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Interaction of metal ions with *N*-glycosylamines: isolation and characterization of the products of 4,6-*O*-benzylidene-*N*-(*o*-carboxyphenyl)-β-D-glucopyranosylamine with different metal ions

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Abstract

Metal-ion complexes of Li^+, Na^+, K^+, Mg^{2+}, Ca^{2+}, Ba^{2+}, Pb^{2+}, Cd^{2+}, Hg^{2+} with 4,6-*O*-benzylidene-*N*-(*o*-carboxyphenyl)-β-D-glucopyranosylamine were synthesized and isolated as solid products and characterized by analytical means as well as by spectral techniques, such as, ^1H and ^{13}C NMR, FTIR, absorption, FAB mass spectrometry, optical rotation and CD. While the alkali metal ions formed ML type of complexes, the other metal ions formed ML_2 type complexes. Molecular weights of the complexes of Li^+, Na^+ and K^+ were established based on the molecular-ion peaks in the FAB mass spectra. The saccharide portion remians in the β-anomeric form even after the complexation. The spectral data, as well as the trends observed in the chemical shifts, indicate the interaction preferences between this glycosyl amine and different metal ions, and further reveal certain structural features of the complexes.

Keywords: 4,6-*O*-Benzylidene-*N*-(*o*-carboxyphenyl)-β-D-glucopyranosylamine; Anthranilic acid; Alkali metal ions; Alkaline earth metal ions; Metal–ion interaction

1. Introduction

Saccharide units are present in glycoproteins, glycolipids and several antibiotics[1]. These play important roles in various biological processes[2]. In some enzymatic reactions of saccharides, alkali, alkaline earth and transition metal ions have been suggested to act in cooperation[3]. Thus, it is important to elucidate the interaction that exists between such saccharide units and metal ions in order to understand their biological chemistry. A prerequisite to this is to have some model studies. The literature is scant with respect to such model studies due to the problems associated with the stereochemistry of the saccharides and the hygroscopic nature of the resultant products[4–6]. In this context, we propose to perform the studies of metal–ion interactions with glycosyl units by isolating and characterizing the resultant products. Therefore, herein we report the synthesis and characterization of metal-ion complexes of alkali, alkaline earth, and Pb^{2+}, Cd^{2+} and Hg^{2+} with an *N*-glycosylamine, 4,6-*O*-benzylidene-*N*-(*o*-carboxy-

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phenyl)-β-D-glucopyranosylamine, as a model study.

2. Experimental

All solvents were purified and dried prior to use by adopting routine procedures. Saccharides (Lancaster, UK), anthranilic acid (SRL, India), metal acetates (SRL, India) of lead, cadmium, mercury, and metal hydroxides (SRL, India) of lithium, sodium, potassium, barium, calcium, magnesium were purchased and used without further purification.

NMR spectra were measured on a Bruker Avance DRX 500 spectrometer operating at 500 MHz for ^{1}H, and 126 MHz for ^{13}C nuclei. FTIR spectra were recorded on a Nicolet Magna IR 550 spectrometer in a KBr matrix in the region of 400–4000 cm^{-1}. The microanalyses were performed on a Carlo–Erba elemental analyser. The FAB mass spectra were recorded on a JEOL SX 102/DA-6000 mass spectrometer using argon as the FAB gas at 6 kV and 10 mA. The absorption spectra were recorded on a Shimadzu UV-2101 spectrophotometer in Me_2SO solution using a compound concentration of 10^{-4} M, in the UV region. Optical rotations were measured on a Jasco DIP-370 digital polarimeter. CD experiments were performed on a JASCO J-600 spectropolarimeter in Me_2SO. While assigning the spectral data, several abbreviations were used, and these include, 'Ar' for aromatic, 'Gly' for glycosidic, 'Sac' for saccharide, 'Ano' for anomeric, and 'Ace' for acetal.

4,6-*O*-Benzylidene-D-glucopyranose was synthesised as per the literature procedure[7] and its identity was confirmed based on analytical and spectral data. The corresponding *N*-glycosylamine, 4,6-*O*-benzylidene-*N*-(*o*-carboxyphenyl)-β-D-glucopyranosylamine (H_4L) was also synthesised using 4,6-*O*-benzylidene-D-glucopyranose and anthranilic acid in a 1:1 molar ratio, and the product was characterized as reported earlier[8].

Metal-ion complexes **1–9**.—All the complexes **1–9** were synthesized using the same general procedure unless otherwise mentioned. A typical procedure for the synthesis of sodium complex **2** is as follows: To a solution of 1.13 g (3.02 mmol) of H_4L in 15 mL of MeOH, 0.13 g (3.20 mmol) of solid NaOH was added, and the mixture was allowed to stir at rt. After 24 h the stirring was stopped, the reaction mixture was concentrated to ~5 mL under vacuum, and to this Et_2O was added to precipitate the product. The product was isolated by filtration and purified by redissolving the product in MeOH, followed by precipitation using Et_2O. The product was further purified by washing with THF (5 mL) followed by drying under vacuum.

