Proc. Indian Acad. Sci. (Chem. Sci.), Vol. 91, Number 5, October 1982, pp. 399–407.

Synthesis, identification and analytical properties of the 5,5′-methylenedisalicylhydroxamic acid (MEDSHA)

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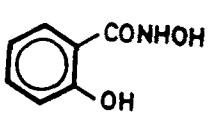
MS received 22 September 1981 ; revised 9 June 1982

Abstract. 5,5′-methylenedisalicylhydroxamic acid (MEDSHA) has been prepared by the reaction of diethyl-5,5′-methylenedisalicylate and hydroxylamine. The solubility, spectral and thermal characteristics, pK values, and reactions with metal ions are reported. Although MEDSHA itself gives precipitates with many metal ions, selectivity can be increased by appropriate control of pH and the use of masking agents, so that it can be used as a reagent for fewer cations.

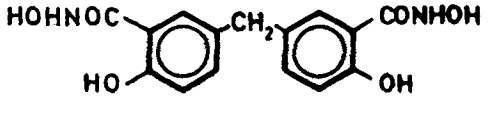
Keywords. Hydroxamic acid ; physicochemical properties ; analytical properties.

1. Introduction

In view of useful analytical applications of hydroxamic acids (Brandt 1960 ; Bass and Yoe 1966; Majumdar 1971) and of salicylhydroxamic acid (SHA, formula I) in particular (Bhaduri 1956; Majumdar and Mukherjee 1960; Pal and Chakraburtty 1963 ; Poddar *et al* 1966), we synthesized and studied 5,5′-methylenedisalicylhydroxamic acid (MEDSHA, formula II) as a new analytical reagent. Since MEDSHA carries two SHA moities bridged through $-CH_2-$, we anticipated improved chelating abilities for it and enhanced insolubility characteristics of its metal derivatives. In this paper we report the synthesis, characteristics and analytical aspects of this reagent.



(I)



(II)

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2. Experimental

2.1. *Material and equipment*

All solvents and chemicals used were of the Reagent Grade.

Infrared spectra were recorded with a Beckman 4240 IR spectrophotometer in the 4000–250 cm^{-1} range, using the KBr pellet technique. The UV–VIS spectrophotometer used was a Beckman ACTA III (1-cm quartz cells). A Hewlett-Packard 5930 A mass spectrometer and a Hitachi Perkin-Elmer R-20 NMR were also used.

The simultaneous TG and DTA analyses of MEDSHA were performed with a Setaram GDTD-10 thermoanalyzer fitted with a B-70 electrobalance with thermocouples of Pt/Pt–Rh in alumina base. The measurements were made in static air atmosphere, at a heating rate of 2° C min^{-1}. Approximately 10 mg samples were taken in an alumina crucible using calcinated α-alumina as reference material.

The solubilities of SHA and MEDSHA in several solvents, were measured by the method of Rose (1966) at 25 ± 0.1° C. The Metrohm E-536 potentiograph with glass and calomel electrodes was used for pH measurements. For determination of the dissociation constants of MEDSHA, both the potentiometric method described by Schwarzenbach *et al* (1947) and the spectrophotometric method described by Thamer (1955) were applied.

2.2. *Synthesis of* MEDSHA

5, 5′-methylenedisalicylic acid (90 g), synthesized employing Oddo's method (Oddo 1940) was taken in ethanol (400 ml) and conc. H_2SO_4 (30 ml) was slowly added. After refluxing the reaction mixture for 3–4 hr, benzene (100 ml) was added. Water produced in the reaction was removed as an azeotrope ethanol-water-benzene (125 ml). The process was repeated five times and the reaction mixture was neutralized with $NaHCO_3$ to obtain a whitish crude ester. The product was extracted with benzene and recrystallized from ethanol. Yield 70% m.p. 100–103° C. Elemental analysis, Found : C, 66.31 ; H, 5.80. Calculated : C, 66·28 ; H, 5·81 for $C_{19}H_{20}O_6$.

The ester (5 g) was slowly added to a stirred solution of hydroxylammonium-chloride (3·5 g) in 12% NaOH (50 ml). The reaction mixture was allowed to stand overnight and 2 N HCl was slowly added to precipitate MEDSHA. The product was purified by recrystallization from water and ethyl acetate-petroleum ether mixture to obtain a colourless powder (m.p. 170 ± 1° C) ; yield 90%, Elemental analysis, Found : C, 56·61 ; H, 4·63 ; N, 9·03. Calculated : C. 56·63 ; H, 4·40 ; N, 8·80 for $C_{15}H_{14}N_2O_6$.

