Shanmuga Sundara Raj, S., Ponnuswamy, M. N., Shanmugam, G. & Kandaswamy, M. (1994). *J. Chem. Crystallogr.* **24**, 83–87.
Sheldrick, G. M. (1990). *Acta Cryst.* A**46**, 467–473.
Sheldrick, G. M. (1991). *SHELXTL-Plus*. Revision 4.1. Siemens Analytical X-ray Instruments Inc., Madison, Wisconsin, USA.
Sheldrick, G. M. (1993). *SHELXL93. Program for the Refinement of Crystal Structures.* University of Göttingen, Germany.
Siemens (1994). *P3 Diffractometer Program.* Version 4.21. Siemens Analytical X-ray Instruments Inc., Madison, Wisconsin, USA.
Singh, T. P., Tiwari, R. K. & Singh, M. (1985). *Acta Cryst.* C**41**, 752–755.
Vijayalakshmi, B. K. & Srinivasan, R. (1975). *Acta Cryst.* B**31**, 999–1003.
Yamane, T., Andou, T. & Ashida, T. (1977). *Acta Cryst.* B**33**, 1650–1653.
Zsolnai, L. (1995). *ZORTEP. An Interactive Molecular Graphics Program.* University of Heidelberg, Germany.

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Complexes Between L-Leucine and its Precipitants

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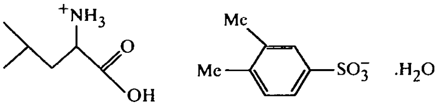
Abstract

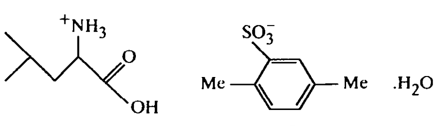
The complexes between L-leucine and aromatic sulfonic acids, L-leucine 3,4-dimethylbenzenesulfonate monohydrate ($C_6H_{14}NO_2^+.C_8H_9O_3S^-.H_2O$), L-leucine 2,5-dimethylbenzenesulfonate monohydrate ($C_6H_{14}NO_2^+.C_8H_9O_3S^-.H_2O$), L-leucine 4-methylbenzenesulfonate monohydrate ($C_6H_{14}NO_2^+.C_7H_7O_3S^-.H_2O$), as well as L-leucine benzenesulfonate monohydrate, exhibit a striking similarity in their packing schemes, which are dominated by van der Waals stacking of the hydrogen-bonded molecular double layers. The tightness of packing of double layers is most likely related to the solubility of the complexes.

Comment

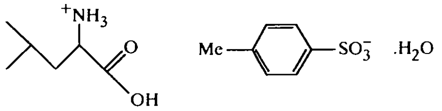
L-Leucine (Leu) is one of the essential mammalian amino acids and is used for intravenous feeding solution. Purification of Leu from hydrolysate of proteins is quite difficult because the hydrolysate contains a large amount of L-isoleucine (Ile) and L-valine (Val). These three amino acids have very similar crystal structures (Harding & Howieson, 1976; Torii & Iitaka, 1970, 1971), thus repetition of the recrystallization of Leu has been ineffective for purification because of formation of mixed crystals. Since the 1950s, many complexes between Leu and aromatic sulfonic acids (called precipitants) have been studied in order to purify Leu efficiently, and some of them are effective for the isolation of Leu. Among these precipitants, 3,4-dimethylbenzenesulfonic acid (Nagai, 1963) (*o*-DMBS) has extreme selectivity for Leu and has been used industrially. A number of precipitants resembling *o*-DMBS are known, *i.e.* 2,5-dimethylbenzenesulfonic acid (*p*-DMBS), 2,4-dimethylbenzenesulfonic acid (*m*-DMBS), *p*-toluenesulfonic acid (*p*-TS) (Hongó *et al.*, 1979) and benzenesulfonic acid (BS) (Hongo *et al.*, 1979). These precipitants form complexes with Leu, but the solubilities of the complexes are different to one another. The reduced solubilities based on Leu at 283 K are 0.82 g/100 g H_2O for the *o*-DMBS complex, 0.96 g/100 g H_2O for the *p*-DMBS complex, 6.24 g/100 g H_2O for the *m*-DMBS complex, 5.82 g/100 g H_2O for the *p*-TS complex and 7.66 g/100 g H_2O for the BS complex. The crystal structures of these five complexes were determined in order to elucidate the relationship between packing arrangement and functions as a precipitant, such as selectivity for Leu and reduced solubility. However, the results for the complex with BS have already been reported (Kimoto *et al.*, 1989) and the refinement of the complex with *m*-DMBS was unsatisfactory. Thus, we report here the crystal structures of the remaining three complexes and compare them with the results for the complex with BS.



