

Article

Synthesis, Characterization, Crystal Structure and Antibacterial Activities of Transition Metal(II) Complexes of the Schiff Base 2-[(4-Methylphenylimino)methyl]-6-methoxyphenol

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Abstract: Five transition metal(II) complexes, [ML₂Cl₂] **1**~**5**, were synthesized from the reaction of MCl₂·nH₂O (M = Mn, Co, Ni, Cu, Cd) and the Schiff base ligand 2-[(4-methylphenylimino)methyl]-6-methoxyphenol (C₁₅H₁₅NO₂, **L**), obtained by condensation of *o*-vanillin (2-hydroxy-3-methoxybenzaldehyde) with *p*-toluidine. They were characterized by elemental analysis, molar conductance, FT-IR spectra, thermal analysis. The structure of complex **1** was determined by single-crystal X-ray diffraction. Its crystal structure is of monoclinic system, space group P2₁/c with a = 9.0111(18) Å, b = 11.222(2) Å, c = 28.130 (6) Å, α = 90 °, β = 92.29(3) °, γ = 90 °, V = 2867.6(10) Å³, Z = 4. The Mn atom is six-coordinate and displays distorted octahedral geometry. The Schiff base ligand and its complexes have been tested *in vitro* to evaluate their antibacterial activity against bacteria, viz., *Escherichia coli*, *Staphylococcus aureus* and *Bacillus subtilis*. It has been found that the complexes have higher activity than the corresponding free Schiff base ligand against the same bacteria.

Keywords: Transition metal(II) complex; crystal structure; Schiff base; antibacterial activity

1. Introduction

Transition metals are necessary for our life, especially Mn, Co and Zn. Manganese is a component of nucleic acids, and can accelerate the synthesis of cholesterol. *o*-Vanillin is a natural aldehyde found in *Andropogon nardus*. It is used to treat bellyaches, and also in spicery [1,2]. Schiff base ligands which usually contain O and N donor atoms have played an important role in coordination chemistry since the late 19th century. Metal complexes with these ligands are becoming increasingly important as biochemical, analytical and antimicrobial reagents, in the design of molecular ferromagnets, in materials chemistry and so on [3-11]. We have previously reported the synthesis and antibacterial activities of Zn and Mn Schiff base complexes [12,13]; as an extension of this work, we now report five new Mn(II), Co(II), Ni(II), Cu(II) and Cd(II) complexes of the Schiff base 2-[(4-methylphenylimino)methyl]-6-methoxyphenol, derived from *o*-vanillin and *p*-toluidine.

2. Results and Discussion

2.1. Elemental analysis, molar conductance

The compositions of the complexes are summarized in Table 1. The C, H, N and M contents (both theoretically calculated values and actual values) are in accordance with the formula ML_2Cl_2 indicating that the Schiff base ligand is neutral. This can be explained by the absence of any deprotonating agent during the synthesis. Complexes in which a Schiff base coordinates as a neutral ligand are still rare. Recent studies [14,15] mention complexes of transition metal (II) ions in which the Schiff base coordinates in this unusual structural form via the phenolic hydroxy oxygen atom and the nitrogen atom remains uncoordinated. Their molar conductance values in DMF solution lie in the range of 11~18 $S \cdot cm^2 \cdot mol^{-1}$, as expected for non-electrolytes [16].

Table 1. Elemental analysis, molar conductance data of ligand and complexes.

Compound	m.p./ °C	Color	Elemental analysis / %*				$\Lambda_M / S \cdot cm^2 \cdot mol^{-1}$
			C	H	N	M	
L	~100	Orange red	74.59 (74.66)	6.30 (6.17)	5.77 (5.81)		2
MnL ₂ Cl ₂ (1)	~260 (dec)	Red	58.97 (59.22)	4.93 (4.97)	5.67 (5.62)	8.89 (9.03)	18
CoL ₂ Cl ₂ (2)	~218 (dec)	Red	58.89 (58.83)	4.92 (4.94)	4.56 (4.58)	9.75 (9.62)	18
NiL ₂ Cl ₂ (3)	~237 (dec)	Orange yellow	58.80 (58.86)	4.88 (4.94)	4.55 (4.58)	9.55 (9.59)	18
CuL ₂ Cl ₂ (4)	~197 (dec)	Brown	58.35 (58.39)	4.86 (4.90)	4.56 (4.54)	10.22 (10.30)	17
CdL ₂ Cl ₂ (5)	~286 (dec)	Red	53.93 (54.11)	4.47 (4.54)	4.18 (4.21)	16.53 (16.88)	11

* Note: values in parentheses are the calculated ones.