Similar procedures were adopted for the synthesis of the other metal-ion complexes, but using metal hydroxides in the case of Li^+, **1**; K^+, **3**; Mg^{2+}, **4**; Ca^{2+}, **5**; Ba^{2+}, **6**, and using metal acetates in the case of Pb^{2+}, **7**; Cd^{2+}, **8** and Hg^{2+}, **9**. In the case of the complexes of the divalent metal ions, **4–9**, a 1:2 metal to ligand ratio was used.

$Li(H_3L)\cdot 3H_2O$ (**1**): mp 148–150 °C; $[\alpha]_D^{25}$ −50.0° (c 1, Me_2SO); FTIR (KBr): 3300 *ν* (O–H) and *ν* (N–H), 2875 *ν* (C–H), 1617, 1584 *ν* (C=O) and *δ* (N–H), 1509 *ν* (C=C), 1384 *ν* (C–O), 1087 *δ* (C–O) cm^{-1}; ^{1}H NMR (Me_2SO-d_6): *δ* 9.943 (d, 1 H, $^3J_{H1,NH}$ 7.32 Hz, Gly′-NH), 7.825 (d, 1 H, Ar-H), 7.368–7.466 (m, 5 H, Ar-H), 7.088 (t, 1 H, Ar-H), 6.732 (d, 1 H, Ar-H), 6.515 (t, 1 H, Ar-H), 5.800 (br, 1 H, Sac-OH), 5.620 (br, 1 H, Sac-OH), 5.600 (s, 1 H, Ace-H), 4.645 (t, 1 H, $^3J_{H1,H2}$ 8.42 Hz, Ano-H), 4.168 (q, 1 H, Sac-H), 3.450–3.669 (m, 6 H, Sac-H); ^{13}C NMR (Me_2SO-d_6): *δ* 171.5 (1 C, COOH), 148.5–111.6 (12 C, Ar-C) 100.6 (1 C, Ace-C), 85.6–66.3 (1 C, Sac-C); FABMS: *m*/*z* 394 $[M+H]^+$; Anal. Calcd for $C_{20}H_{26}LiNO_{10}$: C, 53.70; H, 5.86; Li, 1.55; N, 3.13. Found: C, 54.04; H, 5.34; Li, 1.43; N, 3.57.

$Na(H_3L)\cdot 1.5H_2O$ (**2**): mp 166–168 °C; $[\alpha]_D^{25}$ −51.0° (c 1, Me_2SO); FTIR (KBr): 3369 *ν* (O–H) and *ν* (N–H), 2888 *ν* (C–H), 1613, 1584 *ν* (C=O) and *δ* (N–H), 1508 *ν* (C=C), 1393 *ν* (C–O), 1093 *δ* (C–O) cm^{-1}; UV (Me_2SO) λ/nm ($\varepsilon/M^{-1}cm^{-1}$): 267 (2,729), 314 (5,590); ^{1}H NMR (Me_2SO-d_6): *δ* 10.019 (d, 1 H, $^3J_{H1,NH}$ 7.51 Hz, Gly-NH), 7.821 (dd, 1 H, Ar-H), 7.457–7.475 (m, 2 H, Ar-H), 7.352–7.399 (m, 3 H, Ar-H), 7.084 (t, 1 H, Ar-H), 6.733 (d, 1 H, Ar-H), 6.513 (t, 1 H, Ar-H), 5.812 (br, 1 H, Sac-OH), 5.622 (br, 1 H, Sac-OH), 5.578 (s, 1 H, Ace-H), 4.653 (t, 1 H,

$^3J_{H1,H2}$ 8.65 Hz, Ano-H), 4.168 (dd, 1 H, Sac-H), 3.638 (t, 1 H, Sac-H), 3.485–3.560 (m, 3 H, Sac-H), 3.415 (t, 1 H, Sac-H); ^{13}C NMR (Me_2SO-d_6): δ 171.8 (1 C, COOH), 111.5–148.4 (12 C, Ar-C), 100.6 (1 C, Ace-C), 66.4–85.3 (6 C, Sac-C); FABMS: m/z 410 $[M+H]^+$; Anal. Calcd for $C_{20}H_{23}NNaO_{8.5}$: C, 55.05; H, 5.28; Na, 5.27; N, 3.21. Found: C, 54.53; H, 5.07; Na, 5.79; N, 3.52.

