COMMUNICATION

OBC
www.rsc.org/obc

Isolation of an inclusion complex of naphthol and its benzoate as an intermediate in the solvent-free benzoylation reaction of naphthol

Seiken Nakamatsu,[a] Kazuhiro Yoshizawa,[a] Sinji Toyota,[a] Fumio Toda *[a] and Ivanka Matijasic *[b]

[a] *Department of Chemistry, Faculty of Science, Okayama University of Science, Ridai-cho 1-1, Okayama 700-0005, Japan. E-mail: toda@chem.ous.ac.jp*

[b] *Department of Chemistry, Faculty of Science, Faculty of Science, University of Zagreb, Strossmayerov trg 14,10000 Zagreb, Croatia. E-mail: matijas@rudjer.irb.hr*

Received 17th March 2003, Accepted 29th May 2003
First published as an Advance Article on the web 9th June 2003

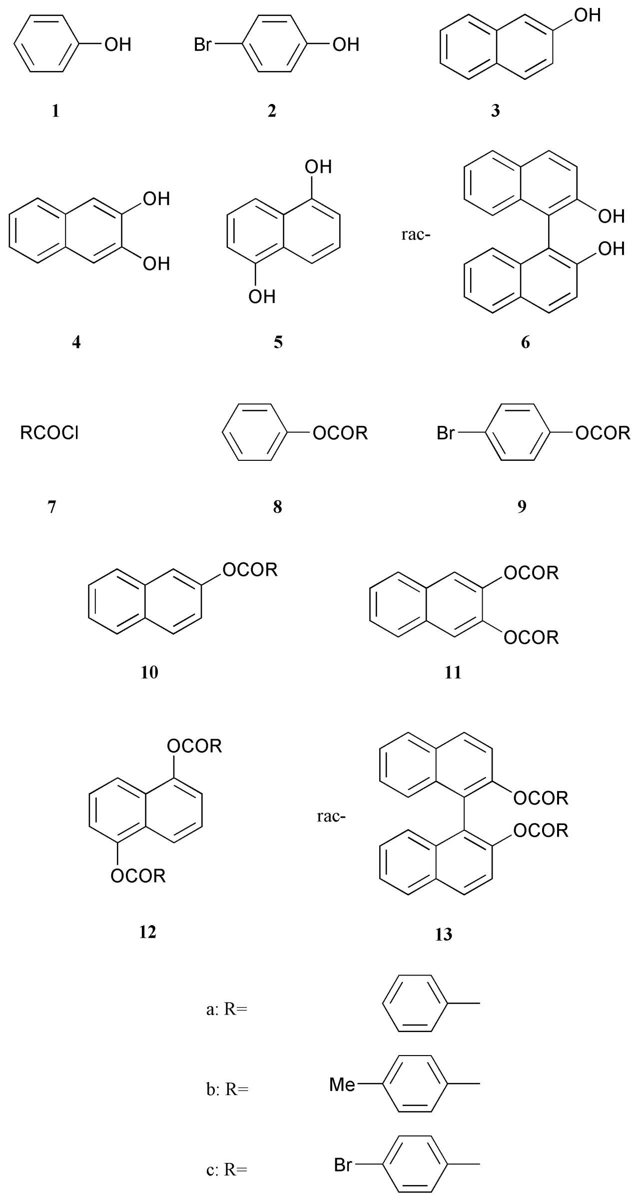
Solvent-free benzoylation of naphthol was found to proceed *via* an inclusion complex intermediate of the naphthol and its benzoate by IR spectral monitoring.

Introduction

From the viewpoint of green and sustainable chemistry, solvent-free organic reactions represent a very important synthetic procedure. Recently, we have been developing various new solvent-free organic reactions.[1] We have also developed a simple, but very useful, method of analyzing organic reaction mechanisms by using continuous IR spectral measurement of the solvent-free reaction. For example, the Thorpe reaction mechanism in the solid state was demonstrated to proceed *via* an imine intermediate by monitoring the reaction by IR spectroscopy.[2] The Rap–Stoermer reaction mechanism was also almost fully clarified by using this technique.[3] Recently, we have found that benzoylation of phenols and naphthols with benzoyl chloride proceeds efficiently under solvent-free conditions, and that the reaction of naphthols involves the formation of an inclusion complex of the naphthol with its benzoate by using IR monitoring. These inclusion complexes have been isolated and shown to be genuine intermediates. The structure of the 2 : 1 inclusion complex of 2,3-naphthalenediol and its *p*-methylbenzoate has also been studied by X-ray analysis.