3. Results and discussion

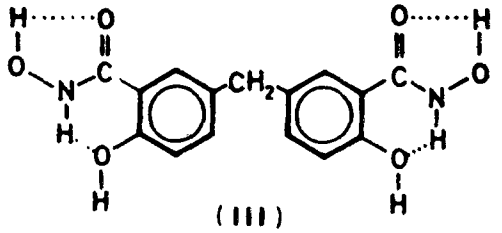
3.1. *Physicochemical properties of* MEDSHA

3.1a. *Spectral and thermal characteristics.* The most important IR bands of MEDSHA are summarized in table 1. The stretching frequency observed at 1620 cm^{-1} and 2870–2955 cm^{-1} correspond to $\nu C = O$ and ν(OH hydroxamic) respec-

tively. The low frequency of these bands indicates hydrogen bonding (Hadži and Prevoršek 1957 ; Mathis 1961 ; Roshama and Agrawal 1978).

On the other hand, it has been observed that the absorption band due to NH stretching vibration when free, appears around 3400 cm^{-1}, but strong hydrogen bonding in the solid state can cause lowering of this band (Mathis 1961). Similarly, the band at 3130 cm^{-1} is assigned to the stretching of the intramolecularly bonded OH phenolic group (Conley 1973).

Thus, it is concluded that the structural type III represents the most probable configuration of MEDSHA, in analogy with the proposed structure for SHA (Larsen 1978).



(III)

Table 1. Spectral properties of MEDSHA

IR	
νNH frequency, cm^{-1}	3290s*
νC = O (amide I band) frequency, cm^{-1}	1620s
νOH hydroxamic frequency, cm^{-1}	2870s 2918s 2955s
νOH phenolic frequency, cm^{-1}	3130s, b
δNH (amide II band) frequency, cm^{-1}	1580s
νC–N (amide III band) frequency, cm^{-1}	1420m
νNO frequency, cm^{-1}	970w

Mass s.	Relative Intensities (%)
M^+ ion (*m/e* 318)	1
base peak (*m/e* 33)	100
$[M-32]^+$	2
$[M-33]^+$	2
$[M-66]^+$	8

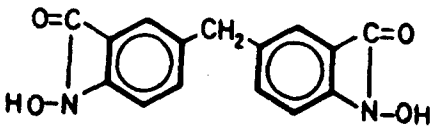
UV s.	ϵ (1 $mol^{-1}cm^{-1}$)
223 nm, λ_1 max (ethanol)	$2'95 \cdot 10^4$
310 nm, λ_2 max (ethanol)	$7'4 \cdot 10^3$
213 nm, λ_1 max (water)	$3'16 \cdot 10^4$
300 nm, λ_2 max (water)	$6'8 \cdot 10^3$

*Abbreviations : s = strong ; m = meedium ; w = wak and b = broad

Mass spectral data of MEDSHA are listed in table 1. The ease with which MEDSHA decomposes at the melting temperature explains the very low abundance (1%) of the molecular ion in the spectrum of this compound. The base peak was located at *m/e* 33, the result of a loss of the NH_2OH groups from the molecular ion. Such a rearrangement agrees with the observed rearrangement of *o*-substituted aromatic amides (Simon and Clerc 1970).

The $[M-32]^+$ ion in the spectrum of MEDSHA indicates that oxygen is lost at the hydroxylamino positions (Bapat *et al* 1969 ; Akers *et al* 1975).

At the first stage of the thermal decomposition of MEDSHA, two molecules of water are eliminated, with a corresponding mass loss on the TG curve occurring between 150 and 202° C and an exothermic peak on the DTA curve at 172° C. The IR spectrum of a sample of MEDSHA heated at 170° C contains a strong absorption centered around 1750 cm^{-1}. This frequency is characteristic of stretching of a C = O which belongs to a four-membered ring (Brewster *et al* 1970). These effects must be attributed to the N-hydroxylactam formation (IV).



(IV)

Finally, the intermediate N-hydroxylactam decomposes in the temperature range 200–600° C, exhibiting a pronounced exothermic peak at 526° C.

The absorption maxima of MEDSHA and their molar extinction coefficients (ϵ), in aqueous and ethanolic solutions, are given in table 1. The absorption spectrum of MEDSHA shows a pH dependence in aqueous solution in the pH range of 6 to 12. This is shown by a hyperchromic and bathochromic effect of the maximum at 213 nm as the pH is increased. At the same time, the maximum at 300 nm is displaced bathochromically. In strong basic medium two new absorption maxima appeared at 325 nm and 243 nm. These effects are attributed to the dissociation steps.

3.1b. *Solubilities of* SHA and MEDSHA *in several solvents.* The results obtained (table 2) indicate that, in all instances, SHA is much more soluble than MEDSHA. However, we have found that the solubility of MEDSHA in water increases exponentially with temperature, according the equation $\ln S = 0{\cdot}059\,T - 4{\cdot}047$ (S, g/l ; T, °C).

