



**RECENT ADVANCES AND APPLICATIONS OF ION CHROMATOGRAPHY IN  
HUMAN BIOLOGICS, FOOD, SOIL AND WATER**

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**ABSTRACT**

Ion chromatography is an entrenched administrative strategy for analyzing anions and cations in natural, sustenance and numerous different samples. It offers a gigantic scope of potential outcomes for choosing stationary and mobile phases. Furthermore, it normally takes care of different partition issues, especially when it is joined with various identification systems. Ion chromatography can likewise be utilized to decide numerous ions and substances in clinical and pharmaceutical examples. Because of a solid ecological effect, metal particle assurance and speciation have gotten noteworthy consideration in the most recent years. Acknowledgment of ion chromatography for anion examination was exceptionally fast, essentially in light of the absence of elective techniques that could rapidly and precisely decide anions in a solitary investigation. This paper is a survey of the use of ion chromatography for the assurance of inorganic cation and anions in Environmental examples like water, Biological liquids, Food materials, and soil.

**KEYWORDS:** Ion Chromatography, Ion Exchange, Cation Chromatography, Anion Chromatography, Human Plasma, Soil, Water, Food materials.

**INTRODUCTION**

The chromatography of ions as practiced today as a result of the merging of two major areas of development, chromatography and ion exchange.<sup>[1]</sup> The first reports by Spedding, Tompkins, and others<sup>[2, 3]</sup> of the chromatographic separation of the rare earth elements. Their use of complexing agents such as citrate to amplify the subtle chemical differences in these closely similar ions was the forerunner of much of present-day practice in the chromatography of metal ions. Bauman and Eichhorn<sup>[4]</sup> and Kunin and Myers<sup>[5]</sup> introduced mass action concepts to ion exchange, described the ion exchange equilibria of the two major types of ion exchange resin, and determined equilibrium constants for several ion exchange reactions. Boyd, Adamson, and Myers<sup>[6]</sup> realized the diffusional nature of the ion exchange process and their theoretical and experimental approaches have been the foundation for much of the work on ion exchange kinetics in the years since. Mayer and Tompkins<sup>[7]</sup> were among the first to tackle the complex theoretical challenge of describing the ion exchange column separation process. Marinsky, Glendenning, and Coryell among others<sup>[8, 9]</sup> were the first to apply ion exchange chromatography to the separation of radioactive species and to couple it directly to radiometric detectors. The years immediately following World War 11 were a golden age for ion exchange. For about two decades, researchers worldwide contributed

prodigiously to the understanding and applications of these fascinating new artifacts, ion exchange resins. Thousands of articles and many books recorded the myriad developments.<sup>[10, 14]</sup> This period was also marked by another significant event in the development of ion exchange chromatography, the separation and automated detection of amino acids, an achievement by Moore and Stein<sup>[15, 16]</sup> that would eventually earn them the Nobel Prize in chemistry in 1972. And subsequent work by Hamilton and co-workers<sup>[17, 19]</sup> presaged much of modern liquid chromatography in that it was an early demonstration of the synergistic coupling of a chromatographic separation with a continuous flow-through detector.<sup>[20]</sup>

Besides the advances in separation, the other key to chromatography's success was the concurrent development of automated detectors. And since many organic compounds absorbed in the UV part of the spectrum, one of the principal detectors that provided this prompt determination of separated species was the flow-through UV photometer. It enabled the detection of species-including ionic species-as diverse as proteins, dyes, pharmaceuticals, and synthetic polymers.<sup>[21, 22]</sup>

But, many common ions did not absorb Visible or UV radiation to any useful extent: alkali metal and alkaline earth metal ions, and anions such as fluoride, chloride,

sulfate, and phosphate, for example. Others such as bromide nitrate, nitrite, and iodide were light absorbing, but in wavelength regions that were inaccessible to the earliest UV detectors.

Thus, the normal photometric methods of UVI Visible detection were deemed unsuited to the measurement of many inorganic ions.<sup>[23]</sup>

The research on conductometric detection brought other benefits besides the direct one of easier detection. The new ion exchange resins that were devised to make suppressed conductometric detection brought "fall-out" benefits in that they eliminated the slow elution and sluggish mass transfer that were characteristic criticisms of the older, high-capacity materials. These improved properties stimulated their use in conjunction with other detectors besides the conductometric varieties.

Conductometric detection was coupled with other methods of separation besides ion exchange. Paired ion approaches were linked to both suppressed and non-suppressed methods. Ion exclusion, originally developed for large-scale separation, was adopted by analytical chromatographs and now enjoys a prominent place in the total repertoire of IC methods.

Today the chromatographic analysis of ionic materials is broadly applied and quickly growing. The number of species that may be determined continues to grow, as does the number of areas of science and technology where IC plays an important role. Table 1.1 gives some idea of the breadth of application of ion chromatography at the present time.