Results and discussion

Solvent-free benzoylation reactions were carried out by heating a stirred mixture of phenols (**1**, **2**, see Scheme 1) or naphthols (**3**–**6**) and benzoyl chloride (**7**). The HCl gas evolved during the reaction was trapped by absorption in water. The reaction mixture was washed with aqueous Na_2CO_3 and water, and air dried to give the corresponding pure benzoates (**8**–**13**) as white powders. For example, a mixture of 2-naphthol (**3**) (2.01 g, 14.4 mmol) and *p*-methylbenzoyl chloride (**7b**) (2.15 g, 13.9 mmol) was heated at 60 °C for 2 h under magnetic stirring. When the mixture started to solidify, it was occasionally stirred using a spatula. The reaction mixture was washed with aqueous Na_2CO_3 and water, and then air dried to give pure 2-naphthyl *p*-methylbenzoate (**10b**) as a white powder (3.36 g, 97% yield, mp 140–141 °C). Benzoylations of all phenols and naphthols with benzoyl (**7a**), *p*-methylbenzoyl (**7b**) and *p*-bromobenzoyl chloride (**7c**) were carried out under the same solvent-free reaction conditions (Table 1). In all reactions, pure products were obtained in good yields just by washing the reaction mixture with aqueous Na_2CO_3 and water.



Scheme 1

In order to clarify the reaction mechanism of the solvent-free benzoylation process, the reactions of **3** or **4** with **7b** at 80–100 °C were monitored by continuous measurements of IR spectra as Nujol mulls (Figs. 1 and 2). First, the reaction of **3** with **7b** at 80 °C was studied. Initially, on mixing of **3** and **7b**, no significant new *ν*OH absorption appeared, and only two *ν*C=O absorptions of **7b** appeared at 1775 and 1740 cm^{-1} (I in Fig. 1). After 10 min of mixing, new *ν*OH and *ν*C=O absorptions

DOI: 10.1039/b303060c

Table 1 Benzoylation of phenol and naphthol derivatives under solvent-free conditions

Phenol or naphthol	Benzoyl chloride	Reaction conditions T/°C	t/min	Product	Mp/°C	Yield (%)
1	**7b**	60	90	**8b**	75–76	80
2	**7a**	60	120	**9a**	106–107	94
2	**7b**	60	120	**9b**	105–106	98
2	**7c**	60	120	**9c**	115	87
3	**7a**	60	120	**10a**	106–107	97
3	**7b**	60	120	**10b**	140–141	98
3	**7c**	60	120	**10c**	133	71
4	**7b**	120	15	**11b**	145–146	99
5	**7b**	120	30	**12b**	219–222	92
6	**7b**	120	15	**13b**	283–284	78

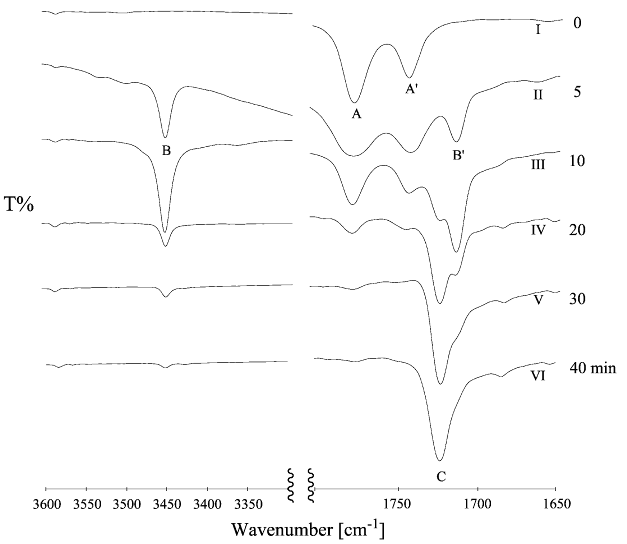


Fig. 1 Monitoring of the solvent-free benzoylation of **3** with **7b** at 80 °C by continuous IR spectral measurements for 40 min in Nujol mulls.