2.2. IR spectra

The IR spectra of the complexes are summarized in Table 2. The broad absorption band at 3,468 cm^{-1} is attributed to the hydroxyl group of the free ligand. In complexes the H atom of the Schiff base ligand has a tendency to migrate to the azomethine N atom *via* N–H···O intramolecular hydrogen bonding and its absorption band appears at 3,445 – 3,449 cm^{-1} , showing coordination of oxygen atom of the phenolic hydroxyl with the central M(II), ion as reported in the literature [17]. The shift of the

C–O (Ph-OH) stretching vibration from $1,257\text{ cm}^{-1}$ to $1,237\text{ cm}^{-1}\sim 1,243\text{ cm}^{-1}$ also supports the coordination of oxygen atoms, so we conclude that coordination bonds were formed between the metal ion and the oxygen atoms of the phenol hydroxyl and the methoxy group [7]. However, a strong band in the free Schiff base ligand occurring at $1,614\text{ cm}^{-1}$, attributed to C=N stretching, is found shifted to higher frequency ($1,637\text{ cm}^{-1}\sim 1,644\text{ cm}^{-1}$), although the azomethine nitrogen atom was regarded as a non M(II)-coordinating atom with [14,15]. A new band at $494\text{ cm}^{-1}\sim 501\text{ cm}^{-1}$ attributed to M–O stretching vibration also appears, whereas no such band was apparent in the ligand [18].

Table 2. Values of IR spectra for the ligand and complexes (cm^{-1}).

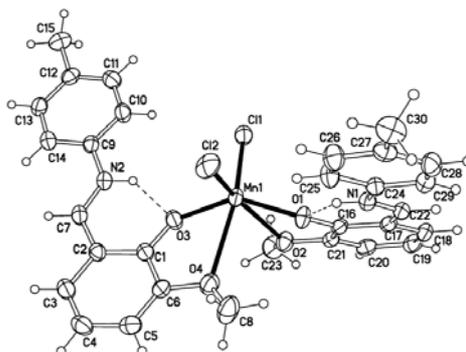
Compound	ν_{OH}	$\nu_{\text{C=N}}$	$\nu_{\text{C-O}}$	$\nu_{\text{M-O}}$
L	3,468 (w)	1,614 (s)	1,257 (s)	
1	3,445 (m)	1,638 (s)	1,237 (s)	497 (w)
2	3,449 (m)	1,641 (s)	1,243 (s)	501 (w)
3	3,447 (m)	1,643 (s)	1,238 (s)	495 (w)
4	3,448 (w)	1,644 (s)	1,237 (s)	494 (w)
5	3,449 (m)	1,637 (s)	1,241 (s)	496 (w)

* Note: s: strong, m: middle, w: weak

2.3. Crystal structure

[MnL₂Cl₂] (**1**): Single crystal X-ray diffraction analysis reveals that complex **1** contains of one Mn(II) atom, two L ligands and two Cl ions (Figure 1). In the [MnL₂Cl₂] unit, the Mn1 atom is six-coordinate by four O atoms of the L ligand 9Mn–O distances in the range of 2.0771(15)–2.6036(17) Å) and two Cl ions (Mn–Cl distances of 2.3921(9) and 2.4233(9) Å respectively), and displays distorted octahedral geometry. There is a weak interaction between Mn(II) and the O2, O4 atoms with Mn–O distance of 2.5228(16) and 2.6036(17) Å. The mean Mn–O(O2,O4) bond distance in **1** is longer than that in the manganese(II) complex [Mn(C₈H₇O₃)₂(H₂O)₂] (2.3506 Å) [19], but shorter than the Mn–O van der Waals radius (3.37 Å), so we know that there exists a weak interaction between Mn(II) and the O2, O4 atoms. The dihedral angles defined by the two phenyl rings of the same L ligand are of 3.113(66)° and 3.040(68)°, so the phenyl rings are almost parallel to each other; this is smaller than that observed in similar Schiff base ligands [20–22]. There are N–H···O intramolecular hydrogen-bonding interactions, which help stabilize this structure.

