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Metal-Ion Interactions with Sugars. The Crystal Structure of $CaCl_2$-Fructose Complex

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The single-crystal structure of $CaCl_2 \cdot 2C_6H_{12}O_6 \cdot 3H_2O$ was determined with Mr=525.34, a=16.054(7) Å, b=7.864(4) Å, c=10.909(5) Å, β=127.894(8)°, V=1086.9(9) Å^3, C2, Z=2 and R=0.0227 for 1727 observed reflections. The fructose moiety of the complex exists as a β-D-pyranose. The calcium ion is surrounded by eight oxygen atoms, These are arranged in symmetry-related pairs derived from four sugar and two water molecules. Three nonvicinal hydroxyl groups of fructose are involved in calcium binding. All the hydroxyl groups and water molecules are involved in forming an extensive hydrogen-bond network.

Key Words : Ca-D-fructose complex, Crystal structure, Coordinate

Introduction

Solution studies show that simple carbohydrates strongly bind calcium ions only if they can provide three contiguous axial-equatorial-axial (ax-eq-ax) hydroxyl groups on six-membered rings or vicinal *cis-cis*-triol groups on five-membered rings.[1-5] D-fructose, which has no 'complexing forms', is a well known ketose occurring widely in nature. However, the single-crystal of Sr-fructose complex reported by our group[6] shows that D-fructose can also coordinate with Sr ions by a different mode. Such metal-fructose interactions in solution may be concluded to be similar to those metal-saccharide interactions in biological fluids that take part in many different biological functions. Metal-carbohydrate interactions have been implicated in a variety of biological processes.[7-11] Therefore the study of metal-monosaccharide interactions is of particular significance.

We are currently investigating the crystal structures of such metal-monosaccharide complexes. The crystals of such complexes are normally difficult to obtain from aqueous solution because of hydrogen bonding. To obtain single crystals of Sr-fructose complex needs several months. In the present work, we synthesised a Ca-fructose complex in methanol solution, and single crystals of the complex were obtained after only three days. The structure of a single crystal was determined by x-ray, and confirmed to be $CaCl_2 \cdot 2C_6H_{12}O_6 \cdot 3H_2O$. The structure is similar to that of the Sr-fructose complex obtained from aqueous solution.

Experimental

Materials. D-Fructose (99.8%) was purchased from Acros and was used without purification. Methanol (AR) and $CaCl_2 \cdot 2H_2O$ (AR) were purchased from Tianjin Chemical Reagent Co., Inc, Tianjin, China, and was used as supplied.

Preparation of Ca(β-D-fructose)$_2$Cl$_2$·3H$_2$O. D-Fructose (0.90 g, 5 mmol) and equivalent amounts of $CaCl_2 \cdot 2H_2O$ were dissolved in Methanol. Clear and prismatic crystals of Ca(β-D-fructose)$_2$Cl$_2$·3H$_2$O were grown by evaporating the solution over three days at room temperature. Anal. Calcd for Ca(β-D-fructose)$_2$Cl$_2$·3H$_2$O: C, 27.44; H, 5.76. Found: C, 27.29; H, 5.78.

Physical Measurements. The structure of Ca(β-D-fructose)$_2$Cl$_2$·3H$_2$O was determined on a Bruker SMART 1000 CCD detector/PLATFORM diffractometer using monochromatic Mo Kα radiation (λ = 0.71073 Å) in the θ range from 2.37° to 25.03° at 293 K. The final cycle of full-matrix least-squares refinement was based on 1727 observed reflections. Calculations were completed with SHELX-97 program.

Results and Discussion

Crystal data are listed in Table 1. Selected bond lengths and bond angles are collected in Table 2. The structure and atom numbering scheme are shown in Figure 1. The projections of the crystal cell in the crystal structure of Ca(β-D-fructose)$_2$Cl$_2$·3H$_2$O along b axis are shown in Figure 2.

The fructose exists in the title complex as a pyranose with the β-D configuration in the $^2C_5$ chair conformation. The calcium ion is surrounded by eight oxygen atoms that form a distorted square-antiprism. The Ca-O distances range from 2.457 to 2.499 Å. The oxygens, in symmetry-related pairs, are derived from four sugar and two water molecules. Of the five hydroxyls available in each fructose molecule, only O(6), O(2), and O(1) are involved in the complex formation.