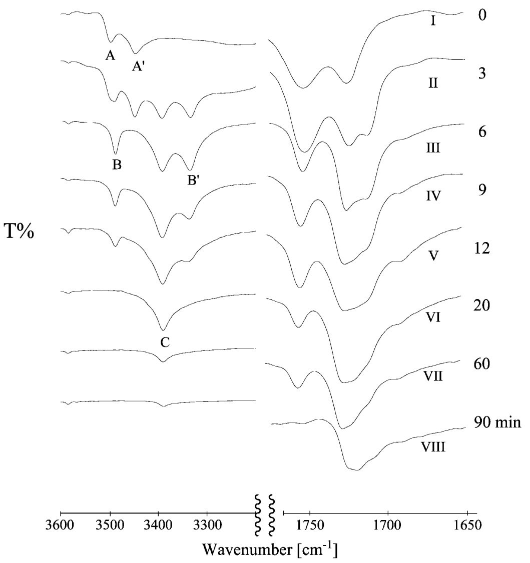


Fig. 2 Monitoring of the solvent-free benzoylation of **4** with **7b** at 100 °C by continuous IR spectral measurements for 90 min in Nujol mulls.

appeared at 3450 and 1710 cm^{-1}, respectively (II in Fig. 1). As the reaction proceeds, a νC=O absorption appeared at 1720 cm^{-1}, in addition to the νC=O absorption at 1710 cm^{-1} (II–IV in Fig. 1). When the reaction mixture was further heated at 80 °C for 10 min, the νOH absorption at 3450 cm^{-1} and νC=O absorptions at 1775, 1740 and 1710 cm^{-1} disappeared and only the νC=O absorption at 1720 cm^{-1} remained (VI in Fig. 1). The spectrum of VI is identical to that of the final product **10b**. The appearance of the νOH and νC=O absorptions at relatively low frequencies 3450 and 1720 cm^{-1}, respectively, during the reaction process suggests the formation of a complex of **3** and **10b**. Hydrogen bond formation between the OH hydrogen of **3** and the C=O oxygen of **10b** would shift their absorptions to lower wavenumber. Recrystallization of **3** and **10b** from diethyl ether gave a 1 : 1 inclusion complex (**14**) as colorless crystals showing νOH and νC=O absorptions at 3450 and 1710 cm^{-1}, respectively. However, **14** did not form crystals appropriate for X-ray analysis.

Secondly, the solvent-free benzoylation reaction of **4** with **7b** at 100 °C was also monitored by IR spectral measurements (Fig. 2). Initially, on mixing **4** and **7b**, the νOH of **4** and νC=O of **7b** appeared at 3500 (A) and 3450 (A′), and 1775 and 1740 cm^{-1}, respectively (I in Fig. 2). As the benzoylation reaction proceeded, new νOH absorptions appeared at 3487 (B), 3338 (C) and 3335 cm^{-1} (B′), and the original νOH absorptions of **4** at 3500 (A) and 3450 cm^{-1} (A′) disappeared after 6 min (II–III in Fig. 2). At the same time, a new νC=O absorption appeared at 1730 cm^{-1} and gradually increased in intensity (II–IV in Fig. 2). After 20 min, only the 3338 cm^{-1} (C) absorption remained as the sole νOH absorption, and the 1740 cm^{-1} absorption remained as the strongest νC=O absorption (VI in Fig. 2). The 3388 cm^{-1} absorption (C) is assigned to the νC=O of the monoester (2-hydroxy-3-naphthyl *p*-methylbenzoate) by comparison of the spectrum with that of an authentic sample. When the reaction mixture was further heated at 100 °C for 90 min, the νOH absorption disappeared and only the νC=O absorption at 1740 cm^{-1} remained (VIII in Fig. 2). The VIII spectrum in Fig. 2 is identical to that of **11b**. The appearance of the new νOH and νC=O absorptions at 3487 (B) and 3335 (B′) and 1730 cm^{-1}, respectively, during the course of the reaction (II–VII in Fig. 2) suggests the formation of a complex of **4** with **11b**. In order to confirm the formation of this complex, both compounds were recrystallized together from diethyl ether to give the 2 : 1 complex (**15**) of **4** with **11b** as colorless plates (mp 140–141 °C, calc. for $C_{46}H_{36}O_8$: C, 77.08; H, 5.06. Found: C, 76.91; H, 4.87%). Since complex **15** showed the 3487, 3335 and 1730 cm^{-1} absorptions and since heating of **15** together with **7b** gave **11b**, **15** was identified as being an intermediate in the solvent-free benzoylation reaction of **4** with **7b**. However, inclusion complex of **1**, **2**, **5** and **6** with their corresponding benzoates were not obtained in separate inclusion complexation experiments.

