TECHNICAL NOTE 73982

Techniques for successful trace anion and trace cation determinations in high purity waters

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Keywords: Dionex IonPac AS17-C, RFIC, Reagent-Free IC, electrolytic water purifier, AutoPrep, Dionex IonPac AS28-4µm column, Dionex ICS-6000 system, Dionex EGC 500 KOH, chloride, sulfate, semiconductor, electronics, UPW, HPW, Dionex IonPac CS16 column, Dionex IonPac CS12A column, Dionex EGC 500 MSA

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1. Introduction

In the electronics industry, ionic contamination, in the range of parts per trillion (ppt, ng/L) to parts per billion (ppb, µg/L) concentrations, is a major concern. This contamination can cause corrosion-related failures, poor product quality, low product yields, and shortened product life. Although methods for reducing ionic contamination are well established, devices continue to decrease in size with smaller clearances on printed circuit boards.[1-4] As a result, it is more challenging and more important to remove ionic contamination that occurs at decreasing concentrations with each generation of devices. Therefore, as a result of these demands, it is more important and more challenging to determine ionic contamination at even lower concentrations. The lab environment and the IC system cleanliness can significantly impact the blank levels, limiting the analytical sensitivity in trace analysis methods. In this document, we will discuss techniques to improve trace anion analysis and how to achieve low detection limits in low ppb to high ppt range. Three techniques demonstrating trace anion determinations using Thermo Scientific™ Dionex™ IonPac™ AS17-C and Thermo Scientific™ Dionex™ IonPac™ AS28-4µm anion-exchange columns from recent and earlier applications will be discussed: 1) Large volume direct injection, 2) Large volume with preconcentration, and 3) Thermo Scientific™ Dionex™ AutoPrep™ method using large volume preconcentration for samples, small volume preconcentration for standards, and an inline water purifier to create a closed loop system. We will briefly discuss trace cation analysis. The general precautions (e.g., lab environment, sample handling, etc.) discussed for trace anion analysis apply to trace cation analysis. Therefore, the discussion in the cation section will focus on the chromatography.

2. Sources of contamination

2.1 Cleanroom environment

Many electronic and medical devices are manufactured in a cleanroom environment. A cleanroom is classified according to the quantity of 0.5 µm diameter particles per cubic meter. A cleanroom classified as ISO 14644-1 Class 4 has a maximum of 10,000 particulates/m^3.[5] The cleanrooms are cooled for worker comfort and designed with laminar airflow to minimize movement of particulate contamination. Personnel are often restricted from using particle-generating or odiferous personal products, garmented with low particulate, electrostatically safe clothing, and pass through a wind tunnel to dislodge loose contamination introduced from outside the cleanroom. Items known to generate particulate contamination, such as paper and pencils, are not allowed in most cleanroom environments. Cleanroom personnel wear booties to cover shoes, hair nets, masks, and headcovers to cover most of the head, over which they don a cleanroom jumpsuit and boots, followed by two sets of disposable gloves. Some cleanrooms may use toxic gases or experiment with toxic microorganisms and include self-contained air systems. Contamination by cleanroom machines and instruments is minimized by being self-contained or limiting exposure to the cleanroom by residing in utility chases. However, ionic and particulate contamination from aerosols can be generated from chemical and chemical-mechanical processes in the cleanrooms, such as plating, cleaning, stripping, and polishing. Inline sampling, air sampling, and analyses of products, sample plates, wipes, and work surfaces have proven effective in controlling ionic contamination in cleanroom environments. To support these analyses, analytical instruments are sometimes located inside the cleanroom to minimize the testing environment contamination and minimize traffic in and out of the cleanrooms.

2.2 Laboratory environment

Other facilities install laboratories outside the cleanroom environment and therefore have additional precautions to minimize cross-contamination. To establish instrumentation for trace ion determinations, select a dedicated low-traffic space away from ceiling vents, volatile reagents, and high-use balances. Select dedicated tools, such as a dedicated balance, cleanroom nitrile gloves, metal spatulas, and stainless-steel tweezers. Diligently maintain a clean work area. After cleaning, place polyester cleanroom wipes on the bench areas. This is a clean zone where tools and vials can be placed. Do not use paper products. Table 1 summarizes sources of contamination.