Leu.*o*-DMBS.H_2O



Leu.*p*-DMBS.H_2O



Leu.*p*-TS.H_2O

All but one of these four complexes crystallize in the orthorhombic space group $P2_12_12_1$ with similar cell parameters. The crystal of the *m*-DMBS complex also has the orthorhombic space group $P2_12_12_1$ with similar unit-cell parameters, *i.e.* a = 9.839 (2), b = 27.86 (1) and c = 6.609 (2) Å. Even though one of them has a different space group ($P2_1$), all the complexes consist of one Leu cation, one precipitant anion and one water molecule per asymmetric unit (Figs. 1, 2 and 3), and exhibit very similar packing schemes.

Hydrogen bonds hold the carboxyl and amino groups of Leu, the sulfonic acid group of the precipitants, and water together in corrugated double layers, while the hydrophobic side chain of Leu and the aromatic rings of the precipitants lie outside the layer (Figs. 4, 5 and 6). The crystal-packing arrangement consists of stacking of these double layers with van der Waals contacts.

All torsion angles of the side chain of Leu are similar to each other, and are also similar to those of free Leu, except for ψ(O—C—C—N), *i.e.* −36 and −26° in the Leu crystal (Harding & Howieson, 1976). The ψ(O—C—C—N) values of the complexes are −6.4 (6) and 173.1 (4)° for Leu.*o*-DMBS.H_2O, −5.7 (6) and 174.9 (4)° for Leu.*p*-DMBS.H_2O, and −9.2 (6) and 168.3 (4)° for Leu.*p*-TS.H_2O, so these differences seem to be caused by the hydrogen-bond scheme including the sulfonic acid group of the precipitants and water.

In the hydrophobic interaction area, some structural differences appear because of the different numbers and positions of the methyl groups in the precipitants. In order to elucidate quantitatively the tightness of the packing of the complex molecule, we tried to calculate the filling factor in the unit cell using space-fill models and van der Waals radii for each atom (CRC Handbook

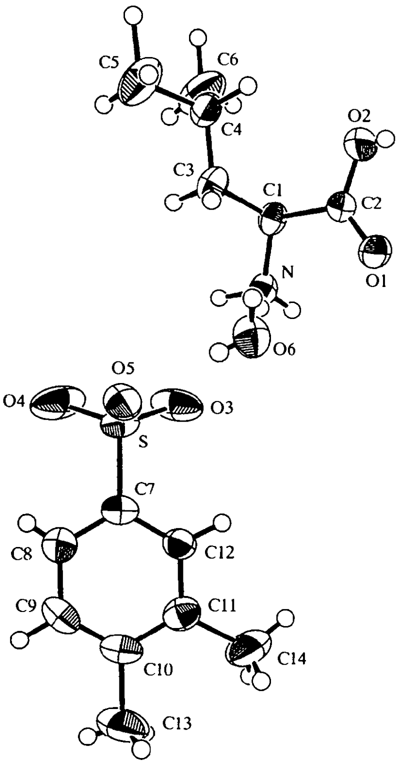


Fig. 1. *ORTEP*II view (Johnson, 1976) of the Leu.*o*-DMBS.H_2O complex. Displacement ellipsoids are plotted at the 50% probability level.