In order to understand why **15** is so stabilized against the benzoylation reaction with **7b** at room temperature, the structure of **15** was studied by X-ray analysis.[4] The crystal structure of **15** is shown in Fig. 3. The C–C bond lengths of the naphthalene-2,3-diol moiety in the host and guest molecule do not differ significantly from those of naphthalene itself,[5] or from those of naphthalene-2,3-diol.[6] Besides, similar values were reported in the complex with a cyclophane derivative[7] and in the molecular complexes of naphthalene-2,3-diol with flavins.[8–10] The diol molecule (**4**) (including hydroxyl O atoms) is

Table 2 Hydrogen bonding geometry in complex **15** (Å, °)

D–H···A	D–H	H···A	D···A	D–H···A
O2–H···O1	0.96(2)	2.15(2)	2.665(2)	112(2)
O2–H···O1$^{\mathrm{i}}$	0.96(2)	1.98(2)	2.765(2)	138(2)
O1–H···O4$^{\mathrm{ii}}$	0.92(2)	1.75(2)	2.672(2)	176(2)
C18–H···O2$^{\mathrm{iii}}$	0.93	2.50	3.360(2)	153

Symmetry codes: (i) $1 - x, -y, 1 - z$; (ii) $1 - x, ½ - y, z$; (iii) $x, ½ + y, 1 - z$.

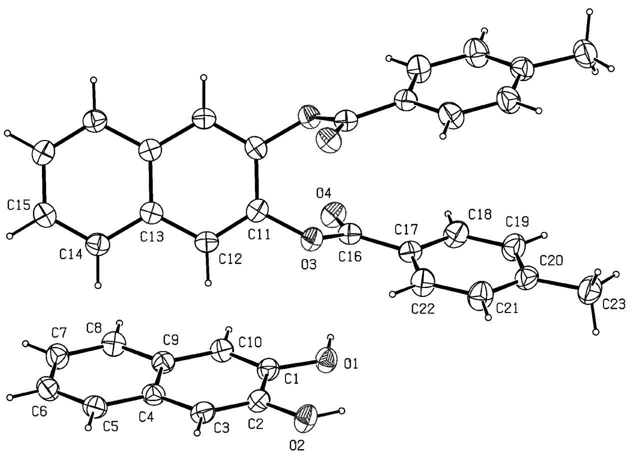


Fig. 3 X-Ray crystal structure of **15** with atom labeling. Thermal ellipsoids are shown at the 50% probability level.

planar, likewise the naphthalene moiety in the diester molecule. In the latter moiety we found the O3 atom out of plane by 0.093(2) Å and the O3–C11–C11′–O3′ torsion angle of 9.2(2)°, due to the bulky substituents in the *ortho*-position. The dihedral angle between the least-squares planes through the two naphthalene rings of host and guest molecule is 57.33(9)° with the closest contact C5···H14 being 2.81 Å. The conformation of the guest molecule can be described by the dihedral angle between the least-squares plane through the naphthalene ring and the plane through the phenyl ring; the value is 59.5(1)°. Two bulky substituents on the naphthalene ring influence not only the conformation of the molecule, but also the crystal packing.

The naphthalene-2,3-diol molecule (**4**) shows the usual intramolecular hydrogen bond present in *ortho*-dihydroxy-aromatic compounds with a O2–H···O1 distance of 2.665(2) Å, a O2–H···O1 angle of 112(2)° and H···O1 distance of 2.15(2) Å (Table 2, Fig. 2). There is also an intermolecular O2–H···O1 hydrogen bond with a symmetry related diol molecule resulting in a dimer. The distance between the least-squares planes of these two related **4** molecules is about 0.095 Å. The O1 atom, which is the acceptor in these two hydrogen bonds, acts as a donor in intermolecular hydrogen bonding to the carbonyl O atom of the guest molecule **11b**. The distances and the angle are indicative of strong hydrogen bonding (Table 2). The core part of the chains present in the hydrogen bonding network is shown in Fig. 4.

