Review

Recent advances in ion chromatography: A perspective

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Abstract

To properly ascertain what are the key advances in a field one must have a vision of where the field is going in the future. Generally such a view is myopic and focuses largely on one's own field of study. To give a clearer view of where ion chromatography is now and where it is going in the future, Herb Laitinen's 'Seven Ages of an Analytical Method' was applied to ion chromatography. Currently, ion chromatography lies in the sixth age, wherein the method is a standard procedure. Recent advances that open new areas of application for ion chromatography are noted as these pull the technique back into the fifth age. However, ion chromatography also teeters on the brink of the seventh age of an analytical instrument, in which a technique of greater convenience, selectivity and sensitivity (i.e., capillary electrophoresis?) replaces it. Thus many of the current advances in ion chromatography are improvements relative to capillary electrophoresis. While often overlooked, probably the most notable improvements in ion chromatography in recent years have been in its convenience. Such improvements are essential for a technique in its sixth age. For if the procedure is to remain a standard method, analysts must be confident and comfortable in its use.

Keywords: Reviews; Ion Chromatography; Inorganic anions; Inorganic cations; Carbohydrates; Amines; Metal complexes

Contents

1. Introduction

In reviewing a field such as Ion Chromatography, it is easy to look back at the advances that have lead to the current state-of-the-art. One can reminisce about the first recorded application of ion-exchange. Heftmann [1] and Ettre [2] contend that this was when Moses arrived in Ma'rah after crossing the Red Sea and found the water undrinkable because it was bitter.

And he cried unto the Lord; and the Lord shewed him a tree, which he cast into the waters, and the waters were made sweet. [3]

The logical explanation of this miracle is that Moses sweetened the water by ion-exchange. One can also reminisce about the first analytical use, when in 1917 Folin and Bell used ion-exchangers in the determination of ammonia in urine [4]. The first chromatographic determination of an inorganic species was in 1937 when Schwab and Jockers separated metal cations [5]. Unarguably, the greatest advance in ion chromatography was the classic paper by Hamish Small et al. in 1975 where simultaneously the use of low capacity stationary phases and suppressed conductivity were introduced [6]. Ion chromatography as presented by Small et al. provided the first analytical technique for rapid and sensitive simultaneous determination of multiple anions.

While hindsight is 20/20, our view of the future and thus the important advances that are currently taking place, is much more myopic. One's impression of what constitutes an advance depends largely on one's own interests. Use of a conceptual framework allows a much more objective view of advances in a field. For this review the classical editorial of Herb Laitinen on 'The Seven Ages of an Analytical Method' [7] was used to clarify my view of where ion chromatography is, and where it is going. In analogy to Shakespeare's seven ages of man, Laitinen identified a common set of seven phases through which an analytical method passes [7].

First, there is the initiation or conception phase, which often occurs outside of analytical chemistry.

Clearly Hamish Small's classic paper [6] represents the first age of ion chromatography. Small, Stevens and Bauman were awarded the 1977 Pittsburgh Applied Analytical Chemistry Award in recognition of this paper.

Second, experimental measurements are made in the research laboratory to establish the validity of the principle as the basis for useful measurements.

The self-proclaimed representative of this second age of ion chromatography was the proceedings of the 1978 conference on Ion Chromatographic Analysis

of Environmental Pollutants [8]. The dedication of these proceedings – 'To the individual who does the best (s)he can with what (s)he's got.' – best indicate the state of the field at this period.

Third, developments in instrumentation bring the method from a laboratory curiosity into the hands of the non-specialist.

The third age of ion chromatography was ushered in by the introduction of the Model 10 Ion Chromatograph at the fall 1975 American Chemical Society (ACS) meeting in Chicago, IL. Dionex corporation, jointly with Dow, were awarded the 1977 Vaaler Award and a 1977 IR100 award in recognition of the significance of this development to the field of analytical chemistry [9].

Fourth, detailed studies of principle and mechanisms are pursued with the aid of improved instrumentation. This represents the stage at which the method matures as an accepted procedure in competition and cooperation with other approaches.