Table 1. Sources of contamination

Source	Recommendation	Comments
DI water	Meets ISO 3696 Grade 1, ASTM Type I or SEMI grade deionized (DI) water.[6-8] The DI water must be 18 MΩ·cm resistivity with low TOC at point-of-use. The DI water system should be in recycle mode and should be free of leaks. The DI water system should be maintained and periodically sanitized for microorganisms.	Microorganisms can contaminate water systems, particularly deionization beds. This is more common in water systems located in high heat and humidity. Acetate, formate, and nitrate are marker ions for microorganism contamination, with nitrate converting to nitrite. Borate and silicate are contaminants that appear from break-through of deionization beds.
Air vent	Isolate the IC system away from air vents.	Source of particulates and sometimes contaminated outside air.
Lab traffic	Isolate the IC system in the lab's lowest traffic area.	Locate the IC system away from high traffic routes. Avoid group gatherings near the IC system.
Lab bench	Isolate the IC system in the lab's lowest traffic area.	Maintain a clean bench. Place cleanroom polyester wipes for clean zones to place tools.
Personal clothing	Source of particulate contamination	Not an issue in a cleanroom as the personal clothing is covered by cleanroom attire. In a laboratory setting, lab coats may minimize particulates from personal clothing.
Gloves	Use cleanroom, low particle, low ionic gloves, such as nitrile. Most gloves are still highly contaminated with ions.	Change gloves after touching personal items (e.g., face, hair, keyboard). Avoid splashes or dripping from gloves to touch standards, samples, or clean containers. Potential contamination sources of sodium, chloride, sulfate, calcium, and magnesium.
Lab coat	Polyester recommended	Cotton garments generate particulates. Lab coats reduce contamination from personal clothes.
Reagents	Avoid analyzing or preparing standards and analyzing samples when others are preparing standards.	Volatile acids and salts of volatile acids (acetate, formate) cause immediate contamination. Similarly, volatile bases and salts of bases (ammonium and amines) cause immediate contamination. Cross-contamination can occur from high concentration standards.
Pipette tips	Use pipettes only for the intermediate and stock standards.	Use the "weigh and pour" method of adding the standard to DI water for µg/L and ng/L standards.
Aerosols and perspiration	Refrain from generating aerosols and droplets from sneezing, coughing, and perspiration.	These are contamination sources via contact or aerosols of sodium, potassium, chloride, and sometimes ammonia. Wash face and hands thoroughly and replace gloves.
Personal products	Avoid lotions, powders, perfumes, makeup, and fingernail polish.	Minimize if all other steps have been made to reduce contamination levels.
Salty foods	Avoid touching and consuming salty foods (e.g., chips, crisps, soy sauce, black bean sauce, pickles, crackers, fries) during work hours.	Thoroughly wash face and hands after breaks and meals and before putting on gloves. Salty foods are contamination sources for sodium and chloride, and sometimes acetate and malate.
Citrus foods	Avoid touching and consuming citrus foods (and other foods with strong odors) during work hours.	Thoroughly wash face and hands after breaks and meals and before putting on gloves.
Paper products	Avoid using paper products (writing paper, towels, lab wipes). The exception is cleanroom lab notepaper which is designed especially for cleanroom environments.	Paper products are a major contamination source of chloride and sulfate.
Elastomers	Avoid using elastomeric materials (e.g., peristaltic and rubber tubing) that are in the flow path. If possible, remove and replace.	Potential contamination sources of sulfate, calcium, and magnesium.

3. Preparation of standards and samples

3.1 Sample and standard containers

Cross-contamination is always a concern in trace ion determinations, including from standard and sample containers and liners in the caps of those containers; therefore, it is important to select containers without cap liners and containers composed of the lowest ionic leachable polymers. Perfluoroalkoxy alkane (PFA), high-density polyethylene (HDPE), and polystyrene (PS) polymer materials generally have the lowest extractable ionic contamination.[9] Polymethylpentene (PMP) is another expensive polymer that may be suitable for trace ion determinations (AN153),[10,11] but further experiments are needed. The material selection is dependent on the sensitivity required, material cost, intended use, and tolerance to cleaning processes needed to reduce the background contamination (often, solvents and elevated temperatures are used). For example, PFA is costly and is not easily molded into sample vials. However, PFA is rugged, less porous to air, and can be cleaned with solvents and elevated temperatures, and therefore suitable for sub-ng/L determinations and for

cleanroom air sampling. PS is transparent, easily molded into sample containers as vials and culture flasks, but PS is incompatible with many solvents and easily melts at elevated temperatures. HDPE is a common material with potentially higher contamination, and therefore suitable for mg/L standards, and once verified clean, suitable for extraction containers. See Tables 2 and 3 for recommendations.