$K(H_3L)\cdot 1.5H_2O$ (**3**): mp 140–142 °C; $[\alpha]_D^{25}$ −62.0° (c 1, Me_2SO); FTIR (KBr): 3408 ν (O–H) and ν (N–H), 2905 ν (C–H), 1618, 1587 ν (C=O) and δ (N–-H), 1513 ν (C=C), 1388 ν (C–O), 1087 δ (C–O) cm^{-1}; UV (Me_2SO) λ/nm ($\varepsilon/M^{-1}cm^{-1}$): 265 (2,290), 320 (6,260); ^{1}H NMR (Me_2SO-d_6): δ 9.987 (d, 1 H, $^3J_{H1,NH}$ 6.96 Hz, Gly-NH), 7.799 (d, 1 H, Ar-H), 7.368–7.466 (m, 5 H, Ar-H), 7.080 (t, 1 H, Ar-H), 6.724 (d, 1 H, Ar-H), 6.509 (t, 1 H, Ar-H), 6.200–6.400 (br, 1 H, Sac-OH), 5.900 (br, 1 H, Sac-OH), 5.576 (s, 1 H, Ace-H), 4.630 (t, 1 H, $^3J_{H1,NH}$ 8.42 Hz, Ano-H), 4.171 (dd, 1 H, Sac-H), 3.146–3.676 (m, 5 H, Sac-H); ^{13}C NMR (Me_2SO-d_6): δ 171.0 (1 C, COOH), 112.3–148.9 (12 C, Ar-C), 100.7 (1 C, Ace-C), 66.5–84.9 (6 C, Sac-C); FABMS: m/z 426 $[M+H]^+$; Anal. Calcd for $C_{20}H_{23}KNO_{8.5}$: C, 53.09; H, 5.09; K, 8.65; N, 3.10. Found: C, 53.11; H, 5.82; K, 8.71; N, 2.53.

$Mg(H_3L)_2$ (**4**). mp 142–144 °C; FTIR (KBr): 3327 ν (O–H) and ν (N–H), 2870 ν (C–H), 1616, 1583 ν (C=O) and δ (N–H), 1505 ν (C=C), 1402 ν (C–O), 1090 δ (C–O) cm^{-1}; UV (Me_2SO) λ/nm ($\varepsilon/M^{-1}cm^{-1}$): 265 (1,790), 321 (9,630); UV (Me_2SO) λ/nm ($\varepsilon/M^{-1}cm^{-1}$): 266 (1,810), 322 (9,630); ^{1}H NMR (Me_2SO-d_6): δ 9.297 (br, 1 H, Gly-NH), 7.896 (d, 1 H, Ar-H), 7.367–7.479 (m, 5 H, Ar-H), 7.200 (t, 1 H, Ar-H), 6.821 (d, 1 H, Ar-H), 6.593 (t, 1 H, Ar-H), 5.578 (s, 1 H, Ace-H), 5.491 (br, 2 H, Sac-OHs), 4.697 (t, 1 H, $^3J_{H1,H2}$ 8.400 Hz, Ano-H), 4.175 (dd, 1 H, Sac-H), 3.275–3.668 (m, 5 H, Sac-H); ^{13}C NMR (Me_2SO-d_6): δ 173.1 (1 C, *C*OOH), 111.9 Me_2SO 148.1 (12 C, Ar-*C*), 100.7 (1 C, Ace-*C*), 66.4–84.9 (6 C, Sac-*C*); Anal. Calcd for $C_{40}H_{54}MgN_2O_{21}$: C, 52.04; H, 5.90, Mg, 2.63; N, 3.04. Found: C, 52.02; H, 5.06; Mg, 2.91, N, 2.54.

$Ca(H_3L)_2\cdot 1.5H_2O$ (**5**): mp > 210 °C; $[\alpha]_D^{25}$ −72.0° (*c* 1, Me_2SO); FTIR (KBr): 3357 ν (O–H) and ν (N–H), 2879 ν (C–H), 1613, 1561 ν (C=O) and δ (N–H), 1508 ν(C=C), 1393 ν (C–O), 1093 δ (C–O) cm^{-1}; UV (Me_2SO) λ/nm ($\varepsilon/M^{-1}cm^{-1}$): 267 (3,400), 321 (7,310); ^{1}H NMR (Me_2SO-d_6): δ 9.551 (d, 1 H, $^3J_{H1,NH}$ 6.000 Hz, Gly-NH), 7.909 (d, 1 H, Ar-H), 7.469 (t, 2 H, Ar-H), 7.347–7.387 (m, 3 H, Ar-H), 7.174 (t, 1 H, Ar-H), 6.813 (d, 1 H, Ar-H), 6.579 (t, 1 H, Ar-H), 5.584 (s, 1 H, Ace-H), 5.556 (br, 1 H, Sac-OH), 5.524 (br, 1 H, Sac-OH), 4.726 (t, 1 H, $^3J_{H1,H2}$ 8.50 Hz, Ano-H), 4.176 (dd, 1 H, Sac-H), 3.20–3.80 (m, 5 H, Sac-H); ^{13}C NMR (Me_2SO-d_6): δ 174.3 (1 C, *C*OOH), 148.5–111.8 (12 C, Ar-*C*), 100.6 (1 C, Ace-*C*), 84.9–66.5 (6 C, Sac-*C*); Anal. Calcd for $C_{40}H_{43}CaN_2O_{15.5}$: C, 57.21; H, 5.12; Ca, 4.78; N, 3.34. Found: C, 56.91; H, 5.42; Ca, 4.77; N, 3.88.