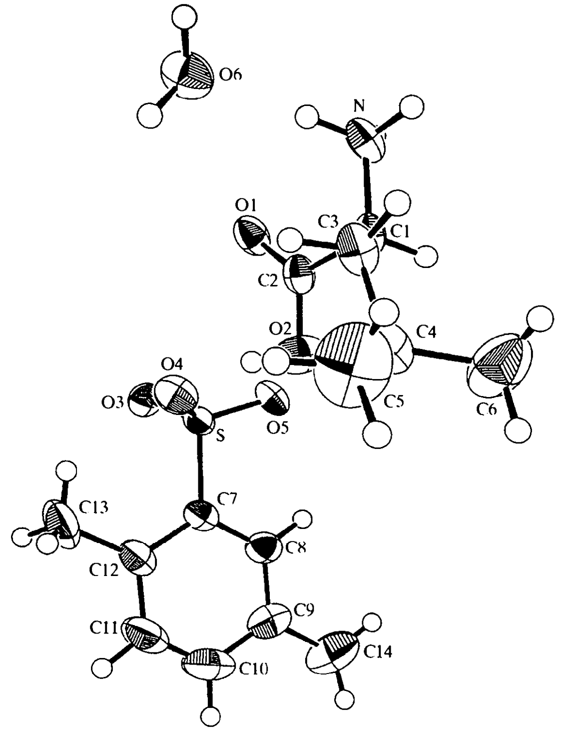


Fig. 2. *ORTEP*II view (Johnson, 1976) of the Leu.*p*-DMBS.H_2O complex. Displacement ellipsoids are plotted at the 50% probability level.

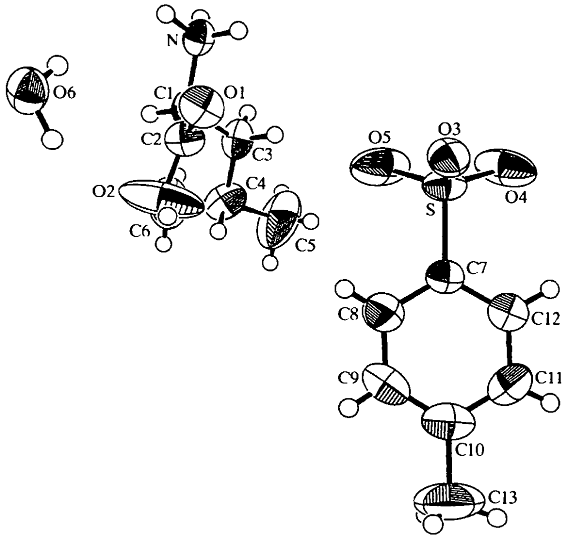


Fig. 3. *ORTEP*II view (Johnson, 1976) of the Leu.*p*-TS.H_2O complex. Displacement ellipsoids are plotted at the 50% probability level.

of Chemistry and Physics, 1986). The results were 66.7% for the BS complex, 64.4% for the *p*-TS complex, 67.2% for the *p*-DMBS complex and 67.6% for the *o*-DMBS complex. These four complexes have similar packing of the hydrophilic areas, so the difference in the filling factors must be mainly due to the tightness of the packing of the hydrophobic areas. From these factors, it is seen that in the crystal of the complex with BS, there is a little cavity in the hydrophobic interaction area. In the case of the crystal of the complex with *p*-TS, having one more methyl group than the BS complex, the *b* axis is elongated by the addition of the methyl group, so that the cavity arises more in the hydrophobic area. In the crystals of the complexes with *o*- and *p*-DMBS, the size of the cavity is apparently decreased by the relatively close packing in these complexes. On the other hand, the filling factor of the *m*-DMBS complex remains 65.7%.