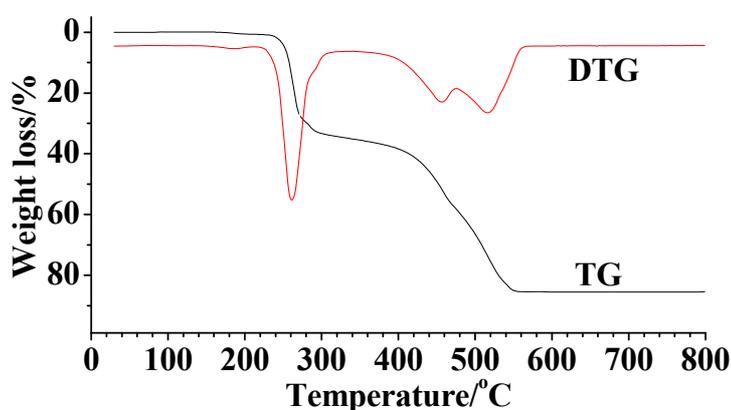
Figure 1. Molecular structure of the complex **1** (probability of ellipsoid is 30%). Intramolecular hydrogen bonds are depicted as dashed lines.



2.4. Thermal analysis

The TG-DTG curves of the complexes are very similar and that of complex **1** is discussed as an example. The TG-DTG curves of complex **1** are shown in Figure 2. The DTG curves show mainly three stages in the decomposition process. The first stage decomposition temperature is in the range of 220.1 °C ~280.3 °C, with a mass loss of 29.56 %, which corresponds to the loss of two *p*-methylbenzenes of a Schiff base ligand (calcd. 29.95 %). In the second to third stage of decomposition in the 285.3°C ~560.6 °C temperature range, the remaining organic ligand molecule and two chloride ions are lost, with a mass loss of 56.90 % (calcd. 57.07 %). The final product is the metal oxide Mn₂O₃ (13.54 %, calcd.12.97 %). These results are in good accordance with the composition of the complexes.

Figure 2. The TG-DTG curve of complex **1**.



2.5. Antibacterial activities

The *in vitro* antibacterial screening of the Schiff base ligand and its complexes dissolved in DMF has been carried out against three bacteria, viz., *Escherichia Coli*, *Staphylococcus Aureus* and *Bacillus Subtilis*, using a filter paper method [23] and an agar medium; the concentration of the test solutions was 5 mg·mL⁻¹ (Table 3). Results showed that the antibacterial effects of these complexes were similar to those of the Zn and Mn complexes [12,13], which we had reported previously.

Table 3. Data of antibacterial activity of ligand and complexes.

Compound	Diameter of inhibition zone (mm)		
	<i>Escherichia Coli</i>	<i>Staphylococcus Aureus</i>	<i>Bacillus Subtilis</i>
L	10.8	10.7	10.7
1	11.8	11.0	11.2
2	11.7	11.7	12.3
3	11.4	11.5	13.3
4	11.4	12.7	13.0
5	18.6	23.1	23.9

* Note: the data in the table are average values of three experiments, the diameter of the filter paper is 10 mm.

It is noteworthy that the complexes have higher activity than the corresponding free Schiff base ligand against the same bacteria, hence, one can conclude that complexation increases the

antibacterial activity. On the other hand, the susceptibility of Schiff base ligand is almost the same for the three bacteria, while its complexes show some differences; the Cd(II) complex has the best antibacterial activities of all complexes against three bacterial spp.

3. Experimental

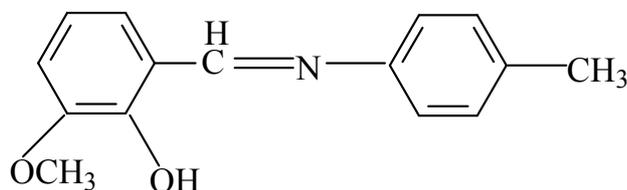
3.1. General

$MCl_2 \cdot nH_2O$, *o*-vanillin, *p*-toluidine, and other chemical reagents were obtained from commercial sources and used without further purification. The metal contents were determined by EDTA complexometric titration after decomposition of a known amount of the complexes with concentrated nitric acid. Elemental analyses were carried out on an Elementar Vario EL III elemental analyzer. IR spectra on KBr pellets were recorded on a Nicolet NEXUS 670 FTIR spectrophotometer in the range of $4,000\text{--}400\text{ cm}^{-1}$. Molar conductivity of the complexes were measured with a Shanghai DDS-11A conductivity meter in methanol ($1.0 \times 10^{-3}\text{ mol} \cdot \text{L}^{-1}$). Thermal analyses were carried out using Mettler-Toledo TGA/SDTA851^e thermal analyzer with a heating rate of $10\text{ }^\circ\text{C} \cdot \text{min}^{-1}$ from $30\text{ }^\circ\text{C}$ to $900\text{ }^\circ\text{C}$ in an air atmosphere.