The maturation of ion chromatography into the fourth age on an analytical method is marked by the establishment of standardized procedures. For ion chromatography the first such method, the American Society for Testing and Materials (ASTM) method for anions in water by chemically suppressed ion chromatography, was first approved in 1984 [10].

Fifth, applications are enlarged in to an ever-widening scope of areas with appropriate modifications in procedures. Research of this type is commonly published both in analytical chemistry journals and in specialized subject material journals.

The proceedings of the previous the International Ion Chromatography Symposia provides evidence for the breadth of current application of ion chromatography [11–15]. Table 1 summarizes the areas of applications from the preceding symposia. Haddad and Jackson provide a far more detailed summary of the applications of ion chromatography [16]. Over 200 pages of their magna opus discuss applications of ion

Table 1
Areas of recent applications of ion chromatography[a]

Area of application	Number of papers
Environmental	40
Product Analysis	26
Food/Agriculture/Biotechnology	21
Biological/Clinical	14
Industrial	11
Geological/Oil	10
Power	8
Drinking Water	7
Pharmaceutical	6

[a]Compiled from the proceedings of the International Ion Chromatography Symposium [11–15].

chromatography! Furthermore, over 30% of the articles were in non-analytical specialist journals including Phytopathology, Journal of Molluscan Studies and Kidney International [16]. Thus, clearly ion chromatography is in or has passed the fifth age of an analytical method.

Sixth, applications of well-established procedures are made to new as well as old problems. Normally, such applications do not appear as research papers in analytical chemistry, but are included in descriptions of experimental procedures. Certain procedures may become highly standardized, and find their way into compilations of standard test methods.

Table 2 provides a current listing of ASTM approved methods. The United States Environmental Protection Agency have also established numerous standard ion chromatographic procedures [17,18]. A further characteristic of the sixth age of an analytical method

is that the methodology is taken for granted. This can appear in many ways, including the methodology only being cited in the experimental procedures. The three ASTM methods listed at the bottom of Table 2 indicate that this is indeed becoming true. In these three methods, the term Ion Chromatographic is incorporated in the title of only one, and even then only as an after-thought. Indeed, method D 2988 mentions ion chromatography only in passing to state that it provides superior data over other possible methodologies! Thus, ion chromatography has entered its sixth age.

Seventh, a period of senescence occurs as other methods of greater speed, economy, convenience, sensitivity, selectivity, etc. surpass the method under consideration.

In order for a method to enter the seventh and final age of an analytical method there must be a rival technique that offers advantages in speed, economy, convenience, reliability, sensitivity, and/or selectivity. Such a candidate method is now present in capillary electrophoresis. While the reliability of capillary electrophoresis is still plagued by the irreproducibility of the electroosmotic flow, the technique has demonstrated the ability to perform faster and more selective analyses with much less sample solution or waste than ion chromatography [19].

These various ages are not truly discrete, however, but rather blend together. Also, a method does not necessarily march inexorably from one stage to the next, but rather undergoes numerous periods of resurgence as new developments in theory and

Table 2
ASTM standard methods for ion-chromatographic determinations[a]

Method	Description
D 5085-90	Test method for determination of chloride, nitrate and sulfate in atmospheric wet deposition by chemically suppressed ion chromatography
D 4327-91	Test method for anions in water by chemically suppressed ion chromatography
D 5542-94	Test methods for trace anions in high purity water by ion chromatography
D 5257-93	Test method for dissolved hexavalent chromium in water by ion chromatography
D 4856-88	Test method for the determination of sulfuric acid mist in the workplace atmosphere (ion chromatographic)
D 2988-92	Test method for water-soluble halide ions in halogenated organic solvents and their admixtures
E 165-94	Test method for liquid penetrant examination

[a] Data from Ref. [10]

instrumentation come along. This review seeks to identify the current age (or ages) of ion chromatography, and then on the basis of this analysis identify some of the advances within the field and potential areas for resurgence. The objective of this article is not be exhaustive. Rather it is to illustrate some of the important trends currently operative in the field of ion chromatography.