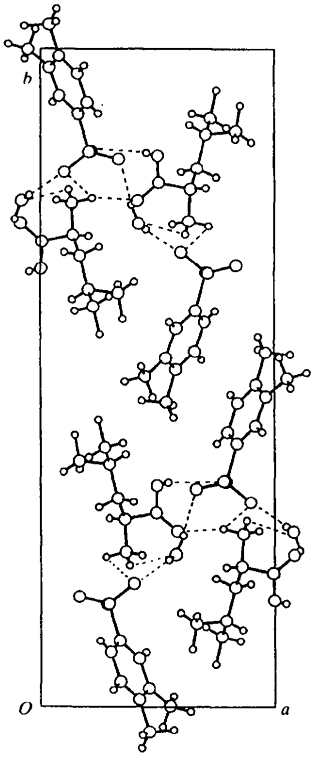


Fig. 4. Packing diagram of the Leu.*o*-DMBS.H_2O complex viewed down the *c* axis.

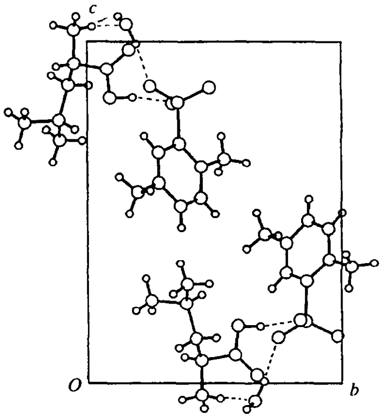


Fig. 5. Packing diagram of the Leu.*p*-DMBS.H_2O complex viewed down the *a* axis.

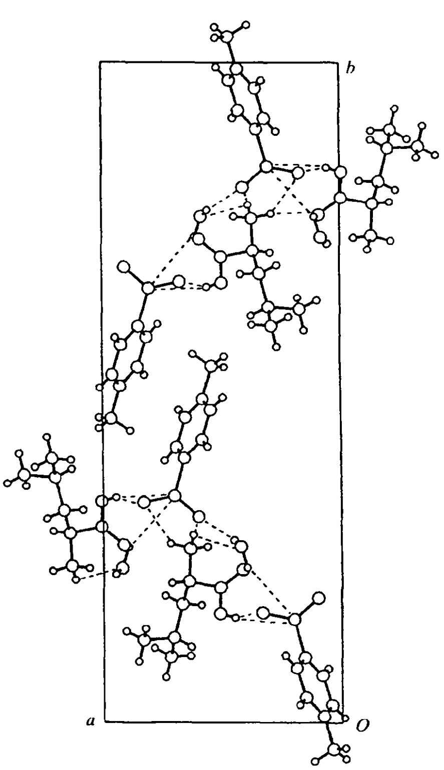


Fig. 6. Packing diagram of the Leu.*p*-TS.H_2O complex viewed down the *c* axis.

From a comparison of the filling factors of the complexes, it is reasonable that the complex of Leu.*o*-DMBS.H_2O has the lowest solubility in these complexes. It is suggested that the tightness of the packing of the hydrophobic region must play an important role in determining the solubility of the complexes.

Experimental

All precipitants were purchased and the crystals of the title complexes were obtained by slow cooling of equimolar warm aqueous solutions of L-leucine and the precipitants.

Leu.*o*-DMBS.H_2O

Crystal data

$C_6H_{14}NO_2^+.C_8H_9O_3S^-.H_2O$
$M_r = 335.41$

Cu $K\alpha$ radiation
$\lambda = 1.5418$ Å

Orthorhombic
$P2_12_12_1$
$a = 9.855$ (7) Å
$b = 28.479$ (9) Å
$c = 6.280$ (1) Å
$V = 1763$ (5) Å^3
$Z = 4$
$D_x = 1.264$ Mg m^{-3}
$D_m = 1.268$ Mg m^{-3}
D_m measured by flotation in isooctane–carbon tetrachloride

Cell parameters from 25 reflections
$\theta = 30$–$40°$
$\mu = 1.870$ mm^{-1}
$T = 298$ K
Plate
0.7 × 0.5 × 0.1 mm
Colourless