It can be seen from Table 2 that the distances between the calcium ions and the water molecules (including Ca(1)-O(7B) and Ca(1)-O(7AA)) is 2.457 Å is which is shorter than the other Ca-O distances. This regular pattern is consistent with those observed in other Ca-sugar complexes.[12-14] It can be interpreted that the calcium ion is coordinated by four fructose molecules, so the environment around the cal-

Table 1. Crystal data and structure refinement parameters for $CaCl_2 \cdot 2C_6H_{12}O_6 \cdot 3H_2O$

Formula	$CaCl_2 \cdot 2C_6H_{12}O_6 \cdot 3H_2O$
Formula weight	525.34
Crystal system, Space group	Monoclinic, C2
a (Å)	16.054(7)
b (Å)	7.864(4)
c (Å)	10.909(5)
β (º)	127.894(8)
V (Å^{-3})	1086.9(9)
Z	2
Dcalcd (Mg/m^3)	1.605
Absorption coefficient (mm^{-1})	0.605
F(000)	552
Crystal size (mm)	0.30 × 0.25 × 0.20
θ Range for data collection (º)	2.37-25.03
Index ranges	-18 ≤ h ≤ 8, -9 ≤ k ≤ 9, -6 ≤ l ≤ 12
Reflections collected/unique	1922 / 1727 [R(int) = 0.0167]
Completeness to θ = 25.03(%)	94.5
Absorption correction	Semi-empirical from equivalents
Max/min transmission	0.8885 and 0.8392
Refinement method	Full-matrix least-squares on F^2
S	1.053
Final R indices [I > 2σ(I)]	R1 = 0.0212, wR2 = 0.0552
R indices (all data)	R1 = 0.0227, wR2 = 0.0560
Absolute structure parameter	0.03(3)
Largest difference peak and hole (e/A^3)	0.139 and -0.167
Data/restraints/parameters	1727 / 1 / 153

Table 2. Selected bond lengths (Å) and angles (º) for $CaCl_2 \cdot 2C_6H_{12}O_6 \cdot 3H_2O$

Ca(1)-O(1)	2.499(3)	O(1)-C(2)	1.436(3)
Ca(1)-O(2)	2.470(3)	O(2)-C(3)	1.436(3)
Ca(1)-O(6)	2.464(3)	O(3)-C(4)	1.429(2)
Ca(1)-O(7)	2.457(3)	O(4)-C(5)	1.406(2)
O(5)-C(5)	1.428(2)	O(5)-C(1)	1.431(3)
O(6)-C(6)	1.424(3)	O(6)-C(6)	1.424(3)
C(1)-C(2)	1.518(3)	C(2)-C(3)	1.524(3)
C(3)-C(4)	1.524(3)	C(4)-C(5)	1.520(3)
C(5)-C(6)	1.525(3)		
O(1)-Ca(1)-O(2)	63.6(13)	O(7)-Ca(1)-O(2)	70.70(9)
O(7)-Ca(1)-O(2)	132.9(10)	C(5)-O(5)-C(1)	115.09(16)
O(5)-C(1)-C(2)	113.10(18)	O(1)-C(2)-C(1)	114.90(17)
O(1)-C(2)-C(3)	107.43(17)	C(1)-C(2)-C(3)	109.92(16)
O(2)-C(3)-C(2)	107.34(16)	O(2)-C(3)-C(4)	110.08(18)
C(2)-C(3)-C(4)	109.77(16)	O(3)-C(4)-C(5)	109.46(15)
O(3)-C(4)-C(3)	110.31(15)	C(5)-C(4)-C(3)	110.56(17)
O(4)-C(5)-O(5)	112.12(16)	O(4)-C(5)-C(4)	107.75(15)
O(5)-C(5)-C(4)	109.49(15)	O(4)-C(5)-C(6)	109.86(15)
O(5)-C(5)-C(6)	103.98(16)	C(4)-C(5)-C(6)	113.71(18)
O(6)-C(6)-C(5)	111.98(15)		

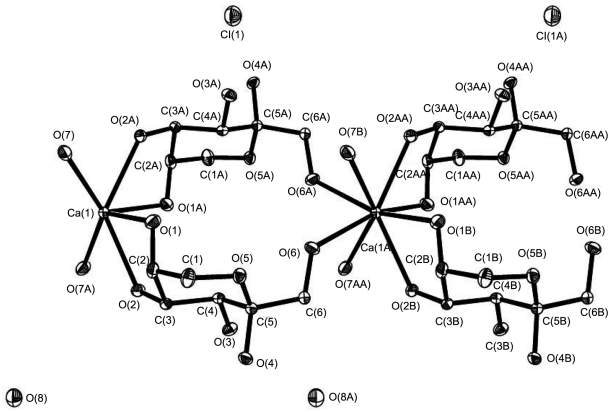

Figure 1. The structure and atom numbering scheme of Ca(β-D-fructose)$_2$Cl$_2$·3H$_2$O.