From the above analysis, ion chromatography currently lies in the sixth age of an analytical method. Thus, the most important advances in ion chromatography will be the development of new areas of application and improvements in technology. Development of new areas of application will pull ion chromatography back into the fifth age. Alternatively, improvements in the convenience, sensitivity and selectivity of ion chromatography relative to capillary electrophoresis will fend off advancement into the seventh age. Therefore it is on these areas that this review will focus.

1.1. New areas of application

The breadth of application of ion chromatography is well represented by the papers within this journal. Thus, rather than try to provide a detailed listing of these applications, I will point out a few of the primary trends.

One of the most notable trends in recent years is the increasing complexity of the samples. Trace ions have been determined in organic solvents [20], hydrofluoric acid [21,22], strong inorganic acids [23] and bases [23,24], nuclear grade uranium [25], hydrocarbons [26] and food [27]. The primary instigator for this emergence has been the development of sample pretreatment techniques, particularly solid-phase extraction [28,29]. Other techniques such as heart-cut [30], combustion chromatography [26] and coupled column chromatography [25] have also played a role. Solid-phase extraction (SPE) cartridges and disks are available containing: C_{18} and polystyrene packings for removal of hydrophobic components; anion-exchanger in OH^- form to neutralize acidic samples; cation-exchanger in H^+ form to neutralize alkaline samples; cation-exchanger in Ag^+ form to selectively eliminate halides (except fluoride); and cation-exchanger in Ba^{2+} form to remove sulfate from samples. Electrolytic sample

pretreatment eliminates the need to regenerate the sample pretreatment system [23,24]. Despite the success in this area, much more work needs to be done. Many common matrices such as acetate and nitrate cannot be satisfactorily eliminated. Furthermore, current procedures, such as the elimination of sulfate using Ba^{2+}, are not wholly satisfactory [28] as some loss of analyte ions occurs due to co-precipitation.

New areas of application can also emerge as the result of development of a new detector. The emergence of biological applications of ion chromatography due to the development of pulsed amperometric detector illustrates this point [31,32]. Pulsed amperometric detection (PAD) allows simple and sensitive monitoring of carbohydrates, polyalcohols, simple alcohols, glycols, alkanolamines, amino acids and sulfur compounds, which do not respond well to conventional conductivity or absorbance detectors. For example, the detection limit for glucose in the chromatogram shown in Fig. 1 is 200 femto (10^{-15}) mol using pulsed amperometric detection [33]. Thus the emergence of additional new applications now awaits the development of new and novel detectors.

While the development of sample pretreatment techniques and new detectors are key factors in the
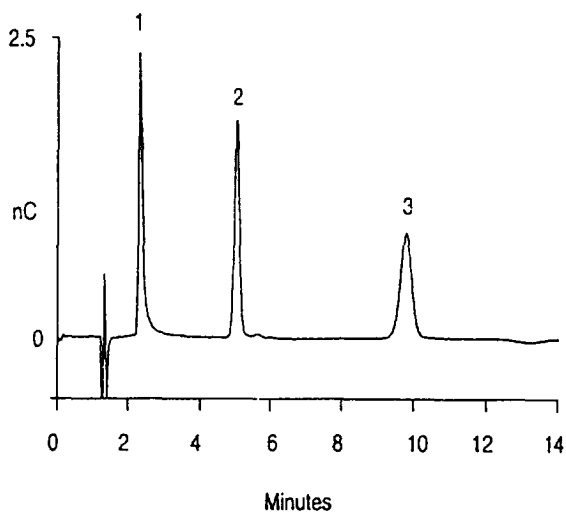

Fig. 1. Pulsed amperometric detection of 10 pmol each of (1) sorbitol, (2) glucose and (3) sucrose. Column, 25 cm×4 mm CarboPac PA1; mobile phase, 100 mM NaOH; flow-rate, 1.0 ml/min; injection volume, 20 μl; detector, prototype Dionex ED40 (reproduced with permission from Ref. [33]).