$Ba(H_3L)_2\cdot 2H_2O$ (**6**): mp 170–172 °C; $[\alpha]_D^{25}$ −27.0° (*c* 1, Me_2SO); FTIR (KBr): 3325 ν (O–H) and ν (N–H), 2880 ν (C–H), 1613, 1586 ν (C=O) and δ (N–H), 1506 ν (C=C), 1382 ν (C–O), 1094 δ (C–O) cm^{-1}; UV (Me_2SO) λ/nm ($\varepsilon/M^{-1}cm^{-1}$): 266 (4,030), 317 (11,980); ^{1}H NMR (Me_2SO-d_6): δ 9.761 (d, 1 H, $^3J_{H1,NH}$ 6.88 Hz, Gly-NH), 7.857 (d, 1 H, Ar-H), 7.346–7.467 (m, 6 H, Ar-H), 7.129 (t, 1 H, Ar-H), 6.775 (d, 1 H, Ar-H), 6.548 (t, 1 H, Ar-H), 5.579 (br, 3 H, Ace-H, Sac-OH's), 4.702 (t, 1 H, $^3J_{H1,H2}$ 7.93 Hz, Ano-H), 4.169 (d, 1 H, Sac-H), 3.392–3.650 (m, 5 H, Sac-H); ^{13}C NMR (Me_2SO-d_6): δ 173.6 (1 C, *C*OOH), 148.4–111.6 (12 C, Ar-*C*), 100.6 (1 C, Ace-*C*), 85.0–66.4 (6 C, Sac-*C*); Anal. Calcd for $C_{40}H_{44}BaN_2O_9$: C, 50.78; H, 4.69; Ba, 14.52; N, 2.96. Found: C, 51.25; H, 4.71; Ba, 13.92; N, 3.23.

$Pb(H_3L)_2$ (**7**): mp 158–160 °C; $[\alpha]_D^{25}$ −26.0° (*c* 1, Me_2SO); FTIR (KBr): 3439 3292 ν (O–H) and ν (N–H), 2878 ν (C–H), 1612, 1585 ν (C=O) and δ (N–H), 1508 ν (C=C), 1378 ν (C–O), 1094 δ (C–O) cm^{-1}; UV (Me_2SO) λ/nm ($\varepsilon/M^{-1}cm^{-1}$): 269 (11,160), 333 (12,960); ^{1}H NMR (Me_2SO-d_6): δ 9.042 (d, 1 H, $^3J_{H1,NH}$ 6.96 Hz, Gly-NH), 7.829 (d, 1 H, Ar-H), 7.459 (d, 2 H, Ar-H), 7.381 (d, 3 H, Ar-H), 7.242 (t, 1 H, Ar-H), 6.884 (d, 1 H, Ar-H), 6.642 (t, 1 H, Ar-H), 5.574 (s, 1 H, Ace-H), 5.397 (s, 2 H, Sac-OH's), 4.767 (t, 1 H, $^3J_{H1,H2}$ 8.78 Hz, Ano-H), 4.165 (dd, 1 H, Sac-H), 3.250–3.676 (m, 5 H, Sac-H); ^{13}C

NMR (Me_2SO-d_6): δ 174.3 (1 C, *C*OOH), 148.5–112.6 (12 C, Ar-*C*), 100.6 (1 C, Ace-*C*), 84.5–66.5 (6 C, Sac-*C*); Anal. Calcd for $C_{40}H_{40}N_2O_{14}Pb$: C, 49.03; H, 4.11; N, 2.86; Pb, 21.14;. Found: C, 48.83; H, 4.04; N, 2.65; Pb, 22.05.

