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A novel transformation of a 1 : 1 : 1 racemic complex of 2,2′-dihydroxy-1,1′-binaphthyl, Me_4N^+ Cl^- and MeOH into a conglomerate in the solid state by heating or contact with MeOH vapour

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The title racemate-to-conglomerate transformation which occurs in the solid state on heating or contact with MeOH vapour has been studied by IR and DTA spectral measurements, microscopic observation, and by X-ray structural and X-ray powder diffraction analysis.

It has been well established that molecules can move quite freely in crystals and crystal-to-crystal in the solid state.[1] By application of such knowledge, host–guest inclusion complexations[1] and solid–solid reactions[2] can be carried out through contact of powdered host with guest and of substrate with reagent, respectively, in the solid state. When the molecular movement is applied to chiral compounds, formation of racemic crystals can be accomplished by mixing both enantiomers in the solid state. For example, when crystals of (*S*)-(−)- (**1b**) and (*R*)-(+)-2,2′-dihydroxy-1,1′-binaphthyl (**1c**) are ground using a mortar and pestle, the racemic crystals (**1a**) were formed.[3] Several similar examples of the formation of racemic crystals in the solid state have been reported.[3] By heating crystals of (−)-3,4-bis(diphenylmethylene)-*N*-methylsuccinimide (**2b**) at 260 °C, half of the **2b** molecules were inverted to the enantiomer (**2c**), and finally the racemic crystals (**2a**) were obtained.[4] Hence the chirality of **2**, which is generated by overlapping of the two inner phenyl groups due to steric crowding, is easily racemized in the solid state.

The reverse racemic-to-chiral conversion in the solid state is a much more interesting subject. We report here an easy transformation of a 1 : 1 : 1 racemic inclusion complex (**4**) of **1a**, tetramethylammonium chloride (**3**) and MeOH into the conglomerate complex **1b·3** and **1c·3** (**5**), *via* the MeOH-free racemic complex (**6**), by heating or exposure to MeOH vapour in the solid state. Very recently, the thermal transformation of racemic crystals of 2,3:6,7-dibenzobicyclo[3.3.1]nona-2,6-diene-4,8-dione (**7**) into conglomerate crystals was found.[5] However, the similar transformation which occurs in an inclusion crystal on heating or contact with MeOH vapour has never been reported.

The racemic complex **4**, prepared by recrystallisation of **1a** (1.43 g, 5 mmol) and **3** (0.55 g, 5 mmol) from MeOH (7 ml) as colourless needles, does not show a sharp mp due to easy release of MeOH. Interestingly, however, when the above recrystallisation was carried out from MeOH (15 ml), the conglomerate complex **1b·3** and **1c·3** (**5**) was produced as colourless prisms (mp 313–315 °C) (Scheme 1). This is the first finding of a concentration-dependent racemate-to-conglomerate crystallisation. This crystallisation experiment was repeated ten times and gave the same result. When the crystallisation was carried out from MeOH (10 ml) at 5 or 25 °C, **4** or **5** was formed, respectively, although both the crystallisations from MeOH (7 and 15 ml) were not affected by the temperature. However, when a single crystal of **5** was added as a seed during the crystallisation experiment from MeOH (7 ml), **5** was formed instead of **4**. Nevertheless, the crystallisation experiment from MeOH (15 ml) gave **5** again by seeding using a single crystal of **4**. These data clearly show that **5** is thermodynamically more stable than **4**. Authentic samples of chiral **1b·3** and **1c·3** were prepared by complexation of **1b** and **1c**, respectively, with **3** in MeOH. Recrystallisation of **1a** and **3** from MeOH in the presence of a chiral seed crystal gave the same chiral crystal in good yield, and so **1a** was easily resolved.

The racemic structure of **4** and the conglomerate structure of **5** were elucidated by HPLC analysis using a column containing the chiral solid phase Chiralpak AD and one piece of single crystal. Although the chiral structure of **5** was determined by X-ray analysis of this single crystal,† **4** did not form crystalline material appropriate for X-ray analysis.

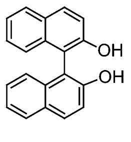
An interesting thermal transformation of **4** into **5** in the solid state was found. This transformation was monitored by measurement of IR spectra in the solid state using the ATR (Attenuated Total Reflection) method (Fig. 1) and by DTA measurement. IR spectral measurements showed that the MeOH-absorption of **4** (A) at 1008 cm^{-1} disappeared on thermal transformation into the MeOH-free intermediate (**6**) (B). By further heating at 160 °C for 5 min, **6** was converted into **5**. The spectrum of **5** (C) was identical to that of authentic **1b·3** (D). Although the spectrum of **6** is very similar to that of **4**, the spectrum of **5** is noticeably different from that of **4**.