The data present in the current manuscript was collected from NCBI, Pubmed, Science Direct, and Elsevier. The search was set with keywords: Ion chromatography, Ion exchange, anion-cation exchange chromatography. The search was further refined and limited to the works performed on soil, human plasma, and water and food materials. All the works ranging from the years 1935 through 2014 were compiled in the following manuscript.

## MATERIALS AND METHODS

### Ion exchangers

Ion exchangers are the most widely used stationary phase in IC. An ion exchanger comprises three important elements: an insoluble matrix, which may be organic or inorganic; fixed ionic sites, either attached to or an integral part of the matrix; and, associated with these fixed sites, an equivalent amount of ions of charge opposite to that of the fixed sites. The attached groups are often referred to as functional groups. The associated ions are called the counter ions. They are mobile throughout the ion exchange and most importantly have the ability to exchange with others of like charge when placed in contact with a solution containing such. It is this latter property that gives these materials their name.

As well as having this fundamental property, ion exchangers, if they are to be useful in IC, should also have the following properties.

1. The ability to exchange their ions rapidly.
2. Good chemical stability over a wide pH range.
3. Good mechanical strength and resistance to osmotic shock.
4. Resistance to deformation when packed in a column and subjected to the flow of the mobile phase.

A variety of materials have been used as matrices on which to anchor the ionic sites of an ion exchanger. In modern IC the two most widely used are silica and organic polymers based on styrene. The excellent chemical stability of the organic-based ion exchange resins gives them a distinct advantage over the pH-sensitive, silica-based materials in many applications.

### Polymer Precursors of Ion Exchange Resins

The most common way of preparing an ion exchange resin is to first form a neutral, styrene-based polymer and then to chemically modify the polymer so as to introduce the ionic functional groups. Alternatively, monomers bearing the required functionality may be polymerized along with a suitable cross-linker to yield an ion exchanger, but materials prepared by this route are not in common use in IC.

There are two principal routes to the polystyrene precursor of most ion exchange resins. The first yields are usually known as gel-type polymers, while the second yields macroporous materials. The difference in structure between the two types has important implications for ion exchange, particularly with regard to the rate of exchange of ions, especially when they are large.

Gel-type polymers are formed by copolymerizing styrene and divinylbenzene in the presence of a catalyst such as a benzoyl peroxide. Divinylbenzene cross-links the polymer into a structure that will swell in solvents but will not dissolve in them.

Gel-type polymers and the ion exchange resins derived from them are often described as being micro porous. The ion exchange resins will readily admit small ions and molecules but resist the intrusion of species of even a few hundred molecular weights. Diffusion through the particles is therefore improved by lowering the degree of cross-linking. Practical resins in IC are formed from polymers with anywhere from 1 % to about 12% DYB. When the beads are fully functionalized, resins of low cross-linking are quite gelatinous and as a result are a too deformable underflow to be broadly useful.

Macroporous polymers are also formed by the suspension polymerization of styrene and divinylbenzene. In this case, however, another water-immiscible solvent is added that is miscible with the monomers but is a relatively poor solvent for the

polymer. This added solvent is sometimes called the porogen since it is largely responsible for the macro porosity that is developed.

Macroporous polymers are widely used to prepare ion exchange resins for large-scale applications. In IC, however, they are mainly used in conjunction with ion interaction reagents.<sup>[25]</sup>

#### Cation exchange resins

The most widely known and used cation exchange resin is formed by sulfonation of styrene-based polymers. Sulfonation, in the presence of a swelling agent, is a very efficient reaction in that essentially all of the aromatic rings in a low to a moderately cross-linked polymer can be monosubstituted with  $-\text{SO}_3^-$  groups. Resins that have a high degree of substitution with the requisite functionality are often termed "conventional" resins to distinguish them from the more specialized, low-capacity materials that are so widely used in IC. Capacity is the terms used to define the concentration of charged sites. High-capacity cation exchangers have capacities of about 5 milli-equivalents per dry gram. Their wet weight or wet volume capacity depends on the degree to which they are swollen by water.<sup>[26]</sup>

Low-capacity cation exchange resins may be prepared by limiting the sulfonation of the polystyrene-DVB bead to a thin surface shell. This may be accomplished by eliminating the swelling agent and exposing the polymer, briefly, to hot concentrated sulfuric acid<sup>[27]</sup> Sulfonation tends to progress into the bead with a relatively sharp boundary and the depth of substitution may be controlled by the time of contact, the temperature of the acid, and the cross-linking of the polymer.<sup>[28]</sup>

#### Anion exchange resins

Ion exchange resins with attached quaternary ammonium groups are the principal anion exchangers of ion chromatography. Resins of high capacity are prepared by a sequence of reactions in which the styrene-DVB polymer is first chloromethylated and the pendant  $-\text{CH}_2\text{Cl}$  groups that are introduced are then quaternized with a tertiary amine  $\text{R}_1\text{R}_2\text{R}_3\text{N}$ . High-capacity anion exchangers have been used in IC principally in suppressor columns for cation analysis, but this applies to is declining as membrane suppressors replace the older column methods.