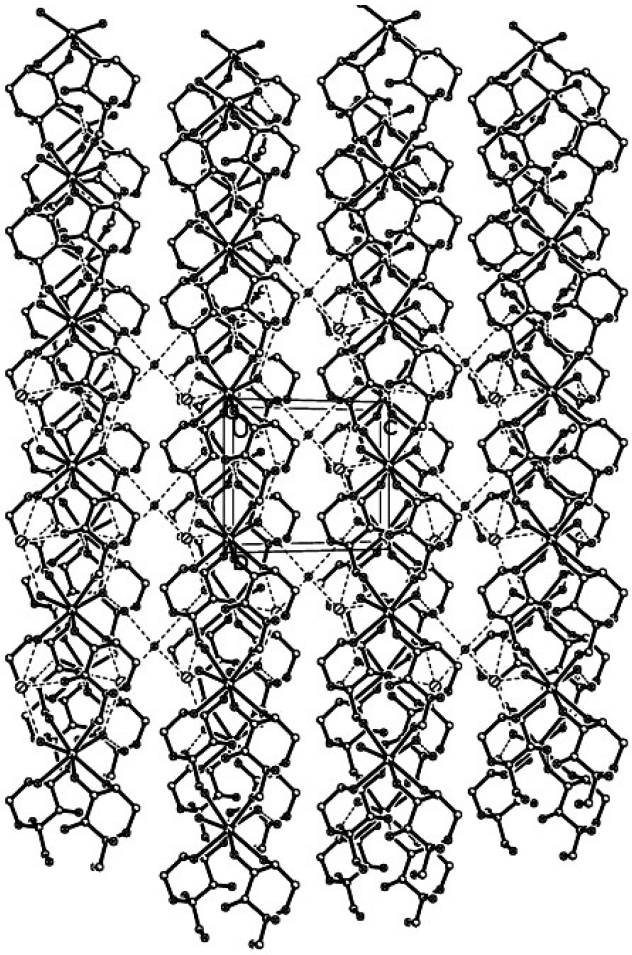

Figure 2. Projection of the packed crystal in the structure of Ca(β-D-fructose)$_2$Cl$_2$·3H$_2$O along b axis.

cium ions is very crowded. Therefore the fructose molecules can not approach Ca^{2+} freely as that the water molecules do.

The D-fructose molecules are arranged in chains parallel to the b-axis, formed by coordination to translation-related calcium ions. The chains are separated by sheets parallel to the a-b plane containing the calcium and chloride ions and the water molecules. As would be expected, there is an extensive network of hydrogen bonds involving hydroxyl

Table 3. Hydrogen bonds for $CaCl_2{\cdot}2C_6H_{12}O_6{\cdot}3H_2O$ with H…A < r(A) + 2.000 Å and <DHA> 110°

D-H...A	d(D-H)	d(H...A)	d(D...A)	<(DHA)
O1-H1...Cl1#1	0.852	2.308	3.143	166.85
O2-H2... O3#2	0.944	1.919	2.775	149.68
O3-H3...Cl1#3	0.981	2.137	3.077	159.92
O4-H4... O8 #4	0.945	1.795	2.706	160.92
O6-H6... Cl1#1	0.877	2.699	3.478	148.80
O7-H7A... O4 #5	0.851	2.023	2.872	175.12
O7-H7B... Cl1#6	0.830	2.285	3.110	172.72
O8-H8...Cl1#7	0.989	2.094	3.069	168.16

Symmetry transformations used to generate equivalent atoms: #1 −x, y, −z+1 #2 −x+1/2, y−1/2, −z+1 #3 x, y, z−1 #4 x, y+1, z #5 x+1/2, y−1/2, z, #6 −x+1, y−1, −z+1 #7 −x+1/2, y−1/2, −z+1

groups, water molecules, and chloride ions, which appears to use all of the hydrogen atoms that are covalently bonded to oxygen atoms (see Table 3). It is by the extensive network of intra- and intermolecular hydrogen bonds that these chains are joined and form a sheet. These sheets are thus organized to form the whole packed crystal structure.