Data collection

Rigaku AFC-5*S* diffractometer
$\omega/2\theta$ scans
Absorption correction: empirical *via* ψ scans (North *et al.*, 1968)
$T_{\min} = 0.485$, $T_{\max} = 0.833$
2142 measured reflections
2142 independent reflections

1687 reflections with $I > 3\sigma(I)$
$\theta_{\max} = 80°$
$h = 0 \rightarrow 13$
$k = 0 \rightarrow 36$
$l = 0 \rightarrow 8$
3 standard reflections every 150 reflections intensity decay: none

Refinement

Refinement on F
$R = 0.044$
$wR = 0.044$
$S = 2.392$
1687 reflections
199 parameters
H atoms not refined
Weighting scheme based on measured s.u.'s; $w = 1/\sigma^2(F)$

$(\Delta/\sigma)_{\max} = 0.052$
$\Delta\rho_{\max} = 0.27$ e Å^{-3}
$\Delta\rho_{\min} = -0.23$ e Å^{-3}
Extinction correction: none
Scattering factors from *International Tables for X-ray Crystallography* (Vol. IV)

Table 1. *Selected geometric parameters (Å, °) for Leu.-o-DMBS.H_2O*

S—O3	1.456 (4)	C4—C5	1.521 (7)
S—O4	1.455 (4)	C4—C6	1.518 (7)
S—O5	1.452 (3)	C7—C8	1.383 (7)
S—C7	1.768 (4)	C7—C12	1.375 (6)
O1—C2	1.195 (4)	C8—C9	1.387 (6)
O2—C2	1.296 (5)	C9—C10	1.378 (6)
N—C1	1.485 (5)	C10—C11	1.399 (7)
C1—C2	1.519 (5)	C10—C13	1.516 (6)
C1—C3	1.526 (6)	C11—C12	1.394 (5)
C3—C4	1.526 (6)	C11—C14	1.510 (7)
O1—C2—C1—N	−6.4 (6)	N—C1—C3—C4	−167.8 (3)
O1—C2—C1—C3	114.6 (5)	C1—C3—C4—C5	−178.3 (4)
O2—C2—C1—N	173.1 (4)	C1—C3—C4—C6	59.7 (5)
O2—C2—C1—C3	−65.9 (5)	C2—C1—C3—C4	73.6 (5)

Leu.*p*-DMBS.H_2O

Crystal data

$C_6H_{14}NO_2^+.C_8H_9O_3S^-.H_2O$
$M_r = 335.41$

Cu $K\alpha$ radiation
$\lambda = 1.5418$ Å

Monoclinic
$P2_1$
$a = 6.163$ (1) Å
$b = 10.199$ (9) Å
$c = 14.140$ (9) Å
$\beta = 94.112$ (9)°
$V = 886.5$ (1) Å^3
$Z = 2$
$D_x = 1.257$ Mg m^{-3}
D_m not measured

Cell parameters from 25 reflections
$\theta = 30$–$40°$
$\mu = 1.860$ mm^{-1}
$T = 298$ K
Plate
0.7 × 0.5 × 0.1 mm
Colourless

Data collection

Rigaku AFC-5*S* diffractometer
$\omega/2\theta$ scans
Absorption correction: empirical *via* ψ scans (North *et al.*, 1968)
$T_{\min} = 0.709$, $T_{\max} = 0.834$
2142 measured reflections
2142 independent reflections

1803 reflections with $I > 3\sigma(I)$
$\theta_{\max} = 80°$
$h = 0 \rightarrow 8$
$k = 0 \rightarrow 13$
$l = -18 \rightarrow 18$
3 standard reflections every 150 reflections intensity decay: none

Refinement

Refinement on F
$R = 0.049$
$wR = 0.060$
$S = 3.729$
1803 reflections
198 parameters
H atoms not refined
Weighting scheme based on measured s.u.'s; $w = 1/\sigma^2(F)$