$Cd(H_3L)_2{\cdot}3.5H_2O$ (**8**): mp 162–164 °C; $[\alpha]_D^{25}$ − 54.0° (*c* 1, Me_2SO); FTIR (KBr): 3473 3323 ν (O–H) and ν (N–H), 2880 ν (C–H), 1621, 1587 ν (C=O) and δ (N–H), 1509 ν (C=C), 1388 ν (C–O), 1097 δ (C–O) cm^{-1}; UV (Me_2SO) λ/nm ($\varepsilon/M^{-1}cm^{-1}$): 266 (3,840), 317 (12,700); ^1H NMR (Me_2SO-d_6): δ 9.021 (d, 1 H, $^3J_{H1,NH}$ 7.04 Hz, Gly-NH), 7.943 (d, 1 H, Ar-H), 7.461 (d, 2 H, Ar-H), 7.381 (d, 3 H, Ar-H), 7.276 (t, 1 H, Ar-H), 6.908 (d, 1 H Ar-H), 6.654 (t, 1 H, Ar-H), 5.586 (s, 1 H, Ace-H), 5.350 (q, 2 H, $^3J_{OH,H}$ 4.51, 5.48 Hz, Sac-OH), 4.792 (t, 1 H, $^3J_{H1,H2}$ 7.89 Hz, Ano-H), 4.183 (dd, 1 H, Sac-H), 3.666 (t, 1 H, Sac-H), 3.554–3.581 (m, 2 H, Sac-H), 3.465 (t, 1 H, Sac-H), 3.281 (t, 1 H, Sac-H); ^{13}C NMR (Me_2SO-d_6): δ 174.0 (1 C, *C*OOH), 148.5–112.4 (12 C, Ar-*C*), 100.6 (1 C, Ace-*C*), 84.5–66.6 (6 C, Sac-*C*); Anal. Calcd for $C_{40}H_{47}CdN_2O_{17.5}$: C, 50.66; H, 4.96; Cd, 11.86; N, 2.96. Found: C, 50.48; H, 5.62; Cd, 12.01; N, 2.46.

$Hg(H_3L)_2{\cdot}H_2O$ (**9**): mp 136–138 °C; $[\alpha]_D^{25}$ − 54.0° (*c* 1, Me_2SO); FTIR (KBr): 3330 ν (O–H) and ν (N–H), 2877 ν (C–H), 1615, 1584 ν (C=O) and δ (N–H), 1507 ν (C=C), 1379 ν (C–O), 1095 δ (C–O) cm^{-1}; UV (Me_2SO) λ/nm ($\varepsilon/M^{-1}cm^{-1}$): 267 (6,810), 315 (12,830); ^1H NMR (Me_2SO-d_6): δ 8.623 (br, 1 H, Gly-NH), 7.881 (br, 1 H, Ar-H), 7.470 (t, 2 H, Ar-H), 7.352–7.390 (m, 4 H, Ar-H), 6.966 (d, 1 H, Ar-H), 6.699 (d, 1 H, Ar-H), 5.592 (s, 1 H, Ace-H), 5.450 (br, 1 H, Sac-OH), 5.361 (d, 1 H, $^3J_{OH,H}$ 4.76 Hz, Sac-OH), 4.767 (t, 1 H, $^3J_{H1,H2}$ 8.54 Hz, Ano-H), 4.192 (dd, 1 H, Sac-H), 3.420–3.680 (m, 5 H, Sac-H); ^{13}C NMR (Me_2SO-d_6): δ 174.3 (1 C, *C*OOH), 148.9–112.9 (12 C, Ar-*C*), 100.6 (1 C, Ace-*C*), 84.4–66.6 (1 C, Sac-*C*); Anal. Calcd for $C_{40}H_{42}HgN_2O_{15}$: C, 48.46; H, 4.27; Hg, 20.23; N, 2.83. Found: C, 48.24; H, 3.94; Hg, 20.45; N, 2.96.

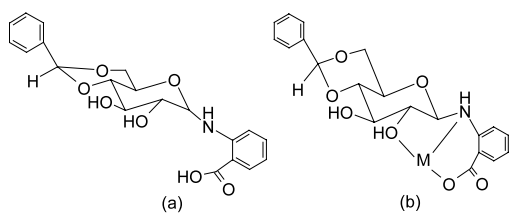

Fig. 1. Schematic representation of (a) the structure of the ligand, H_4L; (b) binding of the metal ion through the formation of five- and six-membered chelates.

3. Results and discussion

The ligand, H_4L_{COOH}, shown in Fig. 1(a), was reacted in a 1:1 molar ratio with alkali metal ions to result in the formation of complexes of the type ML, viz., Li^+, **1**; Na^+, **2**; K^+, **3**. The same ligand was reacted in a 1:2 ratio with metal salts of Mg^{2+}, **4**; Ca^{2+}, **5**; Ba^{2+}, **6**; Pb^{2+}, **7**; Cd^{2+}, **8**; Hg^{2+}, **9** to result in the formation of the complexes of the type ML_2. The complexes were characterised by analytical and spectral methods, including FAB mass spectrometry, ^1H and ^{13}C NMR spectroscopy, FTIR spectroscopy, absorption spectroscopy, optical rotation, and CD studies.