Spectrophotometric measurements indicate that the solutions of MEDSHA ($5{\cdot}10^{-5}$ M) in water are stable for at least five days, whereas the ethanolic solutions are stable for at least a month.

3.1c. *Acidity.* The data presented in table 3 show good agreement between the two sets of values. It seems reasonable to assume that both SHA and MEDSHA should show similar dissociation behaviour. In fact, the pK_a values for MEDSHA are in the same range as those observed for SHA ($pK_1 = 7{\cdot}90$; $pK_2 = 10{\cdot}30$)

Table 2. Solubilities of SHA and MEDSHA in several solvents at 25 ± 0·1° C

Solvent	Solubility, g/l	
	SHA	MEDSHA
Water	2·93	0·08
Ethanol	60·18	30·05
Methanol	93·56	49·26
Acetone	54·06	10·72
Chloroform	1·91	0·88
Dioxane	67·42	8·20

Table 3. Acid dissociation constants of MEDSHA at 25 ± 0·1° C (μ = 0·1M, $KClO_4$)

	Method	
	Schwarzenbach	Thamer
pK_1	7·4 ± 0·1	7·5 ± 0·1
pK_2	8·3 ± 0·3	8·1 ± 0·1
pK_3	9·5 ± 0·1	9·9 ± 0·2
pK_4	10·9 ± 0·8	11·0 ± 0·6

(Kunitake *et al* 1976). There is some controversy regarding the assignment of pK_a values to the dissociations of the –OH, the –NH and the –NOH groups in SHA. While one of the investigating groups (Jabalpurwala *et al* 1964 ; Ingle and Khanolkar 1975 ; Bergmann and Tashma 1975) attributed the low pK_a value to the phenolic OH, this value is ascribed to the –CONHOH function by another group (Exner and Kakač 1963 ; Dutt and Seshadri 1969 ; Desphande and Jahagirdar 1977). On the other hand, it is now an accepted fact that the hydroxamic acids belong to the N-acids (Bauer and Exner 1974).

In a recent study on metallic complexes of MEDSHA we have observed that the hydroxamic groups are more acidic than the phenolic ones (Gazquez 1981). Therefore, we feel that pK_1 and pK_2 of MEDSHA should be ascribed to the dissociation of the –NH groups and pK_3 and pK_4 to the phenolic groups.

3.2. *Chelating properties of* MEDSHA

The reactions of 40 metal ions with MEDSHA were tested at different pH values, and the results are summarized in table 4.

Almost in all cases the respective complex compounds were precipitated, except those of Ag(I) and Au(III). It has been observed that in Pd(II), Mo(VI), Fe(III) Co(II), Co(III) and Fe(II), precipitation takes place at lower pH before intense coloration at higher pH.

Table 4. Reactions of MEDSHA with metallic ions. Effect of several masking agents on the metal–MEDSHA reaction.

Metal–MEDSHA reactions				Masking reactions								
Metal ion	Colour of complex	Optimum pH range	pD[a]	HCl 2N	H_2SO_4 2N	EDTA	F^-	tar	CN^-	SCN^-	PO_4^{3-}	$C_2O_4^{2-}$
Ag(I)	red	7–12	4′0			+ (>11)[b]			+ (>11)	+ (>11)		
Pb(II)	white	3–11	4′5			+ (5–7)			–			
Hg(I)	brown	3–9	4′2			+ (3–9)			+ (3–9)	+ (3–9)		
Hg(II)	yellow	5–9	3′4			+ (7–9)			+ (7–9)	+ (7–9)		
Bi(III)	white	0–12	4′6	+ (<3)	–	+ (<3)						
Cu(II)	green	0–12	4′8	–	+	+ (0–12)		–	+ (3–12)	–		
Cd(II)	white	5–9	3′8			+ (5–7)			+ (5–7)			
Tl(III)	brown	3–7	3′6			+ (3–7)						p(3–7)
Au(III)	red	0–12	3′9	+	+	+ (5–12)			+ (5–12)	+ (5–12)		
Pd(II)	yellow	0–12	4′7	+	+	+ (0–12)			+ (3–12)			
Sn(II)	white	0–5	5′0	–	–	–	p (0–5)	–			–	–
Sb(III)	white	0–4	4′6	p	–	–		+ (0–4)				
Mo(VI)	yellow	0–12	5′8	–	–	–				–	–	–
Os(VIII)	brown	0–5	4′0	+	+	+ (0–5)				+ (0–5)		
Al(III)	white	3–9	4′5			p (3–9)	+ (3–9)	–			–	+ (3–9)
Cr(III)	gray-green	5–12	5′0			+ (5–12)	–		–	–	+ (5–12)	–
Fe(III)	red	0–12	5′7	p	p	+ (0–7)	–	–	–	–	–	–
Co(II)	brown	0–12	5′0	+	p	+ (>11)			+ (0–12)			+ (>11)
Co(III)	red-brown	0–12	5′0	+	+	+ (0–12)			+ (0–12)			–
Ni(II)	green	5–11	4′2			+ (5–11)	–		+ (5–11)		+ (5–11)	p (5–11)
Fe(II)	red	0–12	6′0	+	+	p (0–12)			+ (0–12)			