3.2 Preparing containers and vials

In addition to selecting the polymer, the containers must be cleaned prior to use by rinsing and soaking with ASTM Type I DI water each day for several days to remove any residual contamination from the manufacturing and shipping processes. It is common to find one container has significantly higher contamination than the others. Therefore, prior to use, the ionic contamination should be verified by IC. Containers with higher contamination should not be used until the results show that contamination is low. To determine the extractable contamination, add a set volume of ASTM Type I DI water to the container or vial and analyze the sample after 1 h. If containers are not adequately cleaned, the variable background contamination from the containers can result in inaccurate and imprecise reporting.

Cleaning the containers and vials to remove residual contamination must be done methodically and diligently. To minimize cross-contamination during this process, wear cleanroom nitrile gloves and avoid aerosols from sneezing and talking, splashing from gloves and sink surfaces, touching the threaded surfaces or the top of the container, and discontinuous flow of DI water during the cleaning. Avoid allowing caps (or lids) of containers to touch the lab bench. To avoid this contamination, either hold the cap during the whole rinsing process or place the cap on a dry cleanroom polyester wipe.

Table 2. Recommended materials that minimize ionic contamination from containers[11]

Material	Suitable concentration range	Elevated temperatures	Organic solvents	Recommended containers
HDPE	mg/L to µg/L	Some	Some	mg/L standards, sample extraction containers
PS	µg/L to ng/L	No	No	Sample vials, sample, and standard culture flasks
PFA	µg/L to <1 ng/L	Yes	Yes	Air sampling, ultra-trace applications This material is less porous to air.
PMP	µg/L to <1 ng/L	Yes (Melting point <175 °C)	Some	Air sampling, trace applications where elevated temperatures are used for cleaning containers

Table 3. Recommended containers

Material	Vials	Bottles	Culture flasks or containers
HDPE	Not commercially available in 5–10 mL size	125 mL Thermo Scientific™ Nalgene™ standard bottles: P/N 3321890004*, P/N 03-313-6A** 250 mL Nalgene sample and standard bottles: With septa: P/N 064232* Without septa: P/N 332189-0008** 2 L Eluent bottle: P/N 062510*	Not commercially available for culture flasks.
PS	10 mL vial kit (pkg of 100) with precut septa: P/N 074228*	1 L flask (autosampler wash bottle, or sample storage) from Thermo Scientific™ Nalgene™ Rapid-Flow™ filter flasks: P/N 4551000*, P/N 09-740-25F**	250 mL untreated culture flasks With caps/septa: P/N 064235*
PFA	Not commercially available	250 mL: P/N 16300008*, P/N 02-923-35L** 500 mL: P/N 16300016*, P/N 02-923-35M**	Not commercially available
PMP	Not commercially available	Usually sold as containers	250 mL wide mouth containers: P/N 11-823-31**, P/N 21170250* 1,000 mL wide mouth: P/N: 11-823-33**, P/N: 21171000*

* Thermo Scientific P/N ** Fisher Scientific P/N

3.2.1 Cleaning bottles and flasks

To clean containers (bottles and flasks), turn on the DI water, remove the cap, and rinse the container five times with ASTM DI water. Fill the container to the top with DI water and rinse the cap five times, avoiding splashing towards the container. Cap the container. Store upright to minimize air headspace. Repeat the process for a minimum of three days. It is sometimes expedient to use soaking containers (i.e., containers that other containers are put inside to soak), which should be cleaned in the same manner prior to use.

3.2.2 Cleaning septa

To prepare septa for bottles and flasks, add the septa into a previously cleaned container, partially fill the container, shake the container to wet the septa, and drain. Repeat the process five times each day over a minimum of three days. For µg/L to <1 ng/L methods, food grade aluminum is recommended as a single-injection septum instead of other materials. PTFE single-injection septa (pkg of 100, P/N 074927) are also recommended instead of the "blue septa" in the Dionex ASAP 10 mL vial kits.