NMR studies.—^1H and ^{13}C spectra of the ligand and different metal-ion complexes **1**–**9** were recorded in Me_2SO-d_6 and were assigned upon comparing these spectra of the complexes with that of the ligand H_4L. The comparison clearly demonstrates the formation of metal-ion complexes.

^1H NMR studies.—The resonances corresponding to –COOH, –NH and –OH groups were cross-checked by measuring the spectra after adding D_2O. ^1H NMR spectra of the ligand H_4L and some representative complexes, Na^+, **2**; Ca^{2+}, **5**; Hg^{2+}, **9** are shown in Fig. 2. While the ligand H_4L exhibited its –COOH proton resonance around 12.9 ppm as a broad band, the corresponding metal-ion complexes **1**–**9** were devoid of this resonance, indicating the loss of this proton upon complexation through the carboxylate moiety that results in the formation of a six-membered chelate as shown in Fig. 1(b).

A downfield shift in the glycosylic –NH proton was observed with the metal-ion complexes **1**–**9** to different extents (8.62 to 10.02 ppm) when compared to the same in the ligand (8.43 ppm). The observed downfield shifts ($\Delta\delta$) of the glycosylic N–H in the metal-ion

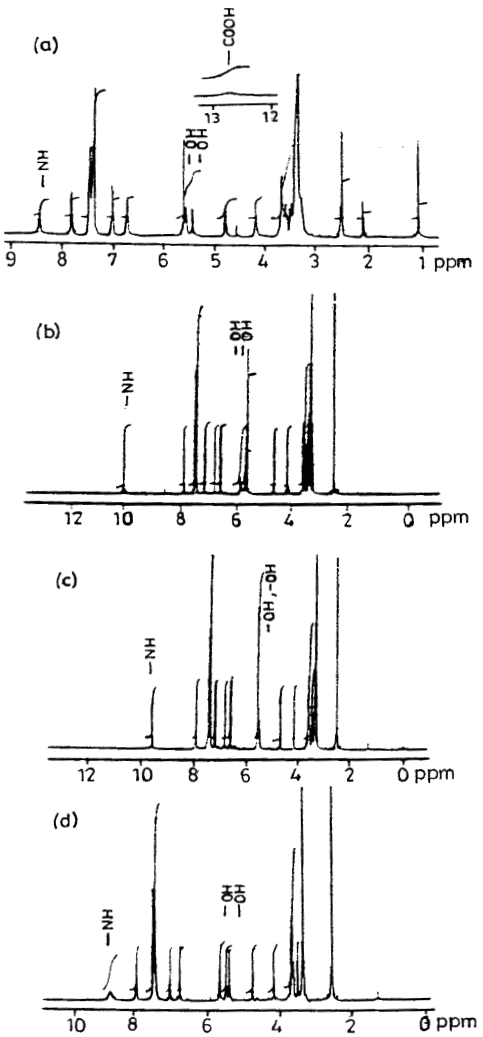

Fig. 2. ^{1}H NMR spectra of (a) H_4L; (b) Na^+, **2**; (c) Ca^{2+}, **5**; and (d) Hg^{2+}, **9** in Me_2SO-d_6.

complexes are in the order, alkali (1.50–1.59 ppm) > alkaline earth (0.90–1.33 ppm) > Pb^{2+} and Cd^{2+} (0.5–0.6 ppm) ≫ Hg^{2+} (0.2 ppm). These results were further corroborated by the downfield shifts observed with the aromatic carbon attached to the glycosylic –NH group in the ^{13}C NMR spectra of the same complexes.

Comparison of the chemical shift values of the saccharide–OH groups of the ligand with the corresponding metal-ion complexes revealed downfield shifts ($\Delta\delta$) of one of the –OH resonances in the case of alkali metal-ion complexes, **1** (0.26 ppm), **2**, (0.27 ppm) and **3** (0.33 ppm). However, the other complexes, **4**–**9** do not exhibit any such downfield shift with either of the –OH groups. It is probable that the –OH group that exhibits downfield shift arises from the 2-OH as this can be involved in the formation of a five-membered chelate with the metal ion as shown in Fig. 1(b).

The saccharide moiety exhibits the β-anomeric form both in the ligand as well as in its metal-ion complexes **1**–**9** as determined from the chemical shift of H-1 as well as its coupling constants with $^{3}J_{C1H,C2H} = 7.9–8.7$ Hz.[9] The acetal proton does not show any change in its chemical shift upon complexation.