Zn(II)	white	5–9	4·0			+ (5–9)			p (5–9)	–	–	+ (5–9)
Mn(II)	white	5–7	4·0			+ (5–7)	–	–	–		–	p (5–7)
Be(II)	white	3–9	5·3			–	+ (5–7)	–				
V(V)	violet	0–7	5·8	–	–	–	–	–		–		–
UO_2^{2+}	orange	3–11	5·0			+ (7–9)	–	–			+ (7–9)	p (7–9)
Ti(IV)	yellow	0–9	6·0	–	–	–	+ (0–7)		–			–
Zr(IV)	white	0–9	5·0	–	–	p (0–7)	p (0–7)	–	–		–	+ (<3)
Th(IV)	white	0–9	5·2	+	+	+ (3–7)	p (0–7)	–			p (0–7)	+ (3–7)
In(III)	white	3–9	4·7			+ (3–7)	–					–
Y(III)	white	3–11	4·9			+ (3–7)	p (3–7)				–	–
Sc(III)	white	0–11	5·2	+	+ (<3)	+ (3–5)	+ (<3)					p (<3)
W(VI)	white	0–4	4·9	–	–	–	–	–	–		–	–
Ga(III)	white	0–7	4·6	p	p	p (<3)	–	–			–	
La(III)	white	4–12	4·8			+ (4–7)						–
Co(IV)	red	3–12	5·0			+ (3–7)		p (3–7)			+ (3–7)	+ (3–7)
Ca(II)	white	5–11	5·2			+ (5–11)	p (5–11)	+ (5–11)			p (5–11)	–
Sr(II)	white	5·9	4·3			+ (7–9)	+ (7–9)				p (7–9)	p (7–9)
Ba(II)	white	5–11	4·3			+ (5–7)	+ (5–7)					p (5–7)
Mg(II)	white	5–11	4·3			+ (5–11)	+ (5–7)	p (5–7)			+ (5–11)	+ (5–11)

tar = tartrate , $C_2O_4^{2-}$ = oxalate

(a) Detection limit (~1g mg metal/l)

(b) + indicates that the metal ion is masked completely ; Numbers in parentheses represent the pH range of masking
– indicates that reaction occurs with MEDSHA

p indicates that the metal ion is masked not completely

The solubilities of the complexes of MEDSHA are lower than those of the corresponding SHA complexes (Bhaduri 1956 ; Poddar *et al* 1966 ; Bhaduri and Ráy 1952 ; Chatterjee 1978), because of the higher molecular weight of MEDSHA. Moreover, this reagent possesses two chelation sites that could be utilized in chelating two metal ions simultaneously, giving rise thereby to very insoluble polynuclear complexes.

Although MEDSHA itself is a highly unselective reagent, selectivity can be increased by appropriate control of pH and the use of masking agents. Data on the influence of various masking agents on the reactions of metal ions with MEDSHA, in aqueous medium, are also summarized in table 4.

The strongest masking agent, over wide ranges of acidity, is EDTA. In the presence of EDTA only a few metals (Sn(II), Sb(III), Mo(VI), Be(II), V(V), Ti(IV) and Sc(III)) react completely with MEDSHA.

Cyanide is a very powerful masking agent for periodic groups IB and IIB, and for Fe(II), Co(II), Co(III) and Ni(II), as they usually form extremely stable cyanide complexes.

On the other hand, it is obvious that strong acid medium increases the selectivity of MEDSHA with regard to some cations, such as Sn(II), Mo(VI), V(V), Ti(IV), Zr(IV) and W(VI). In fact, we have described a new simple method for the spectrophotometric determination of vanadium in HCl 2N medium (Salinas *et al* 1982). This method has been successfully used for determination of vanadium in petroleum crudes and derivatives and is free from the interference of nickel(II), iron (III) and several other elements which are often associated with vanadium.

The most characteristic reaction of the hydroxamic acids is the red-violet complexes which they form with iron(III) in acid medium. It is very interesting to note that iron(III) is precipitated by MEDSHA in the presence of F^-, CN^- and PO_4^{3-}.

As can be seen from table 4, V(V), Mo(VI), Ti(IV), W(VI) and Sn(II) form very stable complexes with MEDSHA. Only Ti(IV) is masked completely by F^- in the presence of MEDSHA. In view of these facts, we are investigating at present the use of a combination of two or more masking agents to improve the selectivity of new methods for the quantitative determination of these ions using 5, 5′-methylenedisalicylhydroxamic acid.

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