The Relationship between the Acoustic Property and the Hydration of Saccharides

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Synopsis. Values of the relative increment of the sound velocity, A, in aqueous solutions of sugars were calculated from the experimental sound velocities. The values of A correlated well with the mean number of equatorial OH groups in a sugar molecule.

Recently, it was found that the limiting diffusion coefficients[1] and the partial molar heat capacities[2] for saccharides in water correlate well with the mean number of equatorial OH groups, $n(e\text{-OH})$, in a sugar molecule. These properties, which are affected by hydration, depend sensitively on the conformation of saccharides in aqueous solution. The accoustic properties of aqueous solutions of saccharides are also thought to depend on the degree of their hydration. Høiland and Holvik,[3] however, showed that the isoentropic partial molar compressibilities of saccharides do not correlate with the number of e-OH groups. Sarvazyan and his co-workers[4,5] theoretically indicated that the relative increment of the sound velocity, $A=(U-U_0)/(U_0m)$, sensitively reflects the solute-water interactions, where U and U_0 are the sound velocity in solutions and pure water respectively, and m is the concentration. In this paper, we report on the values of A calculated from the densities and compressibilities of aqueous saccharides solutions and discuss the relation between the values of A and the conformations of saccharides.

Results and Discussion

Høiland and Holvik obtained the following equations for the densitites, d, and compressibilities, β_s, of the saccharides solutions at 25 °C:

$$d=d_0+\sum_{i=1}^{3} a_i m^i \tag{1}$$

and

$$\beta_s=\beta_s^0+\sum_{i=1}^{3} b_i m^i, \tag{2}$$

where d_0 and β_s^0 are the density and compressibility of pure water, respectively. We obtained the following relation for A in the low concentration range; this relation was calculated from Eqs. 1 and 2 by means of the Laplace relation for the sound velocity:

$$A=-(a_1/d_0+b_1/\beta_s^0), \tag{3}$$

where a_1 and b_1 are the coefficients of the terms proportional to m in Eqs. 1 and 2, respectively.

We calcualted the values of A from Eq. 3 by the use of Høiland and Holvik's data.[3] The values obtained are plotted against $n(e\text{-OH})$ for saccharides in Fig. 1. We used the values of $n(e\text{-OH})$ which were previously calculated.[1,2] The straight line in Fig. 1 was determined by the method of least squares and is represented by

$$A\times 10^2=1.297+0.780\, n(e\text{-OH}), \tag{4}$$

with a very high correlation coefficient of 0.965.

The change of sound velocity in solution is ascribed to two effects: (1) an increase in the sound velocity by the introduction of incompressible solute molecule, and (2) a change in the water structure around the molecule.[6,7] If the solute molecule stabilizes the water structure, the sound velocity in the solution is hastened. We found that the sound velocity in aqueous solutions of alkali chlorides increases with increasing the degree of structure making of an ion, but in a cessium chloride solution, which is the strong structure-breaking ion, it is smaller than that in pure water.[7]

In Eq. 3, the value of a_1 depends on the total number of OH groups in a sugar molecule and the intrinsic volume.[3,8] The value of b_1 depends only on the sugar OH group-water interactions, which differ in different orientation of the OH group. The values of a_1 are positive, but those of b_1 are negative for all the saccharides in Fig. 1.[3] Since $A>0$ for all the saccharides in Fig. 1, the absolute values of a_1/d_0 are smaller than those of b_1/β_s^0. Thus, the value of A mainly reflects the second effect between the above two, and increases with an increase in the degree of hydration.

The e-OH groups in a sugar molecule may be effectively substituted for a water molecule within the water structure; therefore, the hydration of sugar hydroxyl groups has a stereospecific nature. Thus, a

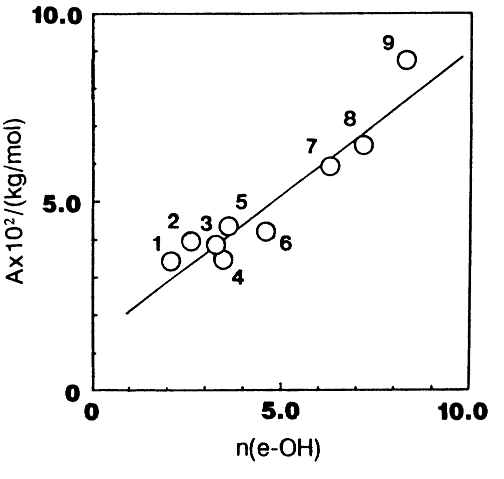

Fig. 1. The relationship between the values of A and the mean number of e-OH groups in each sugar molecule.
1. Ribose, 2. arabinose, 3. mannose, 4. xylose, 5. galactose, 6. glucose, 7. sucrose, 8. maltose, 9. raffinose.

sugar molecule which has a larger number of *e*-OH groups in the molecule has a stronger stabilizing effect on the water structure.[1,9] We showed that ribose, which has only 2.1 *e*-OH groups, hardly affects the water structure.[1] The result of Fig. 1, therefore, is explained by the effect of *e*-OH groups on the water structure. The relative increments of the sound velocities in aqueous solutions of saccharides clearly show the conformation dependence of their molecules.

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