The thermal transformation of **4** into **5** *via* **6** was studied at various temperatures. The lowest temperatures sufficient for the efficient transformation of **4** into **6**, and of **6** into **5** were found to be 100 and 160 °C, respectively.

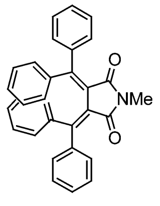
The course of the thermal transformation of **4** into **5** *via* **6** was also investigated by DTA measurement. DTA data showed that MeOH evaporated from **4** at 120 °C to give **6**, the phase-transfer to **5** occurred at 183 °C, and then **5** finally melted at 310 °C.

The transformation of **4** into **5** *via* **6** was also monitored by X-ray powder diffraction analysis. In Fig. 2, the traces of **4** (A) and **6** (B) are similar to each other since both are isomorphous. However, the trace due to the conglomerate **5** (C) is different from those of racemates **4** and **6**, but similar to that of the chiral complex **1b·3** (E).

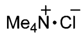
The very interesting transformation of **4** into **5** occurred just by contact of **4** with MeOH vapour in the solid state at room



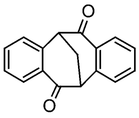
1
a: *rac*-form
b: (*S*)-(−)-form
c: (*R*)-(+)-form



2
a: *rac*-form
b: (−)-form
c: (+)-form


$Me_4\overset{+}{N}\cdot\overset{-}{Cl}$

3



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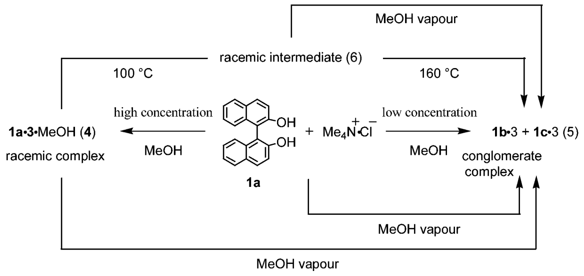

Scheme 1 Formation of **4** and **5** and transformation of the former to the latter by heating or exposure to MeOH vapour.

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temperature (Scheme 1). For example, when powdered or crystalline **4** (30 mg) was kept in a flask filled with MeOH vapour for 30 min at room temperature, **5** was obtained in a quantitative yield. The same treatment of **6** with MeOH vapour also gave **5**. Furthermore, contact of a mixture of powdered **1a** and **3** with MeOH vapour for 30 min gave **5** (Scheme 1), although simple mixing of **1a** and an equimolar amount of **3** using a mortar and pestle for 30 min did not give any complex. The same transformation occurred on contact with EtOH vapour, but $CHCl_3$, Et_2O, toluene and hexane vapours were not effective. The reason for the acceleration of the conglomerate complex formation by MeOH vapour is not clear. However, it is known that solid state reactions proceed faster in the presence of a small amount of solvent.[6] It is believed that molecular movement in the solid state is accelerated by a small amount of solvent molecules.

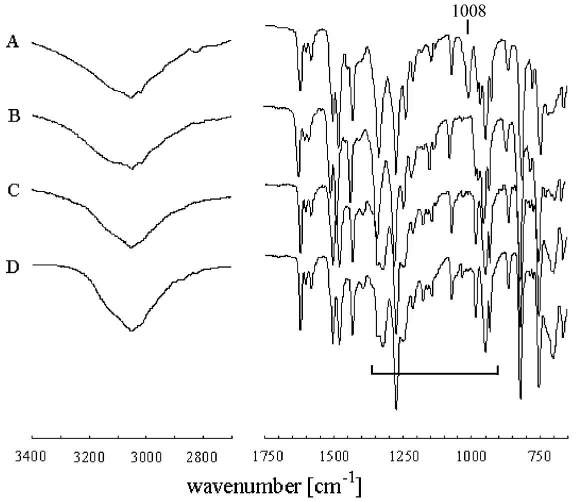

Fig. 1 Monitoring by IR spectral measurements (using the ATR method) of the thermal transformation of **4** into **5** *via* **6**: (A) **4**, (B) **6**, (C) **5**, (D) authentic sample of **1b·3**.