Low-capacity anion exchangers may be prepared by surface quaternization of the fully chloromethylated gel-type bead. The products, however, give poor performance and it is difficult to control their capacity. Using macroporous polymers as starting materials, Barron and Fritz<sup>[30]</sup> were able to prepare low-capacity anion exchangers with useful separation properties. As a first step, they replaced the usual chloromethylating agent, chloromethyl methyl ether, with an aqueous system of paraformaldehyde and concentrated hydrochloric acid. This measure has two principal

advantages over the conventional chloromethylation procedure.

#### Silica and Methacrylate-Based Ion Exchangers

Low-capacity ion exchangers built on a silica base have been known for some time.<sup>[31]</sup> They have been prepared by bonding ionically modified polymers to a totally porous silica microparticle or to a superficially porous particle. Both sulfonate and quaternary ammonium type exchangers are available. Exchangers of this type have good mass transfer characteristics since their ion exchange sites are accessible via relatively large pores. Not surprisingly, therefore, silica-based ion exchangers have provided excellent separations of large organic ions, especially those of biological origins such as polypeptides, vitamins, and nucleotides. The book by Done, Knox, and Loheac<sup>[32]</sup> provide a good many examples of the chromatographic applications of these earlier silica-based exchangers.

For the chromatography of small ions, organic as well as inorganic, exchangers based on silica have a number of disadvantages relative to the total organic ion exchange resins. Their main drawback is their notorious instability in some of the aqueous eluent systems that are so typical of much of modern IC. This is particularly so in high pH eluents. Additionally, the chemistry of bonding to silica does not afford the flexibility in such variables as capacity, cross-linking, and selectivity that is the case in polymer systems. For these reasons, silica-based ion exchangers have a limited use in the IC of small organic and inorganic ions. Acrylate-based ion exchangers manufactured by the Toya Soda Company are being increasingly used in IC, although details on their preparation and structure are sparse. The basic environments are common to many IC systems these resins are superior to silica-based materials but are less stable than resins based on polystyrene.

#### Exchangers with Weakly Functional Groups

Most of the ion exchangers used in modern IC contains strongly acidic or basic groups. Such groups by definition remain highly ionized over a broad range of pH. Some exchangers, on the other hand, contain weakly functional groups whose ion exchange activity is dependent on the pH of the environment. Materials containing the carboxylic acid functional group exemplify weak cation exchangers, while primary, secondary, and tertiary amino substituents are the principal functional groups of weak base resins.

For weak acid resins, their capacity increases with increasing pH, while the reverse is the case for weak base resins. The ability to control ion exchange capacity by varying the pH of the environment can be a very effective means of modulating the overall affinity of the ion exchanger for the eluted ions. However, compared to the use of strongly functional materials, there has been a limited application of resins with weak functionality.<sup>[33, 34]</sup>

### Chelating resins

Since the introduction of organic ion exchange resins, there has been a steady interest in preparing polymers containing groups with the ability to complex or chelate metal ions. Ion exchange resins with chelating groups have been examined from time to time as stationary phases in the separation of metal ions. While these resins have a greater selectivity than conventional exchangers, they do not enjoy widespread use as a chromatographic medium. There are two probable reasons for this. Chelating resins, as a rule, tend to be kinetically inferior to conventional resins, and the resulting inefficiency somewhat cancels their superior selectivity.<sup>[35-37]</sup>

### INSTRUMENTATION

IC instrumentation incorporates: Pump, Injector, Column, Suppressor, Detector and Recorder or Data System.<sup>[38-40]</sup>

#### 1. Pump

The IC pump is thought to be a standout amongst the most important components in the system which needs to give a consistent steady flow of the eluent through the IC-injector, column, and detector. This mixing ability speeds the process of choosing the ideal eluent mixture required for isocratic analysis. There is a series of mobile phase reservoirs that can contain a range of different mobile phases that can be used individually, blended or for mobile phase programming purposes "gradient elution". In fact, all components of an ion chromatograph that may come in contact with either phase of the distribution system should be constructed from an appropriate inert material. This incorporates all mobile phase conduits, valves, pumps, sampling devices, columns, detector sensor cells, and so forth. The solvent reservoirs are associated with a dissolvable solvent valve and a dissolvable developer where a specific solvent or specific solvent program can be chosen. The solvent at that point goes from the selector/programmer to a high-pressure pump. The mobile phase goes from the pump to the sampling device, for the most part, a straightforward turning valve that on revolution puts the example in accordance with the versatile stream which at that point passes on to the column. The exit flow from the column passes either to an ion suppressor or directly to the detector. Gas may come out of the solution at the column exist in the detector, resulting in sharp spikes and storing under helium atmosphere.

#### 1.1. Pumps types

The constant-flow pumps are the most generally utilized in all regular IC applications. Flow rate stability is a vital pump include that recognizes pumps. For size exclusion chromatography, the flow rate has to be extremely stable. Outside electronic control is an exceptionally attractive component when computerization or electronically controlled inclinations are to be run.