emergence of many new areas of application, one can never discount imagination as a source of new areas of endeavor. A truly remarkable application, and one that demonstrates the power of modern ion chromatography, is the determination of isotopic ratios by ion chromatography [34]. Under carefully controlled conditions on a cation-exchange column the retention time of $^{15}NH_4^+$ is 1.012-times that of $^{14}NH_4^+$. This however is not sufficient to allow separation of the two isotopic forms of ammonium. The retention time of the unresolved peak is however a function of the isotopic ratio of nitrogen. Gardner et al. [34] measured the isotope-induced retention time shift by performing multiple sample injections within a single chromatographic run. At 0 and 3 min 2 μM natural abundance ammonium was injected to provide internal standardization of the instrument operation. Then at 6 min isotopically spiked seawater was injected. Fig. 2 shows the resulting chromatograms. The retention time (t_R) shift was the time difference between the second and third peaks minus

that between the first and second peaks. The resultant relationship between percentage of $^{15}NH_4^+$ and the retention time was sigmoidal with the maximum retention time shifts occurring between 25 and 75% $^{15}NH_4^+$.

1.2. Convenience

Researchers in analytical chemistry generally overlook the convenience of an analytical technique in our investigations. For practising analytical chemists, however, the convenience of a technique is of paramount importance. Can a junior technician operate the instrument? Can I be sure that the instrument will work for the intended application? Do we have to continually monitor the instrument or can it run unattended? These are questions that practising analytical chemists must address daily.

An aspect of convenience now associated with ion chromatography is the sophisticated aids available for selection of the column and detector appropriate for a given analysis. For example, the column selection guide presented in a recent vendor's catalogue provides 91 alternate instrumental configurations for performing analysis of inorganic and organic analytes using ion chromatography [35]. In contrast, a similar guide developed a decade earlier provided much less detailed advice [36]. Such detail offers the practising analyst much greater confidence in their selection of analysis conditions, and thus will result in much greater use of ion chromatography.

Unfortunately, comparable advances have not been made in aiding the analyst in optimizing the separation. Column manufacturers provide a list of suitable eluents and a recommended 'optimum' eluent along with their column. While these 'optimum' conditions are indeed very good for the standard ion set for which the conditions were developed, they are not as appropriate if the sample contains more or less ions.

A number of procedures can be applied for optimizing conditions. In the factoral design approach the analyte behavior is mapped out over the range of possible conditions and the optimum conditions are then determined from the accumulated data [37]. The effort involved in such an approach is prohibitive however. Alternatively, chemometric [38,39] or expert systems [40,41] can be used for
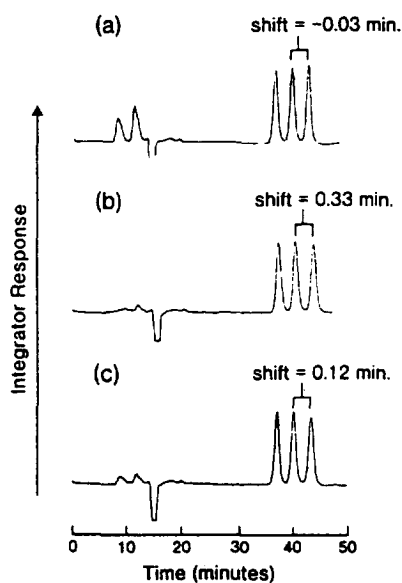

Fig. 2. Chromatograms for sequential injection of 2.0 μM natural abundance ammonium (0 min), of 2.0 μM natural abundance ammonium (3 min) and 2.2 μM ammonium in seawater (6 min) at the following $^{15}NH_4^+/(^{14}NH_4^+ + ^{15}NH_4^+)$ ratios: (a) 0.0037 (i.e., natural abundance); (b) 0.73; (c) 0.46. The retention time shift (marked 'shift') was related to the isotopic ratio of the seawater spiked with $^{15}NH_4^+$ (reproduced with permission from Ref. [34]. Copyright 1991 American Chemical Society).

optimization. It is heartening that this year's symposium sees further discussion of these topics [42,43] after a period of inactivity.