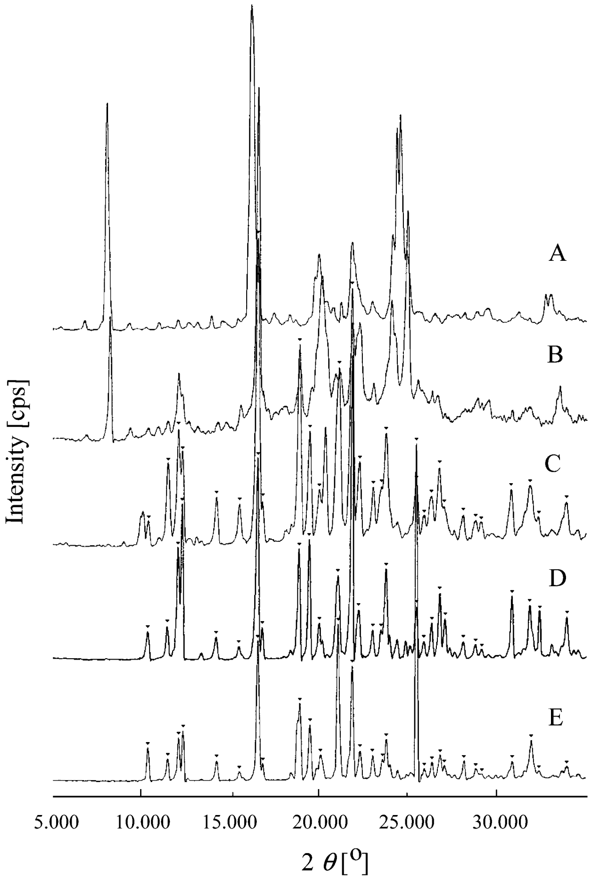

Fig. 2 Monitoring by X-ray powder diffraction analysis of the transformation of **4** into **5** by heating and by exposure to MeOH vapour: (A) **4**, (B) **6**, (C) **5** obtained by thermal transformation of **4**, (D) **5** obtained by exposure of **4** to MeOH vapour, (E) authentic **1b·3**.

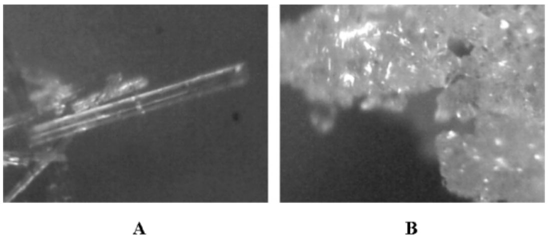

Fig. 3 Microscopic observation of the transformation of **4** (A) into **5** (B) by contact with MeOH vapour in the solid state.

The transformation of **4** into **5** on contact with MeOH vapour was monitored by IR spectral measurement, X-ray powder diffraction analysis and by microscopic observation. The IR spectrum of **5** obtained by exposure of **4** to MeOH vapour is identical to that of an authentic sample of **1b·3** (D in Fig. 1). The X-ray powder diffraction pattern of **5** (D in Fig. 2) obtained by the MeOH vapour experiment is very similar to that of an authentic sample of **1b·3** (E in Fig. 2). Microscopic observation of the transformation of **4** into **5** by contact with MeOH vapour showed a significant change in the crystalline shape (Fig. 3). Exposure of single crystals of **4** (A in Fig. 3) to MeOH vapour for 30 min at room temperature gave conglomerate crystals of **5** (B in Fig. 3).

Notes and references

† Crystallographic data for **1b·3** were collected at 123 K on a Rigaku RAXIS-IV Imaging Plate diffractometer using Mo-K_α radiation. Crystal data for **1b·3**: $C_{24}H_{26}ClNO_2$, M = 395.93, a = 9.0002(1), b = 14.1519(3), c = 16.6811(3) Å, V = 2124.67(6) Å^3, orthorhombic, space group $P2_12_12_1$ (no. 19), Z = 4, D_{calc} = 1.238 g cm^{-3}, Mo-K_α radiation (λ = 0.7107 Å), Flack parameter −0.10(6), R = 0.0434 ($F^2 = 2\sigma$), wR = 0.1632 (all F^2). CCDC 235218. See http://www.rsc.org/suppdata/cc/b4/b404297b/ for crystallographic data in .cif or other electronic format.

1 F. Toda, K. Tanaka and A. Sekikawa, *J. Chem. Soc., Chem. Commun.*, 1987, 279.

2 F. Toda, *Acc. Chem. Res.*, 1995, **28**, 480; K. Tanaka and F. Toda, *Chem. Rev.*, 2000, **100**, 1025; *Organic Solid State Reactions*, ed. F. Toda, Kluwer Academic Publishers, Dordrecht, 2002.

3 F. Toda, K. Tanaka, H. Miyamoto, H. Koshima, I. Miyahara and K. Hirotsu, *J. Chem. Soc., Perkin Trans. 2*, 1997, 1877.

4 F. Toda and K. Tanaka, *Supramol. Chem.*, 1994, **3**, 87; F. Toda, K. Tanaka, Z. Stein and I. Goldberg, *Acta Crystallogr., Sect. B*, 1995, **51**, 856; F. Toda, K. Tanaka, Z. Stein and I. Goldberg, *Acta Crystallogr., Sect. C*, 1995, **51**, 2722.

5 Private communication from Professor Remir G. Kostyanovsky of Russian Academy of Sciences in Moscow.

6 N. Shan, F. Toda and W. Jones, *Chem. Commun.*, 2002, 2374.