The title complex appears to be isostructural with the strontium chloride analogue which is obtained from pure water, but the crystals can be obtained more easily from methanol solution. However, no other fructose-metal complex can be obtained in the IIA group, which indicates that size plays an important role in the coordinating process. Of the two metal-fructose complexes obtained, the bond lengths of Sr-O (2.551 to 2.619 Å) are longer than those of Ca-O (2.457 to 2.499 Å). This indicates that the coordination of Ca^{2+} to fructose is stronger than that of Sr^{2+} and the ionic radius of Ca^{2+} (0.99 Å) is the more suitable size for coordination with fructose. This effect can also be observed from the change of torsion angles of the fructose moiety. The torsion angles of fructose before and after coordinating are compared in Table 4. The torsion angles of the fructose can be seen to have changed on coordination, This change is more obvious in the Fru-Ca complex than in the Fru-Sr complex, which indicates that the Ca^{2+} binds more strongly with D-Fructose than Sr^{2+} does.

Table 4. The torsion angles of fructose and its complexes (°)

Torsion angle	Fructose[15]	Fructose-Ca	Fructose-Sr[6]
C(5)-O(5)-C(1)-C(2)	-58.0	-55.0(2)	-56.1(5)
O(5)-C(1)-C(2)-C(3)	56.5	51.5(2)	53.5(5)
C(1)-C(2)-C(3)-C(4)	-54.7	-52.9(2)	-54.7(4)
C(2)-C(3)-C(4)-C(5)	52.2	56.9(2)	56.7(4)
C(1)-O(5)-C(5)-C(4)	55.6	56.8(2)	57.1(4)
C(3)-C(4)-C(5)-O(5)	-52.7	-57.4(2)	-56.6(4)

Supplementary Material. Crystallographic data (without structure factors) for the structure reported in this paper have been deposited with the Cambridge Crystallographic Data Centre as supplementary publication No. CCDC-197387. Copies of the data can be obtained free of charge on application to the CCDC, 12 Union Road, Cambridge CB2 1EZ, U.K. [http://www.ccdc.cam.ac.uk; Fax: (internat.) +44-1223/336033; E-mail: deposit@ ccdc.cam.ac.uk].

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References

1. Angyal, S. J. *Tetrahedron* **1974**, *30*, 1695.
2. Vasela, A.; Lönnberg, H. *Acta Chem. Scand. Ser. A* **1981**, *35*, 123.
3. Craig, D. C.; Stephenson, N. C.; Stevens, J. D. *Carbohydr. Res.* **1972**, *22*, 494.
4. Morel-Desrosiers, N.; Morel, J. P. *J. Chem. Soc., Faraday Trans.* **1989**, *85*, 3461.
5. Angyal, S. J. *Pure Appl. Chem*. **1973**, *35*, 131.
6. Guo, J.; Zhang, X. *Carbohydr. Res.* **2004**, *339*, 1421.
7. Moore, C. L. *Biochem. Biophys. Res. Commun*. **1971**, *42*, 298.
8. Smith, Q. T.; Lindenbaum, A. *Calcif. Tissue Res*. **1971**, *7*, 290.
9. Hamazaki, H. *J. Biol. Chem.* **1987**, *262*, 1456.
10. Sharom, F. J.; Grant, C. W. M. *Biochem. Biophys. Acta* **1978**, *507*, 280.
11. Weinbaum, G.; Burger, M. M. *Nature* **1973**, *244*, 510.
12. Dheu-Andries, M. L.; Perez, S. *Carbohydr. Res.* **1983**, *124*, 324.
13. Lu, Y.; Deng, G.; Miao, F.; Li, Z. *J. Inorg. Biochem.* **2003**, *96*, 487.
14. Craig, D. C.; Stephenson, N. C.; Stevens, J. D. *Crystal. Struc. Commun*. **1974**, *3*, 195.
15. Kanters, J. A.; Roelofsen, G.; Alblas, B. P. *Acta Cryst*. **1977**, *B33*, 665.