#### 1.2. Constant flow pumps

Constant-flow systems are for the most part of two essential composes reciprocating piston and positive dislodging (syringe) pumps. Reciprocating piston pump can keep up a liquid flow for an inconclusively prolonged stretch of time.

#### 1.3. Reciprocating piston pumps

The pumping rate is controlled by cylinder withdraws or by the cam turning speed. The principal disadvantage of this kind of pump is sinusoidal weight throbs which prompt the need of utilizing pulse dampers.

#### 1.4. Dual piston pumps

Gives a steady and nearly pulse-free flow. Both pump chambers are driven by a similar engine through a typical unpredictable cam; this normal drive enables one cylinder to pump while the other is refilling. Accordingly, the two stream profiles cover each other essentially lessening the throb downstream of the pump; this is envisioned underneath. Its favourable circumstances are: boundless solvent store permitting long haul unattended to utilize; brisk changeover and wipe out ability; wide flow rate range (0.01 to 10 ml/min) is given without outfit change. While its disadvantages are: not entirely remunerated pulsations may be perceptible at high refractive index detector sensitivities, particularly at low flow rates; pump unwavering quality relies upon the tidiness of the mobile phase and kept fixing ability off our check valves on each cycle (e.g. a few times each moment).

Ongoing enhancements include: A computer planned camshaft is utilized to accomplish most overlaps of pump strokes, bringing about basically imperceptible pulsation or ripple and little volume check valves are utilized to enable the pumps to work dependably at flow rates as low as 0.001 ml/min.

#### 2. Injector

In more refined LC, automatic sampling devices are consolidated where sample introduction is done with the assistance of auto-samplers and microprocessors.

Injectors ought to give the likelihood of infusing the liquid sample within the range of 0.1 to 100 ml of volume with high reproducibility and under high pressure (up to the 4000 psi). They should also produce least band broadening and limit possible flow disturbances. The most helpful and broadly utilized sample device for present-day LC is the micro sampling injector valve. With these sampling valves, samples can be brought reproducibly into pressurized columns without the huge interference of flow, even at elevated temperatures.

With industrially accessible programmed sampling devices, expansive quantities of samples can be routinely analyzed by LC without administrator mediation. Such equipment is famous for the analysis of routine samples (e.g., quality control of drugs), especially when

combined with programmed data-handling systems. Programmed injectors are essential in unattended seeking chromatographic parameters, for example, solvent selectivity, flow rate, and temperature streamlining.

The vast majority of the auto samplers have a piston metering syringe compose pump to suck the pre-established test volume into a line and after that exchange it to the moderately expansive loop (~100 ml) in a standard six-port valve. The easiest auto samplers use the special vials with pressurization caps. An extraordinary plunger with a needle, drive the cap down to the vial and dislodge the sample through the needle into the valve loop. The greater parts of the auto samplers are microprocessor controlled and can fill in as an ace controller for the entire instrument.

### 3. Columns

Charged atoms bind electro statically to oppositely charged groups that have been bound covalently on the matrix. Ion exchange chromatography is a sort of adsorption chromatography so that, charged atoms adsorb to ion exchangers reversibly in this way, the particles can be limited or eluted by changing the ionic condition. Ion exchangers can be utilized in column chromatography to isolate molecules as indicated by charge; different features of the molecules are generally critical with the goal that the chromatographic conduct is sensitive to the charge density, charge distribution, and the extent of the molecule. An ion exchange is normally a three-dimensional system or network that contains covalently charged groups. In that a group is negatively charged, it will exchange positive ions and is a cation exchanger. A case of a group utilized in cation exchanger is the carboxyl-methyl gathering. However, if a group is positively charged, it will exchange negative ions and is an anion exchanger. An example of a group used in anion exchanger is the diethyl amino-ethyl group (DEAE). The lattice (stationary stage) can be made of different materials; usually utilized materials are dextran, cellulose, and agarose. Guard column is put front to the separating column. This serves as a protective factor that drags out the life and convenience of the separation section. They are dependable columns intended to expel particles that obstruct the separation column and compounds and particles that could eventually cause "baseline drift", decreased resolution, and decreased sensitivity or create false peaks.

### 4. Suppressor

The suppressor decreases the background conductivity of the synthetic substances used to elute samples from the ion-exchange column which enhances the conductivity estimation of the ions being tried. IC suppressors are membrane-based devices which are intended to change over the ionic eluent to water as a method for improving the sensitivity. It may be utilized with universal detectors to go about as a desalting device, in this manner expelling the interference coming out because of ionic salts in the eluent. Suppressors are ordinarily utilized

with aqueous eluents, so there is a need to build up whether these suppressors can be utilized with the aqueous/organic eluents expected to elute organic analytes which are held on the stationary phase during their connection.

