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Foreword

Advances in liquid chromatography of carbohydrates

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In the last 20 years, high-performance liquid chromatographic methods have developed from a mild curiosity into an everyday necessity for researchers in the field of carbohydrate chemistry. Those who have worked in the field during this period remember that early h.p.l.c. systems were characterized by unstable stationary phases, troublesome injection systems, and unstable, relatively insensitive detectors. While many viewed these inadequate systems as just a passing fantasy, others continued to rapidly develop and improve them so that today scores of manufacturers market extremely useful, specialized columns and instruments for the analysis of carbohydrate compounds.

In most fields of chemistry, new analytical methods are based upon fundamental knowledge or theory generated by previous workers. This is clearly true for today's state-of-the-art h.p.l.c. methods for carbohydrate analysis. For instance, the original discovery by Roseman *et al.*[1] that neutral sugars were retained on strongly basic anion-exchange resins, was important in the eventual development of the high-performance anion-exchange chromatography systems of today. For examples of the remarkable utility of these techniques, see the articles in this issue by van Riehl and Olieman (p. 39), Cefalu *et al.* (p. 117), Townsend *et al.* (p. 211), Paskach *et al.* (p. 1), and Ammeraal *et al.* (p. 179). In these papers, methods for the separation and ultrasensitive detection of monosaccharides, sugar alcohols, sugar degradation products, malto-oligosaccharides, "high mannose" oligosaccharides, and various food carbohydrates are given.

In 1953, Wheaton and Bauman[2] demonstrated that mixtures of electrolytes and non-electrolytes could be easily separated on cation exchangers with water as the eluent. In 1959, both Felicetta *et al.*[3] and Jones *et al.*[4] demonstrated that mixtures of neutral sugars could be separated from each other on cation-exchange resins which were converted into the Ba^{2+} or Ca^{2+} form. Since that time, numerous other workers have made significant contributions to the understanding and enhancement of this type of separation so that today h.p.l.c. columns packed with cation-exchange resins in a large variety of ionic forms, including Ca^{2+}, Ag^{+}, Pb^{2+}, Na^{+}, and H^{+}, are routinely used in laboratories around the world for separation of numerous sugars, sugar derivatives, and oligosaccharides. For an example of the use of the H^{+}-form, see the paper in this issue by Hotchkiss *et al.* (p. 81; Figs. 4 and 5).

One of the first h.p.l.c. stationary phases used in carbohydrate separations, the

aminopropyl silica gel bonded phase, was first reported[1] over 15 years ago. After significant improvements in manufacturing processes, these types of phases are still widely used for separations of both neutral (normal-phase separation) and acidic (weak anion-exchange separation) carbohydrates. The articles by Nieman *et al.* (p. 15) and Hotchkiss *et al.* (p. 81) in this issue demonstrate the utility of these column types for analysis and preparative isolation of neutral and acidic oligosaccharides, respectively.

Although alkyl-bonded (reversed-phase) silica gels have been used very sparingly for the separation of neutral sugars, the articles in this issue by Preston *et al.* (p. 147), Preston and Rice (p. 137), and Heyraud and Leonard (p. 105) demonstrate that they can be used very effectively in an "ion-pairing" mode for the separation of acidic oligosaccharides derived from pectins and alginates.

Over 40 years ago, Whistler and Durso[2] reported the class separation of oligosaccharides on columns packed with charcoal-Celite® mixtures. Over the years, numerous investigators have used modifications of that method for the analytical and preparative separation of carbohydrates. The excellent selectivity that carbohydrates showed toward charcoal column packings led many researchers to postulate that they could be useful for h.p.l.c. separations of sugars and oligosaccharides. Until recently, however, no forms of charcoal or carbon were available that possessed the correct size, shape, and mechanical stability for high-performance separations. In this issue, Koizumi *et al.* (p. 67) now describe the first use of a carbon-based stationary phase for separation of sugars as well as linear and cyclic oligosaccharides.

What separation techniques will be available for the carbohydrate researcher twenty years from now? One can certainly expect many advances in the available technology. Tomorrow's methods will probably provide faster analyses on more selective columns and allow more selective and sensitive detection of analytes. Other related forms of separation, however, such as capillary zone electrophoresis (c.z.e.), which can perform complex separations in very short times and use only miniscule amounts of solvents, will surely find increased utility. Recently, Al-Hakim and Linhardt[3] used this method to analyze complex disaccharides derived from chrondroitin and dermatan sulfate. In this volume, Honda *et al.* (p. 193) describe the c.z.e. separation of reducing mono- and oligo-saccharide derivatives. Another separation method, supercritical fluid chromatography (s.f.c.) has also found recent application[4] to analysis of complex carbohydrates. Additional enhancements of this instrumentation, which is readily coupled to mass spectrometers, are very likely.

I would like to thank all the authors who contributed papers to this special thematic issue on liquid chromatographic separations of carbohydrates. I also thank the Editors of *Carbohydrate Research*, particularly Prof. David C. Baker who handled the majority of the papers, for the skillful and timely editorial work that made this volume possible.

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