also examined. When the 3/1 mixture of *d*- and *l*-$NaClO_3$ was used, (*S*)-**2** was obtained in 92% yield with 97% *ee* (Entry 11). The reaction using a 1/3 mixture of *d*- and *l*-$NaClO_3$, afforded (*R*)-**2** with 97% *ee* (Entry 12). Thus, the final configuration of **2** formed is dependent on the major enantiomorphs of $NaClO_3$ in the mixture.

The very high enantioselectivity observed in the present asymmetric reaction may be explained as follows: Chiral $NaClO_3$[5b] induces a very small enantiomeric enrichment in the alkanol **2** that is initially formed from aldehyde **1** and iPr_2Zn.[10] The subsequent asymmetric autocatalysis[11] of **2** with amplification of *ee* then automultiplies **2** to afford the alkanol **2** possessing the corresponding absolute configurations with high *ee* values in high yields. Further mechanistic details are now under investigation.

In summary, we have demonstrated for the first time that a chiral inorganic ionic crystal, namely *d*- or *l*-$NaClO_3$, induces asymmetry in the highly enantioselective synthesis of an organic compound. Thus, the present reaction correlates the chirality of $NaClO_3$ with the absolute configuration of an organic compound.

Experimental Section

Preparation of crystals and powders of *d*- or *l*-$NaClO_3$: Recrystallization of $NaClO_3$ from water gave small crystals. A small crystal was put in an aqueous solution of $NaClO_3$ at room temperature, and the mixture was left until the size of the crystal reached over 5 mm. The chirality of the crystal was determined by polarimetry.[12] Crystals of *d*-$NaClO_3$ were ground into a powder using a pestle and mortar (particle size: 5–12 μm), washed with diethyl ether, and dried in vacuo before use.

Typical experimental procedure (Table 1, Entry 2): A 1M solution of iPr_2Zn in toluene (0.15 mL) was added dropwise with stirring (60–70 rpm) over 30 min to a suspension of aldehyde **1**[13] (9.4 mg, 0.05 mmol) and *d*-$NaClO_3$ (222 mg, 2.09 mmol) in toluene (0.2 mL) at 0 °C. After the mixture had stirred for 12 h, toluene (4.8 mL), a 1M solution of iPr_2Zn in toluene (0.4 mL), and a solution of **1** (37.6 mg, 0.2 mmol) in toluene (1.5 mL) were added successively. After 3 h, toluene (14 mL), a 1M solution of iPr_2Zn in toluene (1.6 mL), and a solution of **1** (151 mg, 0.8 mmol) in toluene (4 mL) were added and the mixture was stirred for a further 3 h. The reaction was quenched by adding 1M hydrochloric acid (4 mL) and then made alkaline with saturated aqueous sodium bicarbonate (12 mL). The mixture was filtered through celite, and the separated aqueous layer was extracted with ethyl acetate. The combined organic layer was dried over sodium sulfate and concentrated. Purification of the residue by thin layer chromatography on silica gel(hexane/ethyl acetate 2/1) gave **2** (242 mg, 1.04 mmol, 99%). $[\alpha]_D^{28} = -33.1$ ($c = 2.21$, $CHCl_3$). The *ee* value was determined as 98% by HPLC analysis on a column with a chiral stationary phase (Daicel Chiralcel OD, eluent 3% 2-propanol in hexane, flow rate 1.0 mL min^{-1}, UV detector at 254 nm, retention time: 18 min for (*S*)-**2**, 27 min for (*R*)-**2**).

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[1] a) Asymmetric Synthesis (Eds.: T. Hayashi, K. Tomioka, O. Yonemitsu), Kodansha, Tokyo, **1998**; b) Comprehensive Asymmetric Catalysis (Eds.: E. R. Jacobsen, A. Pfaltz, H. Yamamoto), Springer, Berlin, **1999**; c) Catalytic Asymmetric Synthesis, 2nd ed. (Ed.: I. Ojima), Wiley, New York, in press.

[2] a) W. A. Bonner, *Origins Life Evol. Biosphere* **1991**, *21*, 59; b) A. Eschenmoser, *Science* **1999**, *284*, 2118; c) A. G. Cairns-Smith, *Chem. Brit.* **1986**, 559; d) V. Avetisov, V. Goldanskii, *Proc. Nat. Acad. Sci. USA*, **1996**, *93*, 11435; e) S. Mason, *Chem. Soc. Rev.* **1988**, *17*, 347; f) L. Keszthelyi, *Q. Rev. Biophys.* **1995**, *28*, 473.

[3] W. A. Bonner, P. R. Kavasmaneck, F. S. Martin, J. J. Flores, *Science* **1974**, *186*, 143.

[4] K. Soai, S. Osanai, K. Kadowaki, S. Yonekubo, T. Shibata, I. Sato, *J. Am. Chem. Soc.* **1999**, *121*, 11235.

[5] a) T. M. Lowry, *Optical Rotatory Power*, Dover, New York, **1964**, p. 337; b) C. W. Bunn, *Chemical Crystallography*, Clarendon, Oxford, **1961**, Chap. 2 and 3, p. 11.
[6] a) D. K. Kondepudi, R. J. Kaufman, N. Singh, *Science* **1990**, *250*, 975; b) D. K. Kondepudi, K. L. Bullock, J. A. Digits, J. K. Hall, J. M. Miller, *J. Am. Chem. Soc.* **1993**, *115*, 10211; c) D. K. Kondepudi, C. Sabanayagam, *Chem. Phys. Lett.* **1994**, *217*, 364; d) J. M. McBride, R. L. Carter, *Angew. Chem.* **1991**, *103*, 298; *Angew. Chem. Int. Ed. Engl.* **1991**, *30*, 293.
[7] R.-Y. Qian, G. D. Botsaris, *Chem. Eng. Sci.* **1998**, *53*, 1745.
[8] E. Ferroni, R. Cini, *J. Am. Chem. Soc.* **1960**, *82*, 2427.
[9] R. D. Gillard, J. D. P. da Luz de Jesus, *J. Chem. Soc. Dalton Trans.* **1979**, 1779.
[10] (*R*)-**2** with 2% *ee* was obtained in 4% yield when the reaction was performed at $-73\,^{\circ}C$ for 1 h in the presence of *l*-$NaClO_3$.
[11] a) K. Soai, T. Shibata, H. Morioka, K. Choji, *Nature* **1995**, *378*, 767; b) T. Shibata, T. Hayase, J. Yamamoto, K. Soai, *Tetrahedron: Asymmetry* **1997**, *8*, 1717; c) T. Shibata, J. Yamamoto, N. Matsumoto, S. Yonekubo, S. Osanai, K. Soai, *J. Am. Chem. Soc.* **1998**, *120*, 12157; d) K. Soai, T. Shibata, *Yuki Gosei Kagaku Kyokaishi* (*J. Synth. Org. Chem. Jpn.*) **1997**, *55*, 994; e) K. Soai, *Enantiomer* **1999**, *4*, 591; f) K. Soai, T. Shibata, I. Sato, *Acc. Chem. Res.*, submitted.
[12] W. T. Astbury, *International Critical Tables* **1933**, *7*, 353.
[13] T. Shibata, S. Yonekubo, K. Soai, *Angew. Chem.* **1999**, *111*, 749; *Angew. Chem. Int. Ed.* **1999**, *38*, 659.

  0044-8249/00/11208-1572 $ 17.50+.50/0