^{13}C NMR studies.—Considerable downfield shifts were observed in the carbon chemical shifts of the carboxylic acid moiety in the metal-ion complexes, **1**–**9** when compared to the same in the ligand. The average down-field shifts ($\Delta\delta$) observed with the carboxylate carbon follows a trend: alkali complexes **1**–**3** ($\sim$1.7 ppm) < alkaline earth complexes **4**–**6** ($\sim$4.0 ppm) < Pb^{2+}, Cd^{2+} and Hg^{2+} complexes **7**–**9** ($\sim$4.5 ppm). Similar order has been observed in the binding efficiency of *s*-block elements when the reactions were carried out with heparin[10] and chondroitin-4-sulfate.[11]

On the other hand, the average downfield shifts ($\Delta\delta$) observed with the anomeric (C-1) carbon follows the order: alkali complexes **1**–**3** ($\sim$1.0 ppm) > alkaline earth complexes **4**–**6** ($\sim$0.75 ppm) > Pb^{2+}, Cd^{2+} and Hg^{2+} complexes **7**–**9** ($\sim$0.3 ppm). This trend supports that observed in the proton chemical shifts of the glycosylic –NH.

FTIR studies.—Comparison of the FTIR spectra of the complexes **1**–**9** with the corresponding ligand indicated the complex formation. FTIR spectra of the ligand H_4L and some representative complexes, Li^+, **1**; Mg^{2+}, **4**; Hg^{2+}, **9** are shown in Fig. 3. In the ν_{OH} region of the spectra, the complexes **1**–**9** exhibited broad bands compared to those of the ligand, indicating that the interactions associated with the saccharide –OH and glycosylic –NH groups were modified upon complex formation. A broad band observed around 3350 cm^{-1} in the ligand spectrum is shifted in the complexes to higher frequency and appears with the presence of some shoulders. Further, the spectral changes observed in the case of the metal-ion complexes in the region 1000–1500 cm^{-1} are also indicative of the binding

of the ligand to the metal-ion center. Strong bands were observed for the metal-ion complexes **1**–**9** around 755 and 699 cm^{-1}, indicating the presence of the β anomer. These values are also supported by a literature report[12]. Presence of the β anomer was also concluded based on the chemical shifts and coupling constants observed in the ^1H NMR spectra of the complexes and the corresponding data is reported in the experimental section.

Comparison of the stretching vibration of the carbonyl group of the carboxylic acid between the ligand and the metal-ion complexes **1**–**9** shows a shift by 62–71 cm^{-1} towards lower frequency, indicating the coordination of the carboxylic acid group with the metal ion. The difference[13] between ν_{as} (COO^-) and ν_s (COO^-) observed in case of alkali metal-ion complexes **1**–**3** (~ 200 cm^{-1}) suggests a monodentate binding nature for the carboxylate moiety, whereas the same for **4**–**9** (124–137 cm^{-1}) suggests a bidentate mode of binding.

Absorption studies.—Comparison of the absorption spectrum of the ligand with that of the metal ion complexes **1**–**9** indicated complex formation. The band observed around 330 nm shifted to lower wavelength by about 10–17 nm in the metal-ion complexes. In addition to this, the metal-ion complexes exhibited another band around 270 nm. However, the ratio of the intensity of the 330 nm to 270 nm band, varies from the alkali **1**–**3** (2–3.3), to the alkaline earth **4**–**6** (2–5) to the post transition ions **7**–**9** (1.1–3.3), indicating that the binding nature of the ligand is different in different metal-ion complexes. Such intensity ratio analysis would be of use in establishing the binding of metal ions with the saccharide based biopolymers and/or antibiotics.

Optical rotation and CD studies.—Optical rotation measurements of all the complexes were found to be levorotatory (see Section 2). The CD spectra of the ligand H_4L and the metal-ion complexes all exhibited a negative Cotton effect around 310 nm. The corresponding spectrum of the ligand and some representative spectra of the complexes, Na^+, **2**; Ca^{2+}, **5**; Ba^{2+}, **6** and Hg^{2+}, **9** are shown in Fig. 4.

FAB mass spectral studies.—Mass spectra of the ligand and its complexes Li^+, **1**; Na^+, **2** and K^+, **3** exhibited molecular-ion peaks, and thereby the corresponding molecular weights were confirmed.