An alternative approach for computer-assisted optimization in ion chromatography that has not received as much attention is the use of a suitable retention model as the basis for the optimization procedure [44]. Experimental studies have demonstrated that the retention behavior in ion chromatography obeys the Linear Solvent Strength model. That is a linear relationship exists between the logarithm of the capacity factor and the logarithm of the concentration of the competing ion in the eluent. This has been demonstrated for anion separations using hydroxide eluent [45], cation separations using nitric acid eluent [46] and anion separations using phthalate eluents [47]. Thus it should be possible to use a commercial chromatographic optimization package such as DryLab (LC Resources) that is based on the Linear Solvent Strength model for optimization of ion chromatographic separations. Unfortunately while DryLab has been applied to optimization of ion-pair separations, it has not yet been validated for ion chromatographic determinations. Thus there is still a need for commercially available optimization software for aiding analysts in optimizing their ion chromatographic determinations.

Some significant advances have been made in improving the operational convenience of ion chromatography. The recent development of electrochemical self-regulating suppression is an example [48]. This suppressor uses electrolysis of deionized water to generate the acid or base for the suppression neutralization reaction. Furthermore, electrodialysis, resulting from the electric field, enhances the suppressor's neutralization capacity. Eluents as concentrated as 150 mM NaOH can be neutralized directly in this fashion. In addition to the better performance and improved signal to noise of this device relative to chemical suppression, the developers comment that it makes 'suppression less like a post-column treatment... and more like an integral part of the overall detection scheme'. That is, it made suppression more convenient to use.

The advantages of hydroxide as an eluent for suppressed ion chromatography of anions are well documented [45]. These include lower post-suppression conductivity than carbonate/bicarbonate eluents, better calibration linearity and better

suitability for gradient elution. However, many analysts are reluctant to use hydroxide eluents due to irreproducible retention times as a result of carbon dioxide from the atmosphere altering the eluent strength. Strong et al. [49,50] developed a more convenient and reproducible means of preparing hydroxide eluents. In their system, high purity NaOH is generated electrochemically in-line. Under isocratic elution conditions their electrochemically generated NaOH eluents yield marginally more reproducible retention times than conventional carbonate/bicarbonate eluents. More significantly, since electrical current to the generator governs the eluent concentration, only an isocratic pump is required to perform gradient IC. Fig. 3 shows a gradient separation of a number of anions of widely differing retention characteristics using electrochemically generated NaOH eluent. Baseline noise levels were equivalent to that in isocratic separations (and thus so are the limits of detection) and the retention time reproducibility was impressive (0.05–0.25%).

1.3. Selectivity

Advancements continue to be made in the stationary phases available for ion chromatography.
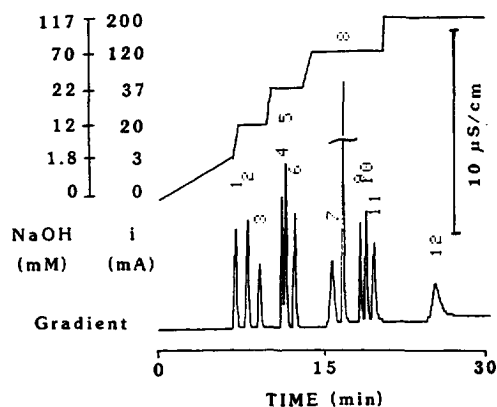

Fig. 3. Suppressed ion-chromatographic separation of anions of widely differing retention characteristics using an on-line electrochemically generated NaOH eluent. Sample, 100 μM each of (1) fluoride; (2) iodate; (3) formate; (4) bromate; (5) chloride; (6) nitrite; (7) nitrate; (8) sulfate; (9) phosphate; (10) arsenate; (11) chromate; (12) iodide. The separation was performed on a Dionex AS5A column (reproduced with permission from Ref. [50]. Copyright 1991 American Chemical Society).