$(\Delta/\sigma)_{\max} = 0.051$
$\Delta\rho_{\max} = 0.21$ e Å^{-3}
$\Delta\rho_{\min} = -0.50$ e Å^{-3}
Extinction correction: none
Scattering factors from *International Tables for X-ray Crystallography* (Vol. IV)

Table 2. *Selected geometric parameters (Å, °) for Leu.-p-DMBS.H_2O*

S—O3	1.458 (4)	C4—C5	1.535 (8)
S—O4	1.461 (3)	C4—C6	1.53 (1)
S—O5	1.461 (4)	C7—C8	1.391 (7)
S—C7	1.759 (4)	C7—C12	1.409 (7)
O1—C2	1.199 (6)	C8—C9	1.373 (7)
O2—C2	1.312 (6)	C9—C10	1.40 (1)
N—C1	1.478 (6)	C9—C14	1.49 (1)
C1—C2	1.518 (6)	C10—C11	1.35 (1)
C1—C3	1.546 (6)	C11—C12	1.387 (8)
C3—C4	1.519 (8)	C12—C13	1.504 (8)
O1—C2—C1—N	−5.7 (6)	N—C1—C3—C4	−164.3 (4)
O1—C2—C1—C3	114.5 (5)	C1—C3—C4—C5	−170.7 (5)
O2—C2—C1—N	174.9 (4)	C1—C3—C4—C6	66.9 (6)
O2—C2—C1—C3	−64.9 (6)	C2—C1—C3—C4	77.2 (6)

Leu.*p*-TS.H_2O

Crystal data

$C_6H_{14}NO_2^+.C_7H_7O_3S^-.H_2O$
$M_r = 321.39$
Orthorhombic
$P2_12_12_1$
$a = 9.866$ (2) Å
$b = 28.201$ (9) Å
$c = 6.250$ (2) Å
$V = 1739$ (1) Å^3
$Z = 4$
$D_x = 1.228$ Mg m^{-3}
D_m not measured

Cu $K\alpha$ radiation
$\lambda = 1.5418$ Å
Cell parameters from 25 reflections
$\theta = 30$–$40°$
$\mu = 1.875$ mm^{-1}
$T = 298$ K
Plate
0.7 × 0.5 × 0.2 mm
Colourless

Data collection

Rigaku AFC-5*S* diffractometer
$\omega/2\theta$ scans
Absorption correction: empirical *via* ψ scans (North *et al.*, 1968)
$T_{\min} = 0.575$, $T_{\max} = 0.693$
2115 measured reflections
2115 independent reflections

1806 reflections with $I > 3\sigma(I)$
$\theta_{\max} = 80°$
$h = 0 \rightarrow 13$
$k = 0 \rightarrow 36$
$l = 0 \rightarrow 8$
3 standard reflections every 150 reflections intensity decay: none

Refinement

Refinement on *F*
$R = 0.047$
$wR = 0.055$
$S = 2.86$
1806 reflections
189 parameters
H atoms not refined
Weighting scheme based on measured s.u.'s; $w = 1/\sigma^2(F)$

$(\Delta/\sigma)_{\max} = 0.04$
$\Delta\rho_{\max} = 0.23$ e Å^{-3}
$\Delta\rho_{\min} = -0.35$ e Å^{-3}
Extinction correction: none
Scattering factors from *International Tables for X-ray Crystallography* (Vol. IV)

Table 3. *Selected geometric parameters (Å, °) for Leu.-p-TS.H_2O*

S—O3	1.447 (3)	C4—C5	1.512 (8)
S—O4	1.445 (3)	C4—C6	1.506 (7)
S—O5	1.442 (3)	C7—C8	1.370 (6)
S—C7	1.763 (4)	C7—C12	1.355 (6)
O1—C2	1.200 (4)	C8—C9	1.379 (6)
O2—C2	1.285 (5)	C9—C10	1.350 (7)
N—C1	1.472 (4)	C10—C11	1.367 (7)
C1—C2	1.515 (5)	C10—C13	1.516 (6)
C1—C3	1.529 (5)	C11—C12	1.386 (6)
C3—C4	1.504 (6)		
O1—C2—C1—N	−9.2 (6)	N—C1—C3—C4	−168.4 (3)
O1—C2—C1—C3	112.0 (5)	C1—C3—C4—C5	−176.0 (5)
O2—C2—C1—N	168.3 (4)	C1—C3—C4—C6	61.3 (6)
O2—C2—C1—C3	−70.5 (5)	C2—C1—C3—C4	72.6 (5)