The one unusual, but consistent, deviation in bond angles from 120° which occurs in **4** involves the oxygen atom which is an acceptor in the internal hydrogen bond. In our structure the O1 atom bends about 5.5° toward the donor hydroxyl group. Similar characteristics have already been observed in structures found in the CSD: in **4**[6] [114.7(2) and 115.3(2) Å]; in the cyclophane complex[7] [113.4(4) Å]; and in three different complexes with flavin derivatives[8–10] [115.1(3) and 115.2(3); 112(1) and 113(1); 114.8(8) and 115.4(8), respectively].

The crystal packing of two entities (Fig. 5) is a result between different intermolecular forces. The O–H···O hydrogen bonding pattern is already described. Other possible attractive interactions are parallel stacking of entities with π electrons and CH···O hydrogen bonds. Our structure consists of both interactions. A face-to-face π–π alignment is a rare phenomenon, while the usual π–π interaction is an offset or slipped stacking, *i.e.* the rings are parallel displaced. The methylated phenyl rings and naphthalene diol molecules from two neighbouring hydrogen bonded chains are almost parallel with an interplanar angle of 5.1° and a mean separation of 3.57 Å in the offset stacking. The next aromatic moiety in the same stacked column is the second *p*-methylphenyl ring of the diester molecule. The intermolecular distance of two symmetry related phenyl rings is rather large, 3.86 Å, with an interplanar angle of 10.6°. This value is just slightly above the limit of 3.8 Å suggested as approximately the maximum contact for which π–π interactions are accepted.[11]

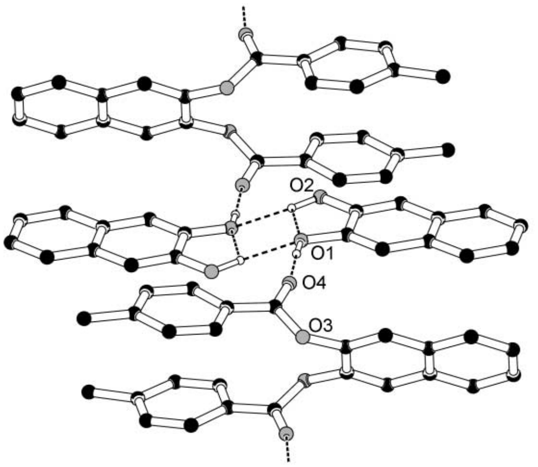


Fig. 4 A basic part of the hydrogen bonding network. Hydrogen atoms on carbon are omitted for clarity.

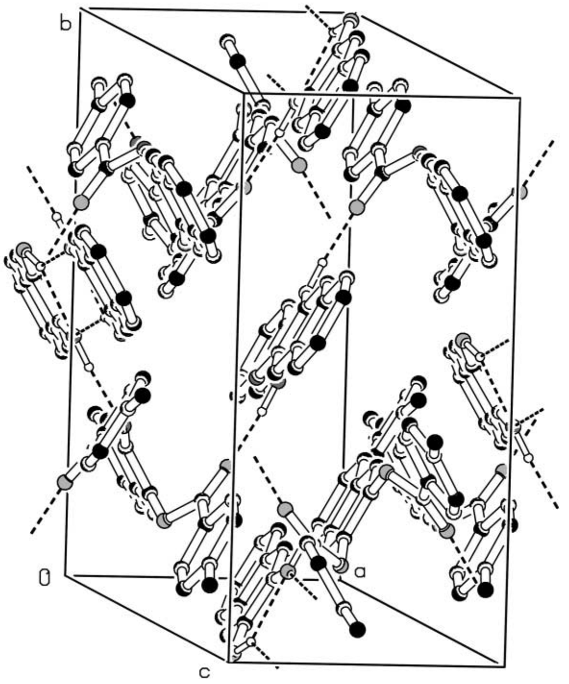


Fig. 5 Molecular packing of **15**. Hydrogen bonds are denoted as dashed lines.

An additional factor that appears to influence the packing is a weak C–H···O hydrogen bonding between guest and host molecules: the C18–H···O2 distance of 3.359(2) Å and C18–H···O2 angle of 153° complete an interesting ribbon motif. Several close herringbone or edge-to-face interactions of the C–H···π type[12] were observed for the H12 and H14 atoms ranging from 2.81 to 3.05 Å.

Acknowledgements

The financial support of this work from the Ministry of Science and Technology, Croatia, is gratefully acknowledged.