PITTCON 1994 and 1995 saw the introduction of thirteen new ion-exchange columns [51,52]. Anion-exchange columns continue to be the primary area of activity with eight new columns introduced. The GAT AN300 (GAT/SP, Bremerhaven, Germany), Sarasep ANSC (Metachem Technologies, Torrance, CA, USA), Star-Ion A300 (Phenomenex) and IonPac AS12 (Dionex [53]) all display improved separation of fluoride from the water dip, as illustrated by the Star-Ion A300 in Fig. 4a. Lowering the degree of cross-linking within the polymeric stationary phase

yields the very high water content necessary for effective retention of highly hydrated anions such as fluoride. Coincidentally (or not) the ease of analysis of fluoride is often cited as an advantage of capillary electrophoresis relative to ion chromatography [54]. The Star-Ion column provides additional versatility as it can also separates fluoride and acetate (Fig. 4b).

Recent PITTCONs have also seen the introduction of two additional cation-exchange columns. The Dionex IonPac CS12A is a polymer based (ethyl-vinylbenzene with 55% divinylbenzene) cation-ex-
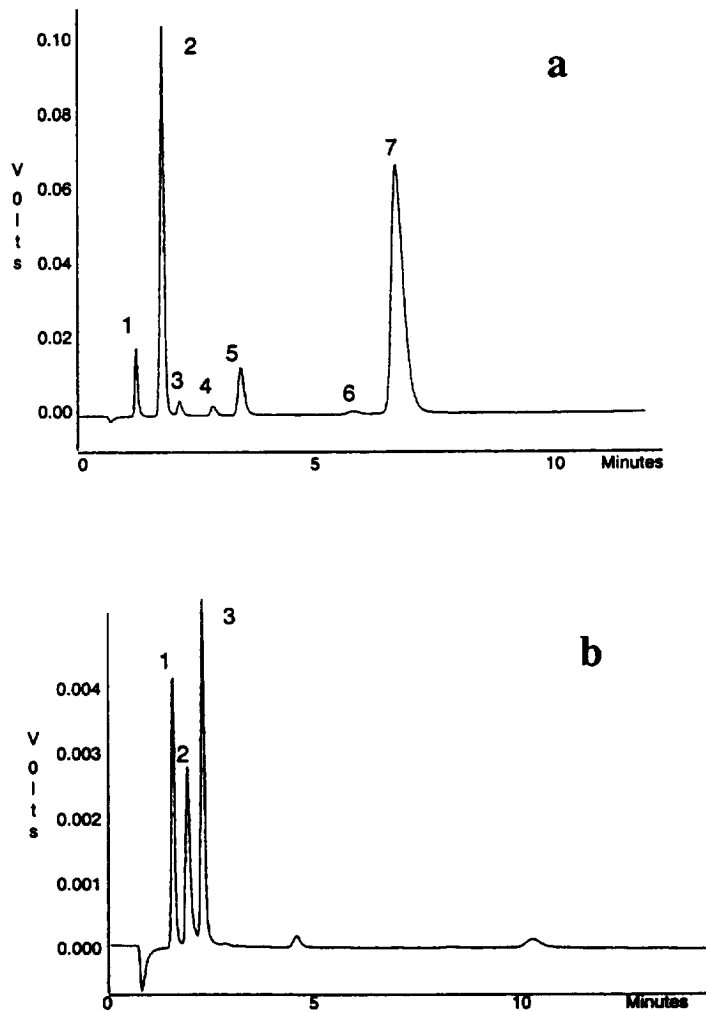