3.2. Syntheses

$C_{15}H_{15}NO_2$ (**L**): Schiff base ligand (Figure 3) was prepared by the direct solution reaction, as reported in the literature [24], it was recrystallized in methanol before use.

Figure 3. Structure of Schiff base ligand.



MCl_2L_2 : Preparation of MnL_2Cl_2 (**1**). The appropriate transition metal chloride salt (1 mmol) dissolved in anhydrous alcohol (10 mL) was stirred with Schiff base **L** (0.57 g, 2 mmol) in anhydrous alcohol (20 mL) and refluxed for 2 h in a water bath; after cooling to room temperature a solid deposited, which was washed with ethanol and dried. Yield 0.40 g (65%). Red single crystals of complex (**1**) suitable for X-ray diffraction were obtained from its mother liquid after slow evaporation at room temperature for five days.

3.3. Crystal structure determination

A single crystal of **1** with approximate dimensions $0.32 \times 0.26 \times 0.08\text{ mm}^3$ was selected and coated with vaseline. Intensity data for the complex **1** was measured with a Rigaku R-AXIS RAPID diffractometer with graphite-monochromated Mo- $K\alpha$ radiation ($\lambda = 0.71073\text{ \AA}$) at 296 K. Empirical absorption corrections were applied by use of the *ABSCOR* program. The structures were solved by direct methods and all calculations were performed with the aid of the SHELXL PC program [25]. The structures were refined by full-matrix, least-squares minimization of $\Sigma(F_o - F_c)^2$ with anisotropic

thermal parameters for all atoms except H atoms. The crystal data of the complexes **1** was summarized in Table 4, selected bond lengths and angles in Table 5.

Table 4. Crystallographic Data for Complex **1**.

Empirical formula	C ₃₀ H ₃₀ Cl ₂ MnN ₂ O ₄	Density (g/cm ³)	1.409
Formula weight	608.4	<i>M</i> (mm ⁻¹)	0.685
T/ K	293(2)	<i>F</i> (000)	1260
Crystal system	monoclinic	Max. and min. trans.	0.947 and 0.808
Space group	P2 ₁ /c	Data/restraints/parameters	6453 / 0 / 352
<i>a</i> (Å)	9.0111(18)	θ range /°	2.31 to 27.48
<i>b</i> (Å)	11.322(2)	Limiting indices	-11 ≤ <i>h</i> ≤ 11, -14 ≤ <i>k</i> ≤ 14, -36 ≤ <i>l</i> ≤ 36
<i>c</i> (Å)	28.130(6)	Reflections collected/ unique	11540 / 6453
α (°)	90	R _{int}	0.0262
β (°)	92.29(3)	GOOF on <i>F</i> ²	0.938
γ (°)	90	<i>R</i> and <i>wR</i> (<i>I</i> > 2σ(<i>I</i>))	<i>R</i> = 0.0424, <i>wR</i> = 0.0984
<i>V</i> (Å ³)	2867.6(10)	<i>R</i> indices (all data)	<i>R</i> = 0.0782, <i>wR</i> = 0.1076
<i>Z</i>	4	(Δρ) _{max} , (Δρ) _{min} (e ⁻ Å ⁻³)	0.504 and -0.504

Table 5. Selected Bond Lengths (Å) and Bond Angles (°) for Complex **1**.