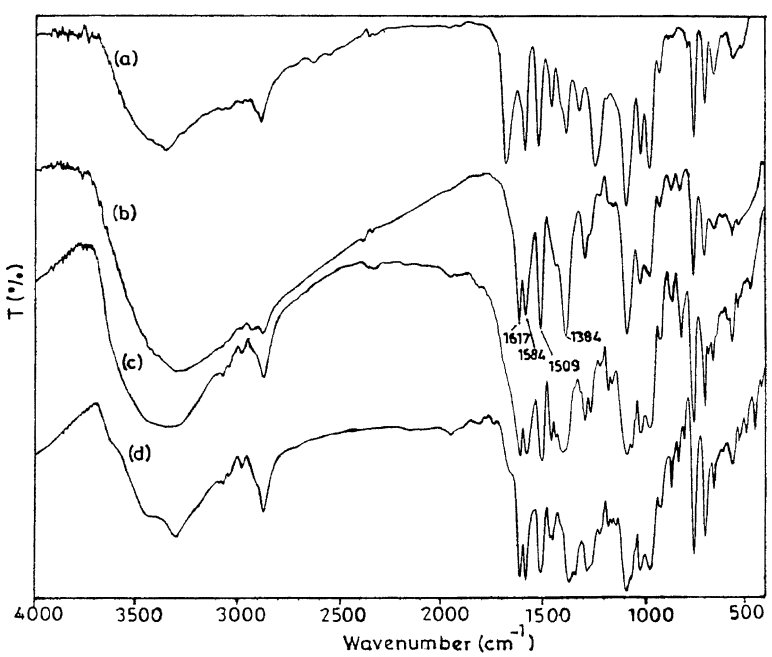

Fig. 3. FTIR spectra of (a) H_4L; (b), Li^+, **1**; (c), Mg^{2+}, **4**; and (d), Hg^{2+}, **9** in KBr.

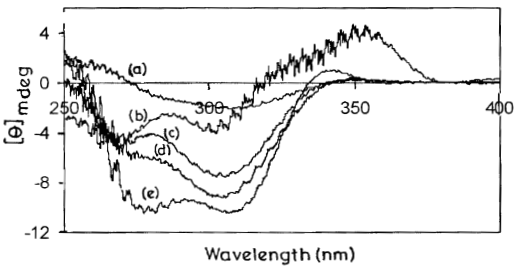

Fig. 4. CD spectra of the compounds (a) Hg^{2+}, **9**; (b), H_4L; (c) Ba^{2+}, **6**; (d), Ca^{2+}, **5**; and (e) Na^{+}, **2** in Me_2SO.

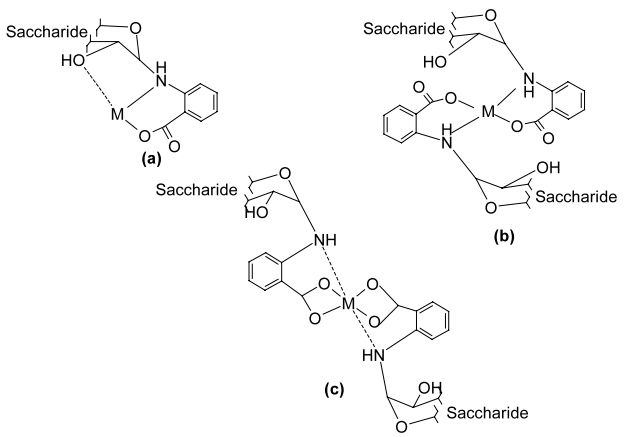

Fig. 5. Proposed structural motifs for the binding of (a) alkali ions; (b) alkaline earth ions; and (c) Pb^{2+} and Cd^{2+}. The broken line indicates possible weak interactions.

Nature of the products and conclusions.— The study of complexation of *N*-glycosylamine with different metal ions show binding of the carboxylate, the glycosylic –NH and, in a few cases, the saccharide –OH group. Even after binding to metal ions, the anomeric configuration of the saccharide was unaltered and remained in the β form. All the trends observed with the ^1H and ^{13}C chemical shifts together indicate that, while the alkali metal ions **1–3** exhibit a rather strong affinity towards the glycosylic moiety, those of Pb^{2+}, Cd^{2+} and Hg^{2+} exhibit an affinity with the carboxylate portion, and the alkaline earth ions **4–6** exhibit an intermediate behavior. These results, when combined with those obtained from FTIR studies, allow structural motifs to be proposed for the binding of these metal ions as shown in Fig. 5. In the lattice, the metal-ion centers may acquire higher coordination numbers to fulfil the coordination sphere through sharing. While the common coordination numbers are four to six with the alkali ions, these are from six to eight in case of the alkaline earth ions. Indeed, such sharing was observed in the case of the K^+ complex of 4,6-*O*-ethylidene-*N*-(*o*-carboxyphenyl)-β-D-glucopyranosylamine as revealed in our recent single-crystal X-ray diffraction study[14].

Complexations of the saccharides with metal ions are generally hampered by some problems, such as easy anomerisation, conformational change and configurational inversion in the presence of metal ions, weak acidic nature of the saccharide –OH groups[15], etc. These were overcome by selective blocking as well as by C-1 N-glycosylation[14] as reported in this paper. Thus the present studies of the interaction of metal ions with simple *N*-glycosylamines, such as 4,6-*O*-benzylidene-*N*-(*o*-carboxyphenyl)-β-D-glucopyranosylamine, as well as 4,6-*O*-ethylidene-*N*-(*o*-carboxyphenyl)-β-D-glucopyranosylamine, serve as models for understanding the interactions that may occur between the saccharide-based biological molecules and metal ions.

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