Fig. 4. Ion-chromatographic separation of: (a) standard EPA 300.0A anions; (b) early eluting anions. Column, 10 cm×4.6 mm Star-Ion A300; eluent, 1.7 mM NaHCO$_3$–1.8 mM H$_2$CO$_3$; flow-rate, 2.0 ml/min; injection volume, 20 μl; detection, suppressed conductivity. Sample (a): (1) fluoride (2 mg/l); (2) chloride (20 mg/l); (3) nitrite (2 mg/l); (4) bromide (2 mg/l); (5) nitrate (10 mg/l); (6) phosphate (2 mg/l); (7) sulfate (60 mg/l). Sample (b): (1) fluoride (2 mg/l); (2) acetate (35 mg/l); (3) chloride (4 mg/l) (courtesy of Phenomenex).
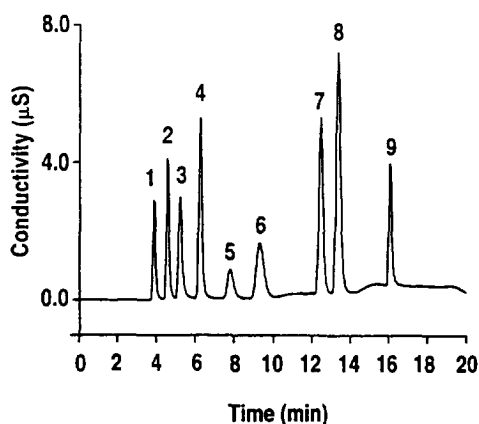
Fig. 5. Separation of Group-I and -II cations and volatile amines. Column, 25 cm×4 mm, 8–9 μm IonPac CS12A; mobile phase, step gradient of 8 m*M* sulfuric acid–4% acetonitrile to 14 m*M* sulfuric acid–4% acetonitrile to 25 m*M* sulfuric acid–5% acetonitrile; flow rate, 1.0 ml/min; detection, conductivity with suppression from a CSRS-II Autosuppressor unit; temperature, 40°C. Sample: (1) lithium (0.5 ppm); (2) sodium (2.0 ppm); (3) ammonium (2.5 ppm); (4) potassium (5.0 ppm); (5) morpholine (10.0 ppm); (6) 2-diethylaminoethanol (10.0 ppm); (7) magnesium (2.5 ppm); (8) calcium (5.0 ppm); (9) cyclohexylamine (15.0 ppm) (courtesy of Dionex).

change column recommended for determination of Group I and II cations, ammonium, and other amines. Fig. 5 shows a representative gradient separation of cations and volatile amines obtained using the IonPac CS12A column operating at 40°C. This separation demonstrates the improved thermal and solvent stability of the columns. Dionex has also introduced the IonPac ICE-AS6 ion exclusion column for the separation of carboxylic acids and alcohols with improved peak efficiencies and peak shapes. Its stationary phase is possesses both sulfonic acid and carboxylic acid functional groups, which allow improved selectivity.

1.4. Sensitivity

Sensitivity developed through detection is often associated with improved selectivity. This is clearly evident in applications of atomic spectroscopy to ion-chromatographic determinations. Recent activity in this area has focused on the use of inductively coupled plasma–mass spectrometry (ICP–MS) as a

detector for ion-chromatographic separations [55,56]. Metals which have been speciated in this manner and their associated detection limits include arsenic (20–300 pg), lead (0.2–3900 pg), tin (2–1000 pg), mercury (7 pg), chromium (20–50 pg), lanthanides (1–5 pptr), phosphorus (400–4000 pg), sulfur (7000 pg), vanadium (110 pg) and nickel (30 pg). Recently ICP–MS has been coupled to an ion chromatographic system for the determination of IO_3^-, BrO_3^-, Cl^-, ClO_3^-, Br^- and I^-, with detection limits of 25 ng for I species, 0.8 ng for Br species and 36 ng for Cl species [57].

Postcolumn reaction detection is an alternate means of achieving enhanced sensitivity and selectivity, and in many ways the preferred means. The low cost and simplicity of postcolumn reaction detection allows dedication of the chromatographic system to a single application. Whereas, the high cost of ICP–MS systems generally precludes such a possibility in most laboratories. The establishment of the ASTM and EPA methods for chromium using postcolumn reaction detection with diphenylcarbazide is a clear indication of the preference for simpler and more convenient methods [58,59]. Dasgupta has provided an exhaustive and highly readable review of postcolumn reaction detection methodologies [60], and so only a few of the more recent developments are discussed herein. An extremely sensitive and selective detector for iodide has been developed based on its catalytic effect of the reaction between hypochlorite and 4,4'-bis(dimethylamino)diphenylmethane. Detection limits for iodide are 0.02 ng [61]. Bromide also responds but with a detection limit of only 15 ng. The use of chloramine-T as a source of hypochlorite for this detector has never been completely satisfactory. Recent studies have shown that N-chlorosuccinimide/succinimide is more suitable, and has achieved detection limits of 0.12 ng I in seawater [62].

