Sweetness and life

How sugars dissolve in water may play an important role in biological processes

PhD

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Sugars are important biological materials. They are key components of the genetic molecules DNA and RNA. They also play crucial parts in many biochemical cycles, some of which have been turning as long as life itself. These cycles include the photosynthetic production of sugar from sunlight, water and carbon dioxide – the method of energy storage in plants, and the use of sugar directly in metabolic processes in animals. Although such cycles are understood in general chemical terms, little is known about many of them at the molecular level.

Even our knowledge of molecules as simple as the hydrated structure of sugars in solution is fragmentary and usually inferred from X-ray or neutron crystallographic studies. How water molecules are arranged and bound around biological molecules such as sugars in cells is vital for understanding their function and behaviour.

Isotopic substitution

Neutron diffraction with isotopic substitution is the only method that can give information on all aspects of the hydration structure of ions and molecules at atomic resolution. The technique relies on the fact that different isotopes of the same elements have identical chemical structures but appreciably different neutron scattering properties.

In this experiment, three chemically identical aqueous solutions of glucose ($C_6H_{12}O_6$) with differing ratios of hydrogen and deuterium atoms were prepared at three different concentrations of the sugar. The glucose molecule has a ring structure of five carbon atoms and one oxygen atom with hydrogen and hydroxyl groups (OH) attached. Both hydrogen and deuterium atoms on the hydroxyl groups of the sugar molecules and the water molecules exchange rapidly with each other. Therefore, deuterium atoms can be incorporated into the sugar molecules themselves.

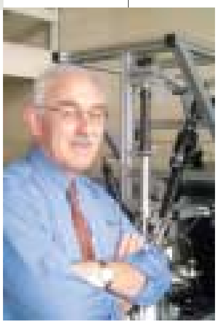
Relatively simple calculations on the measured diffraction patterns allow us to deduce structural aspects of the exchangeable hydrogens.

With our first results from the D4C diffractometer at ILL, we have proved that even in solutions that are as much as 50 per cent by weight glucose, certain geometrical aspects of the water structure are almost unperturbed! This contrasts strikingly with simple salt solutions such as lithium chloride in which the water structure around the ions is dramatically changed. The glucose results imply that the hydration structure around the exchangeable hydrogens in the hydroxyl groups is similar to the water structure itself. This is undoubtedly related to the biological role of sugars in metabolic processes.

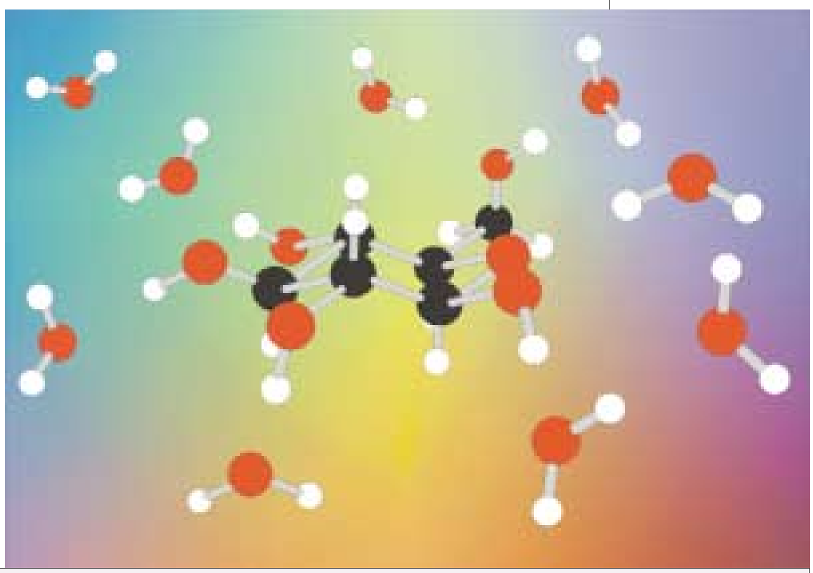
Although our present studies have been applied only to exchangeable hydrogens in the sugar solution, we are confident that, in this ongoing programme, we will also be able to apply the same technique to each hydrogen atom in the sugar structure that is not exchanged in solution.

In this way we will be able to make a major contribution to understanding the hydration properties of sugars, and by extension provide a critical and quantitative assessment of computer simulation studies of hydrated sugar molecules. ■

George Neilson



The sugar molecule, glucose, depicted in a hydrated environment



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