Because of the poor ratio of the number of reflections to the number of parameters, the H-atom parameters were not included in the refinement.

For all compounds, data collection: *MSC/AFC Diffractometer Control Software* (Molecular Structure Corporation, 1988); cell refinement: *MSC/AFC Diffractometer Control Software*; data reduction: *MSC/AFC Diffractometer Control Software*; program(s) used to solve structures: *MITHRIL* (Gilmore, 1984); program(s) used to refine structures: *ALLS* (Lapp & Jacobson, 1979); software used to prepare material for publication: *PLUTO* (Motherwell & Clegg, 1983) and *ORTEP*II (Johnson, 1976).

The authors would like to thank Professor T. Yamane and Dr A. Suzuki of Nagoya University, Japan, for helpful advice. They also thank members of the Crystal Physics Laboratory of Tohoku University, Japan, and the editors of the IUCr.

Supplementary data for this paper are available from the IUCr electronic archives (Reference: OA1024). Services for accessing these data are described at the back of the journal.

References

CRC Handbook of Chemistry & Physics (1986). Edited by R. C. Weast, 67th ed. Boca Raton, USA: CRC Press.
Gilmore, C. J. (1984). *J. Appl. Cryst.* **17**, 42–46.
Harding, M. M. & Howieson, R. M. (1976). *Acta Cryst.* B**32**, 633–634.
Hongo, C., Yoshioka, R., Yamada, S. & Chibata, I. (1979). *J. Chem. Tech. Biotechnol.* **29**, 145–148.
Johnson, C. K. (1976). *ORTEP*II. Report ORNL-5138. Oak Ridge National Laboratory, Tennessee, USA.
Kimoto, H., Saigo, K., Ohashi, Y. & Hasegawa, M. (1989). *Bull. Chem. Soc. Jpn*, **62**, 2189–2195.
Lapp, R. L. & Jacobson, R. A. (1979). *ALLS. A Generalized Crystallographic Least-Squares Program.* Department of Energy Report IS-4708 UC-4. Ames Laboratory-DOE, Iowa State University, Ames, Iowa 50011, USA.
Molecular Structure Corporation (1988). *MSC/AFC Diffractometer Control Software.* MSC, 3200 Research Forest Drive, The Woodlands, TX 77381, USA.
Motherwell, W. D. S. & Clegg, W. (1983). *PLUTO. Program for Plotting Molecular and Crystal Structures.* University of Cambridge, England.
Nagai, D. (1963). Japanese Patent No. 40-11373.
North, A. C. T., Phillips, D. C. & Mathews, F. S. (1968). *Acta Cryst.* A**24**, 351–359.
Torii, K. & Iitaka, Y. (1970). *Acta Cryst.* B**26**, 1317–1326.
Torii, K. & Iitaka, Y. (1971). *Acta Cryst.* B**27**, 2237–2246.

Acta Cryst. (1998). C**54**, 641–643

10-Chloro-6,7-dihydro-5*H*-benzo[6,7]cyclohepta[1,2-*b*]quinoline and 10-Methyl-6,7-dihydro-5*H*-benzo[6,7]cyclohepta[1,2-*b*]quinoline

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(Received 5 June 1997; accepted 21 November 1997)

Abstract

The quinoline ring systems in the title molecules, $C_{18}H_{14}ClN$ and $C_{19}H_{17}N$, are planar. The cycloheptane rings are in half-chair conformations and the crystal structures are stabilized by van der Waals interactions.

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