A number of postcolumn reaction detectors based on the fluorescent reagent 8-hydroxyquinioline-5-sulfonic acid (HQS) have been developed in recent years. These include reagents that respond selectively to aluminum [63,64], zinc, cadmium [65] and magnesium [66]. Most other metals form non-fluorescent or weakly fluorescent complexes with HQS [67]. More non-specific fluorescence responses have been achieved using displacement equilibria

where Mg^{2+} is displaced from EDTA or CDTA by metal ions eluting from the column react with HQS [68,69]. An interesting new class of postcolumn reaction detectors have been introduced based on the formation of ternary complex. Co-ordination-unsaturated ternary complexes form when a metal involved in a binary complex with a ligand (or ligands) has additional coordination sites available for complexation by a second ligand. The coordination chemistry of the metal, the dentation of the first type of ligand and the dentation of the second ligand all govern the selectivity. In addition in fluorometric analysis the ligand-metal complex must also fluoresce. Ye and Lucy have demonstrated the selectivity and sensitivity of this detector for the determination of hexadentate ligands [70] and metal-EDTA complexes [71]. Fig. 6 shows the separation of four metal–EDTA complexes using the lutetium and HQS as the fluorescent reagent. It is noteworthy that the concentration of the metal–EDTA complexes in Fig. 6 is at the detection limit for the best absorbance detection scheme for these species.
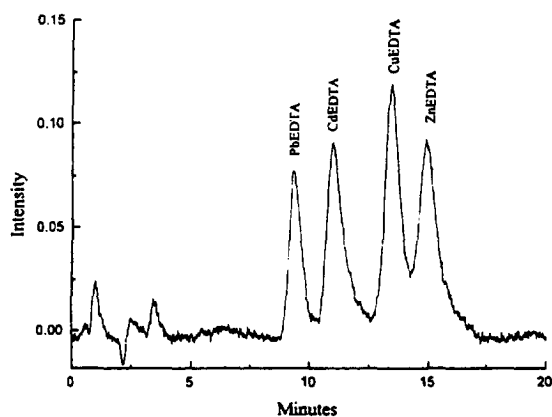

Fig. 6. Ion-chromatographic separation of 1 μM each of $Pb(EDTA)^{2-}$ (25 ng), $Cd(EDTA)^{2-}$ (20 ng), $Cu(EDTA)^{2-}$ (18 ng) and $Zn(EDTA)^{2-}$ (18 ng) with postcolumn formation of a ternary fluorescent complex. Column, 15 cm×3.9 mm packed with 5 mm Delta-Pak C_{18} particles equilibrated with 1 mM HTAB in 35% methanol; eluent, 1.0 ml/min of 0.6 mM potassium phosphate (pH 7.53) in 6 mM K_2SO_4; post-column reaction, 0.2 ml/min 0.1 mM Lu^{3+} and 1 mM HQS in 50 mM acetate buffer at pH 4.0, passage through 1000 ml of reaction coil, and addition of 0.2 ml/min 1 M AMP (pH 13.0) (reproduced with permission from Ref. [71]. Copyright 1995 American Chemical Society).

2. Conclusions

Since its introduction in 1975, ion chromatography has matured to become a standard analytical methodology. This review discusses some of the efforts to introduce new areas of application and improve the selectivity and selectivity of ion chromatography. Nonetheless, the most significant advances currently taking place are those which improve the convenience of ion chromatography. Such technological advances are the electrochemical suppression and eluent generation. However, just as important are advances such as the vastly improved column selection guide provided by one vendor. Further advances in convenience are required however. Commercial software for aiding method development is sorely needed as ion chromatography moves into more complex analyses in the hands of non-specialists.

One might ask whether a strong focus on convenience is warranted or prudent for ion chromatography. There is strong evidence to suggest that it is appropriate. Certainly the most publicized and heralded technological advance of recent years was the introduction of Windows 95. This product's sole purpose is to make the microcomputer and electronic highway more user friendly, i.e., more easy to use. Finally, there was a company who in 1888 made convenience their watchword. Their slogan at that time was 'You press the button and we'll do the rest'. You may have heard of them. Their name is Kodak.

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