Presentation of a suppression device between the column and the detector can be relied upon to cause some degree of peak broadening due to diffusional impacts. The state of the analyte band will likewise be affected by hydrophobic adsorption impacts, particularly when the adsorption and desorption forms are moderate.

### 5. Detectors

Current LC detectors have a wide power range regularly permitting both analytical and preparative scale keeps running on a similar instrument. A detector should have the accompanying properties: low drift and noise level (especially crucial in trace analysis), high sensitivity, immediate response, wide linear dynamic range, low dead volume (negligible peak broadening), cell design which takes out remixing of the separated bands, insensitivity to changes in kind of the solvent, flow rate and temperature, operational simplicity and reliability. It ought to be non-destructive.

**5.1. Electrical conductivity detector** is regularly utilized. The sensor of the electrical conductivity detector is the least complex of all the detector sensors and comprises just two electrodes arranged in an appropriate flow cell. The sensor comprises two electrodes fixed into a glass flow cell. In the electric circuit, the two electrodes are arranged to a component in one arm of a Wheatstone bridge. At the point when ions move into the sensor cell, the electrical impedance between the electrodes changes and the 'out of adjusting motion' from the bridge is fed to a reasonable electronic circuit. The 'out of adjusting' signal isn't intrinsically directly identified with the ion concentration in the cell. Therefore, the electronic circuit adjusts the response of the detector to give a yield that is directly identified with the ion concentration.

**5.2. Amperometric detection** is an extremely sensitive technique. On a fundamental level, voltammetric detectors can be utilized for all compounds which have functional groups which are effectively diminished or oxidized. Apart from a few cations (Fe<sup>3+</sup>, Co<sup>2+</sup>), it is chiefly anions such as cyanide, sulfide, and nitrite which can be determined in the ion analysis sector. The most vital applications lies in the analysis of sugars by anion chromatography and in clinical examination utilizing a type of Amperometric detection know as Pulsed Amperometric Detection (PAD).

**Table 1.1: Types of samples analyzed by ion chromatography<sup>[24]</sup>**

Acid rain	Ores
Analgesics	Pesticides
Chemicals	Pharmaceuticals
Detergents	Physiological fluids
Drinking water	Planting baths
Fermentation broths	Protein hydrolysates
Fertilizers	Pulping liquors
Foods and beverages	Soil and plant extracts
High-purity water	Wastewater

**Table 1.2: Recent Works on Ion Chromatography.**

SAMPLE	SOURCE	METHOD	ELUENTS	DETECTION MODE	REFERENCE
Caffeine, theobromine, and theophylline	Foods and pharmaceutical preparations	Anion-exchange chromatography	100 mmol <sup>-1</sup> HCl	Ultraviolet absorbance detections at 274 nm	[42]
Perchlorate	Foods and beverages	Anion-exchange chromatography	90% acetonitrile + 10% water	IC-ESI-MS/MS	[43]
Arsenic	Rice	Cation-exchange chromatography	10 mm (NH <sub>4</sub> ) <sub>2</sub> CO <sub>3</sub> pH Adjusted with NH <sub>4</sub> OH, 12.5 mm HNO <sub>3</sub>	Ic-Icp-ms	[44]
Iron(III), copper(II), nickel(II), zinc(II), cobalt(II), lead(II) and cadmium(II)	Edible vegetable oils And fats	Cation-exchange chromatography	2.0 mm sodium carbonate and 0.75 mm sodium hydrogen carbonate solution	Variable-wavelength UV-Vis detection system,	[45]
Food colorants	Drinks	Anion-cation exchange chromatography	HCl, acetonitrile, water	Dionex ad20 absorbance detector.	[46]
Artificial sweeteners, preservatives, Caffeine, theobromine, and theophylline	Food	Anion-cation exchange chromatography	NaH <sub>2</sub> PO <sub>4</sub> (ph 8.20) solution containing 4% (v/v) acetonitrile	Wavelength-switching ultraviolet absorbance detection	[47]
Chloride	Petroleum coke	Microwave-induced combustion	Ethanol, Na <sub>2</sub> CO <sub>3</sub> , (NH <sub>4</sub> ) <sub>2</sub> CO <sub>3</sub> , H <sub>2</sub> O <sub>2</sub> solution, NaHCO <sub>3</sub> , H <sub>2</sub> SO <sub>4</sub>	Conductivity detector	[48]
Biogenic Amines	Alcoholic beverages	Cation-exchange chromatography	Deionized (di) Water, methane sulfonic acid	Electrochemical detection	[49]
Sulfur dioxide	Food	Rapid distillation method	Sodium carbonates, sodium bicarbonates	Electrochemical Detector	[50]
Anions	Milk	Anion-exchange chromatography	Water. 0.01 % thiomersal	Suppressed conductivity detection.	[51]
Biogenic Amines	Food	Cation-exchange Chromatography	Sodium Perchlorate, perchloric Acid-water	Pulsed Amperometric Detection	[52]
Nitrate and nitrite	Meat Products	Cation-exchange Chromatography	Sodium hydroxide, 50% (w/w), sodium nitrate	Uv absorbance detection	[53]
Isomers	Food	Anion-exchange chromatography	Sodium hydroxide 50% solution, Type I deionized water, 0.5 M HCl, 0.67 M HCl, 2 M HCl, sodium phytate	UV detection or chemically suppressed conductivity detection	[54]
Chloride, nitrate, and sulphate	Vodka and rum	Anion-cation exchange chromatography	Sodium bicarbonate, sodium carbonate,	Conductometric detector	[55]