Bond	Dist.	Bond	Dist.	Bond	Dist.
Mn(1)–O(3)	2.0771(15)	O(1)–C(16)	1.307(2)	O(4)–C(8)	1.420(3)
Mn(1)–O(1)	2.0885(15)	O(2)–C(21)	1.369(2)	N(1)–C(22)	1.308(3)
Mn(1)–Cl(2)	2.3921(9)	O(2)–C(23)	1.423(3)	N(1)–C(24)	1.418(3)
Mn(1)–Cl(1)	2.4233(8)	O(3)–C(1)	1.306(3)	N(2)–C(7)	1.302(3)
Mn(1)–O(2)	2.5229(16)	O(4)–C(6)	1.375(3)	N(2)–C(9)	1.411(3)
Mn(1)–O(4)	2.6036(17)				
Angle	(°)	Angle	(°)	Angle	(°)
O3–Mn(1)–O(11)	146.55(6)	Cl(2)–Mn(1)–O(2)	158.05(4)	C(7)–N(2)–C(9)	128.51(19)
O3–Mn(1)–Cl(2)	103.21(5)	Cl(1)–Mn(1)–O(2)	84.43(5)	C(5)–C(6)–O(4)	126.2(2)
O1–Mn(1)–Cl(2)	91.32(5)	C(16)–O(1)–Mn(1)	123.39(13)	O(4)–C(6)–C(1)	112.9(2)
O3–Mn(1)–Cl(1)	91.55(5)	C(21)–O(2)–C(23)	118.34(18)	N(2)–C(7)–C(2)	123.3(2)
O1–Mn(1)–Cl(1)	111.66(5)	C(21)–O(2)–Mn(1)	109.75(12)	C(10)–C(9)–N(2)	117.6(2)
Cl(2)–Mn(1)–Cl(1)	110.27(3)	C(23)–O(2)–Mn(1)	125.46(15)	C(14)–C(9)–N(2)	122.7(2)
O3–Mn(1)–O(2)	92.23(6)	C(1)–O(3)–Mn(1)	124.31(14)	C(29)–C(24)–N(1)	123.57(19)
O1–Mn(1)–O(2)	67.63(5)	C(22)–N(1)–C(24)	128.11(18)	C(25)–C(24)–N(1)	116.89(19)

4. Supplementary Material

Supplementary crystallographic data have been deposited with the Cambridge Crystallographic Data Centre, CCDC No. 700722. Copies of this information may be obtained free of charge from The Director, CCDC, 12 Union Road, Cambridge CB2 1EZ, UK (Fax: + 44 1223 336033; Email: deposit@ccdc.cam.ac.uk or www: <http://www.ccdc.cam.ac.uk>).

References and Notes

- Huang, Y.S. *Chemistry of Spicery Oil*; Shanghai Science and Technology Press: Shanghai, P.R. China, 1959; p.333.