Note and references

1 For reviews see for example: (*a*) F. Toda, *Synlett*, 1993, 302; (*b*) F. Toda, *Acc. Chem. Res.*, 1995, **28**, 480; (*c*) F. Toda, *Supramol. Sci.*, 1996, **3**, 139; (*d*) F. Toda, *Compr. Supramol. Chem.*, 1996, **6**, 465; (*e*) K. Tanaka and F. Toda, *Chem. Rev.*, 2000, **100**, 1025; (*f*) F. Toda, *Organic Solid State Reactions*, Kluwer Academic Publishers, Dordrecht, 2002.

2 K. Yoshizawa, S. Toyota and F. Toda, *Green Chem.*, 2002, **4**, 68.

3 K. Yoshizawa, S. Toyota, F. Toda and I. Csöregh, *Green Chem.*, 2003, **5**, 353.

4 Crystal data for **15**. $2C_{10}H_8O_2\cdot C_{26}H_{20}O_4$, $M = 716.75$, orthorhombic, space group *Pcnb* (no. 60), $a = 7.448(1)$, $b = 15.243(1)$, $c = 31.849(1)$ Å, $V = 3615.8(6)$ Å^3, $Z = 4$, $T = 293(1)$ K, $F(000) = 1504$, GooF = 1.027, $D_c = 1.317$ g cm^{-3}, μ(Cu-Kα) = 0.729 mm^{-1}, $R_{int} = 0.0270$. 5596 reflections were measured, 3062 unique were used in all least-squares calculations, $R_1(F) = 0.0434$ for 2383 reflections with $F_o > 4\sigma(F_o)$, wR_2 $(F^2) = 0.1272$ for all unique reflections and 255 parameters. Intensity data were collected on a Nonius Kappa CCD diffractometer up to $2\theta_{max} = 130.20°$ using graphite-monochromated Cu-Kα radiation ($\lambda = 1.54178$ Å). The structure was solved by the direct methods (SHELXS97)[13] and refined by full-matrix least squares based on F^2 using SHELXL97.[14] The O–H hydrogen atoms were found from a difference Fourier syntheses and refined freely. The remaining C–H hydrogen atoms were introduced in calculated positions and allowed to ride on their parent atoms. At convergence, the peaks and troughs of the difference density map did not exceed 0.21 and −0.19 e Å^{-3}, respectively. The figures were prepared using PLATON98.[15] CCDC reference number 207265. See http://www.rsc.org/suppdata/ob/b3/b303060c/ for crystallographic data in CIF or other electronic format.

5 D. W. J. Cruickshank, *Acta Crystallogr.*, 1957, **10**, 504; D. W. J. Cruickshank, *Tetrahedron*, 1962, **17**, 155.

6 J. A. Herbert and M. R. Truter, *J. Chem. Soc., Perkin Trans. 2*, 1980, 1253.

7 V. K. Bel'skii, E. V. Karchenko, A. N. Sobolev, V. E. Zavodnik, N. A. Kolomiets, G. S. Prober and L. P. Oleksenko, *Zh. Strukt. Khim.*, 1990, **31**, 116.

8 J. L. Wells, B. L. Trus, R. M. Johnston, R. E. Marsh and C. J. Fritchie, Jr, *Acta Crystallogr., Sect. B*, 1974, **30**, 1127.

9 M. C. Kuo, J. B. R. Dunn and C. J. Fritchie, Jr., *Acta Crystallogr., Sect. B*, 1974, **30**, 1766.

10 C. H. Fritshie, Jr and R. M. Johnston, *Acta Crystallogr., Sect. B*, 1975, **31**, 454.

11 C. Janiak, *J. Chem. Soc., Dalton Trans.*, 2000, 3885.

12 I. Dance, in *The Crystal as a Supramolecular Entity*, ed. G. R. Desiraju, John Wiley & Sons, Chichester, 1996, p. 168.

13 G. M. Sheldrick, SHELXS97, Program for the Refinement of Crystal Structures, University of Göttingen, Germany, 1997.

14 G. M. Sheldrick, SHELXL97, Program for the Refinement of Crystal Structures, University of Göttingen, Germany, 1997.

15 A. L. Speck, PLATON98, Program for the Display and Analysis of Crystal and Molecular Structures, University of Utrecht, The Netherlands, 1998.