			deionised water		
Sweeteners	Food and beverages	Anion-cation exchange chromatography	KOH	Conductivity detector	[56]
Na <sup>+</sup> , NH <sub>4</sub> <sup>+</sup> , K <sup>+</sup> , Mg <sup>2+</sup> , Ca <sup>2+</sup> , Cl <sup>-</sup> , NO <sub>3</sub> <sup>-</sup> , SO <sub>3</sub> <sup>-</sup>	Snow and ice cores	Anion-cation exchange chromatography	0.0018 m Na <sub>2</sub> CO <sub>3</sub> -0.0017 m NaHCO <sub>3</sub> 0.0125 m H <sub>2</sub> SO <sub>4</sub>	Conductivity detector	[57]
Inorganic P colloids	Environmental Samples	Colorimetric method(CM),diffusion gradient technique(DGT)	NaOH	Conductivity detector	[58]
Fluoride	Coal and Geological Materials	Anion-exchange chromatography	0.0015 M NaHCO <sub>3</sub> , 0.025 NH <sub>2</sub> SO <sub>4</sub>	Conductivity Detector	[59]
Nitrate, Nitrite and Ammonia Ions	Water, wastewater, air, food products	Cation-exchange Chromatography	Na <sub>2</sub> CO <sub>3</sub> ,NaHCO <sub>3</sub>	UV detector	[60]
Arsenic and Sulfur Species	Environmental Samples	Cation-exchange Chromatography	Na <sub>2</sub> CO <sub>3</sub> , NaOH	Hewlett-Packard model 1700B recorder with 1-V span	[61]
Sulfate and Nitrate	Soils	Cation-exchange Chromatography	NaHCO <sub>3</sub> ,Na <sub>2</sub> CO <sub>3</sub>	Conductivity Detector	[62]
Anionic, Neutral, and Cationic Species of Arsenic	Environmental Samples	Anion-cation exchange chromatography	Sodium carbonate, sodium Hydroxide, and 4% (v/v) methanol	ICPMS Detection	[63]
Organic acids	Soil Extracts	Anion-cation exchange chromatography	DI, acetonitrile and NaCl, NaOH,H <sub>2</sub> SO <sub>4</sub>	Conductivity Detection, spectrophotometric UV-VIS detector	[64]
Amino acids	Human plasma	Cation Exchange Chromatography	Trilithium citrate tetrahydrate, LiCl <sub>3</sub> , Lithium hydroxide, Thiodiglycol, Caprylic acid, Citric acid	Spectrophotometry at 570 and 440nm with Ninhydrin reaction	[65]
Pyruvic acid and Lactic acid & Vanillymandelic acid	Plasma & Urine	Anion exchange chromatography	NaHCO <sub>3</sub> and Na <sub>2</sub> CO <sub>3</sub>	Electrochemical Detection	[66]
<sup>78</sup> Se, <sup>72</sup> Se	Human urine	Anion exchange chromatography	25mm sodium hydroxide and 2% methanol	Icp-ms detector	[67]
Sulfide	Human and Rat brain	Electric potential	1M NaOH	Dionex Electrochemical Detector	[68]
Nitrate and Nitrite	Human Saliva	Anion exchange chromatography	2.7mm Na <sub>2</sub> CO <sub>3</sub> and 0.3mm NaHCO <sub>3</sub>	Suppressed Conductivity Detector	[69]
Sulfide	Gastro-Intestine	Electric potential	Oxalic acid, In 50% sodium hydroxide solution	Electrochemical	[70]
Halo acetic acid and Perchlorate	Drinking Water	Anion exchange chromatography	Na <sub>2</sub> CO <sub>3</sub> and NaOH	Dionex Electrochemical Detector	[71]
NH <sub>4</sub> <sup>+</sup> , K <sup>+</sup> , Na <sup>+</sup> , Mg <sup>2+</sup> , Ca <sup>2+</sup>	Rainwater and Takahashi river water	Cation exchange chromatography	Oxalic acid pH adjusted to 7.0 with LiOH	Conductivity detector	[72]
Fluoride, chloride, Nitrite, bromide, nitrate, phosphate and sulphate	Seawater	Cation and anion exchange chromatography	Na <sub>2</sub> CO <sub>3</sub>	Conductivity detector	[73]
NH <sub>4</sub> <sup>+</sup> , K <sup>+</sup> , Na <sup>+</sup> , Mg <sup>2+</sup> , Ca <sup>2+</sup>	Water	Cation exchange chromatography	3 mm Methane sulfonic acid	Potentiometric sensor array detector	[74]