2. Zhu, R.H.; Xue, Q.C. *Handbook of Synthesis Practical Spicery*; Light Industry Press: Beijing, P.R. China, 1986; p.167.
3. Holm, R.H.; O'Connor, M. The Stereochemistry of Bis-Chelate Metal(II) Complexes. *Prog. Inorg. Chem.* **1971**, *14*, 241-401.
4. Holm, R.H.; Evert, G.W.; Chakravorty, A. Metal Complexes of Schiff Bases and β -Ketoamines. *Prog. Inorg. Chem.* **1966**, *7*, 83-214.
5. Coles, S.J.; Hursthouse, M.B.; Kelly, D.G.; Toner, A.J.; Walker, N.M. Halide titanium(IV) Schiff base complexes; fluoride and bromide derivatives and evidence for a new seven-coordinate chloride intermediate. *J. Chem. Soc., DaltonTrans.* **1998**, 3489-3494.
6. Miyasaka, H.; Ieda, H.; Matsumoto, N.; Crescenzi, R.; Floriani, C. Assembling Bi-, Tri- and Pentanuclear Complexes into Extended Structures Using a Desolvation Reaction: Synthesis, Structure, and Magnetic Properties of Manganese(III)-Schiff-Base-Hexacyanoferrate Polymeric Compounds and Their Derived Extended Structures. *Inorg. Chem.* **1998**, *37*, 255-263.
7. Rodriguez deBarbarin, C.O.; Bailey, N.A.; Fenton, D.E.; He, Q.Y. Zinc(II) complexes derived from potentially hexadentate (N_4O_2) acyclic ligands containing pyridinyl and phenolic groups. *J. Chem. Soc. Dalton Trans.* **1997**, 161-166.
8. Kato, M.; Muto, Y. Factors affecting the magnetic properties of dimeric copper(II) complexes. *Coord. Chem. Rev.* **1988**, *92*, 45-83.
9. Matsushita, T.; Asada, H.; Nakamura, T.; Negoro, S.; Yaguchi, Y.; Sugino, S.; Fujiwara, M. Abstracts Poster Presentations (U). *J. Inorg. Biochem.* **2001**, *86*, 321-330.
10. Iglesias, R.; Marcos, M.; Serano, J.L.; Sierra, T. Ferroelectric Behavior of Chiral Bis(salicylideneaniline) Copper(II), Vanadium(IV), and Palladium(II) Liquid Crystals. *Chem. Mater.* **1996**, *8*, 2611-2617.
11. Cano, M.; Oriol, L.; Pinol, M.; Serano, J.L. Photopolymerization of Reactive Mesogenic Schiff Bases and Related Metallomesogens. *Chem. Mater.* **1999**, *11*, 94-100.
12. Yu, Y.Y.; Zhao, G.L.; Wen, Y.H. Syntheses, Characterizations, Crystal Structures and Antibacterial Activities of Two Zinc(II) Complexes with a Schiff Base Derived from o-Vanillin and p-Toluidine. *Chinese J. Struct. Chem.* **2007**, *26*, 1395-1402.
13. Guo, H.M.; Zhao, G.L.; Yu, Y.Y. Synthesis, Characterization, Crystal Structures and Antibacterial Activities of Transition Metal(II) Complexes with a Schiff Base Derived from o-vanillin and p-toluidine. *Chinese J. Inorg. Chem.* **2008**, *24*, 1393-1399.
14. Zhao, G.L.; Feng, Y.L.; Liu, X.H. Synthesis, Characterization, Crystal Structure and Kinetics of Thermal Decomposition of Zn(II) Complex. *Chinese J. Inorg. Chem.* **2005**, *21*, 598-602.
15. Zhao, G.L.; Wen Y.H.; Yu, Y.Y. Synthesis, Crystal Structure and Kinetic Mechanism of Thermal Decomposition of a Zinc(II) Complex with N-Salicylidene-p-toluidine. *Chinese J. Struct. Chem.* **2006**, *25*, 609-615.
16. Geary, W.J. The use of conductivity measurements in organic solvents for the characterisation of coordination compounds. *Coord. Chem. Rev.* **1971**, *7*, 81-122.
17. Yeap, G.Y.; Ha, S.T.; Ishizawa, N.; Suda, K.; Boey, P.L.; Mahmood, W.A.K. Synthesis, crystal structure and spectroscopic study of para substituted 2-hydroxy-3-methoxybenzalideneanilines. *J. Mol. Struct.* **2003**, *658*, 87-99.

18. Nakamoto, K. *Infrared and Raman spectra of Inorganic and Coordination Compounds*, 5th Ed.; John Wiley & Sons: New York, NY, USA, 1986; pp. 232-234.
19. Gao, J.; Liu, Y. Diaquabis(vanillinato- κ^2O,O')manganese(II). *Acta Cryst.* **2005**, *E61*, m1692-m1693.
20. Zhu, S.Z.; Zhu, S.F.; Jin, G.F.; Li, Z.T. Strong phenyl-perfluorophenyl π - π stacking and C-H \cdots F-C hydrogen bonding interactions in the crystals of the corresponding aromatic aldimines. *Tetrahedron Lett.* **2005**, *46*, 2713-2716.
21. Harada, J.; Harakawa, M.; Ogawa, K. Torsional vibration and central bond length of N-benzylideneanilines. *Acta Cryst.* **2004**, *B60*, 578-588.
22. Teoh, S.G.; Yeap, G.Y.; Teo, S.B.; Declercq, J.P. Protonated ligand outer-sphere complexes formed from the reaction of SnCl₄ with benzalideneaniline and related imines: X-Ray crystal structure of Bis[N-Benzalideneanilinium] Hexachlorostannate(IV). *J. Coord. Chem.* **1995**, *36*, 215-223.
23. Qian, C.R.; Huang, Y.X. *Experiments in Microorganisms*. 3rd Ed.; Peking University Press: Beijing, P.R. China, 1999; p. 54.
24. Yeap, G.Y.; Ha, S.T.; Ishizawa, N.; Suda, K.; Boey, P.L.; Mahmood, W.A.K. Synthesis, crystal structure and spectroscopic study of para substituted 2-hydroxy-3-methoxybenzalideneanilines. *J. Mol. Struct.* **2003**, *658*, 87-99.
25. Sheldrick, G.M. *SHELXS97 and SHELXL97*. Göttingen University: Göttingen, Germany, 1997.

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