Arsenic and chromium	Water	Cation Exchange Chromatography	KNO <sub>3</sub> at pH 9.8	ICP-MS	[75]
Halogen, Metalloids and non metal species	Drinking Water	Anion exchange chromatography	3.5mm Na <sub>2</sub> CO <sub>3</sub> and 1.0mm NaHCO <sub>3</sub>	Conductivity detector and ICP-MS	[76]
Selenium	Water	Anion exchange chromatography	Dilute NaOH	ICP-MS Detector	[77]
Selenite, selenate and selenocyanate	Water	Anion exchange chromatography	NaOH	Non-Dispersive (ND) Flame atomic absorption spectroscopy (FAAS)	[78]
Bromine	Drinking Water	Anion exchange chromatography	Potassium sulphate, sodium nitrate, sodium carbonate and sodium hydrogen carbonate	Conductivity detector with mass spectrometry detection with electrospray Ionisation	[79]
Cyanide	Drinking Water	Anion exchange chromatography	NaOH	Amperometric Detector	[80]
Bromate	Drinking Water	Cation Exchange Chromatography	Dilute NaOH	ICP-MS Detector	[81]
Bromate	Bottled Drinking Water, and Municipal Drinking Water	Cation Exchange Chromatography	Carbonate	Conductivity detector	[82]
Iodide	Sea Water	Anion exchange chromatography	0.35 M NaClO <sub>4</sub> + 0.01 M sodium phosphate buffer (pH 6.1)	UV Detection	[83]
Perchlorate	Ground Water and Drinking Water	Anion exchange chromatography	100 mm sodium hydroxide	Conductivity detector	[84]
Magnesium, calcium, strontium and barium	Water	Cation exchange chromatography	0.15m KCl mobile phase at pH 3,	Paired Emitter-Detector diode	[85]
Iodide and thiocyanate	Seawater	Matrix-elimination IC	0.2 mm NaCl and 0.3 mm Zwittergent-3-14	Uv detection	[86]
Chromium	Waste Water	Anion exchange Chromatography	0.1M ammonium hydroxide.	ESI-ICPMS	[87]
Iodate and Iodine	Sea Water	Anion exchange Chromatography	20mm NH <sub>4</sub> NO <sub>3</sub> at pH 5.6	ESI-ICPMS	[88]
NH <sub>4</sub> <sup>+</sup> , K <sup>+</sup> , Na <sup>+</sup> , Mg <sup>2+</sup> , Ca <sup>2+</sup> , Li <sup>+</sup>	Environmental water	Cation exchange chromatography	26 mm methane sulfonic acid	Electrochemical detector with the conductivity cell	[89]
Perchlorate	High Saline water	Anion exchange chromatography	100 mm NaOH	Conductivity Detector	[90]
Arsenic and Selenium	Ground Water	Anion exchange chromatography	NaOH	ICP-MS	[91]
K <sup>+</sup> , Na <sup>+</sup> , Mg <sup>2+</sup> , Ca <sup>2+</sup>	Terrestrial waters from Antarctica	Anion & cation exchange chromatography	0.020 m methanesulfonic acid	Dionex conductivity Detector	[92]
Bromate and Iodate	Ozonized water	Anion exchange chromatography	Ammonium carbonate	ICP-MS	[93]

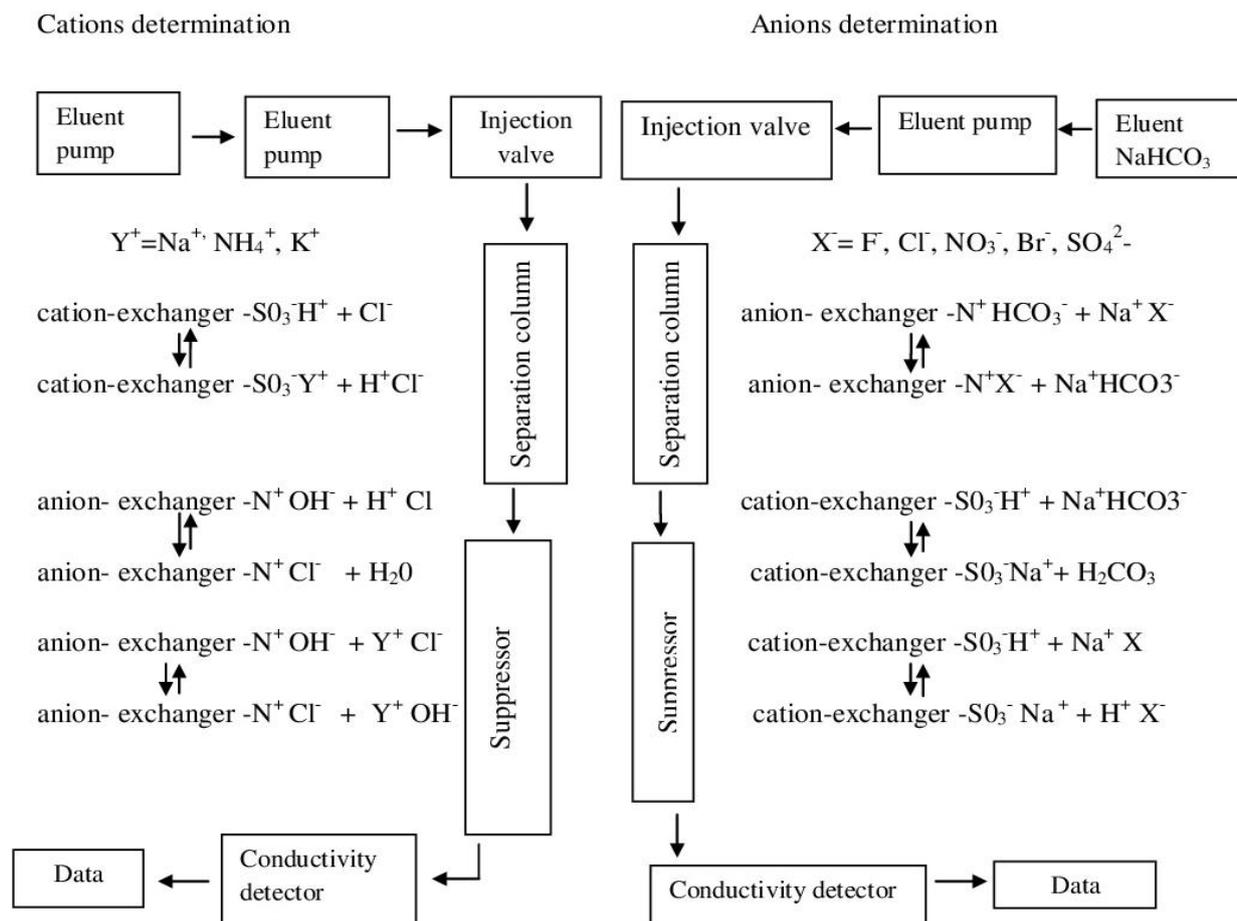


Fig. 1: Block diagram of the ion chromatography with suppressed conductivity detection.<sup>[29]</sup>

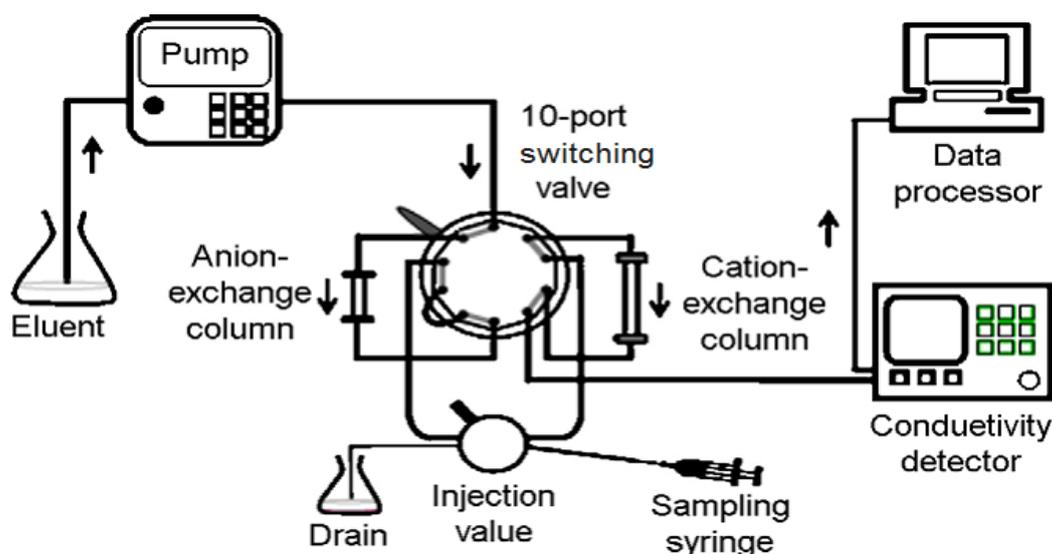


Fig. 2: Schematic diagram of the instruments used for the simultaneous separation of anions and cations.<sup>[41]</sup>

## CONCLUSION

IC is an adaptable and intense method for the examination of numerous particles and substances exhibit in clinical and pharmaceutical samples. Its most important advantages are a broad range of applications; well-developed hardware; many detection options; good accuracy and precision; high selectivity and separation

efficiency; good tolerance to sample matrices; and low cost of consumables. The coupling of ion chromatography to electrospray mass spectrometry provides a potential future direction, with improved sensitivity and selectivity compared to conductivity based detection, however, associated cost and complexity for routine analysis is currently relatively

high. It has undergone a tremendous development and can be regarded today as one of the most versatile analytical methods for all kinds of ionic compounds.

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