3.2.3 Cleaning sample vials

Sample vials can be pre-cleaned as an assembled vial or as individual parts in soaking containers. To clean assembled vials, rinse a pair of stainless-steel tweezers, shake off the excess water, pick up the septa, and insert it into the vial cap. Add DI water to the vial at approximately 50% of the vial volume and screw on the cap. Vigorously shake the vial, unscrew the cap, and discard the DI water. Repeat five times for each vial. Fill the vial with DI water to the top. Repeat the process for a minimum of three days. When requiring single digit µg/L to ng/L sensitivity, this process was found to be more effective than cleaning the vials as separate parts.

To clean the sample vial as separate parts, add the caps, septa, and vial bodies to separate pre-cleaned soaking containers. Partially fill the soaking container with DI water, shake, and decant. Repeat five times, fill, and soak overnight. Repeat the process for a minimum of three days. To use these cleaned vials, decant the vials, caps, and septa. Rinse, shake, and decant three times. Using the stainless-steel tweezers, remove a cap. Rinse the cap three times holding the cap with the tweezers or with gloved fingers without touching the inside of the cap. Shake off the excess liquid. Repeat the process with the septa using the tweezers. Insert the septa into the vial cap. Repeat the process with the vial by removing the vial body with the tweezers and rinsing the vial while holding the vial in the middle. Rinse the vial three times, shake out excess liquid, add sample or DI water, and assemble the vial. Repeat as needed for each vial. Refill the soak containers with caps, vial bodies, and septa. Repeat the rinsing, shaking, decanting, and soaking processes.

3.3 Preparation of stock, intermediate standards, and working standards

Use commercially available 1,000 mg/L anion standards or prepare standards. Make a 100 mL final volume of 1,000 mg/L stock standards in 125 mL high-density polyethylene (HDPE) containers. From these stock standards, prepare a 1 mg/L combined anion standard. To determine possible cross-contamination in the nitrate and nitrite standards, prepare 1 mg/L separate intermediate standards of nitrate and nitrite from the 1,000 mg/L nitrate and nitrite stock standards. Prepare 10 µg/L individual standards from the 1 mg/L intermediate standards. Other single ion standards can be evaluated in the same manner to verify their purity.

Take aliquots from this dilute standard to make working standards in the high-ng/L (ppt) to low-µg/L (ppb) range. Pipette tips can also contribute to contamination. To avoid cross-contamination, prepare the working standards by weighing the amount of water and 1 mg/L mixed standard added to the 250 mL pre-cleaned culture flask. To follow this process, rinse the flask three times and shake-out the excess water. Tare the flask on a clean balance. Remove the flask and fill the flask to the ~200 mL mark with DI water directly from the DI water system while avoiding water droplets on the outside of the flask or touching the DI water system. Weigh the flask and record the amount of DI water added to the flask. Carefully pour an aliquot from the 1 mg/L mixed standard without touching the neck of the flask. Record the total weight and calculate the concentration in the flask, for example, 205 g of DI water and standard to 209 g total. The concentration is 4 g (mL) of 1 mg/L diluted to 209 g, resulting in 19.14 µg/L working standard. Prepare other working standards in a similar way using the 1 mg/L mixed standard or other µg/L standards. Prepare the flask cap by rinsing three times and shaking off the excess. Cap the flask and carefully mix the new standard. Record the concentration on lab tape affixed to the flask. Lab tape has less extractable ionic contamination than markers. Prepare the cation working standards for trace cation determinations in a similar way. Store the flasks upright to minimize the surface area exposed to the air in the flask.

Stock standards are stable for at least one month when stored in a refrigerator at 4 °C. Dilute stock standards at the low-mg/L (ppm) levels should be prepared fresh weekly. Working standards at the low-µg/L (ppb) and ng/L (ppt) range should be made fresh daily.

3.4 Preparation of samples

To minimize contamination during sample collection, prepare sample containers several days before sampling. Verify that the sample container is clean by rinsing the container with DI water, adding DI water, extracting for 1 h, and analyzing the resultant water. Please note that for industrial applications (i.e., water purification, cleaning, and delivery systems), contaminants can build up in sampling ports and other "t-joints". To minimize this contamination and obtain a representative sample, allow the DI water to discharge for more than 30 s at the sampling port before sampling. Do not use hose or tubing on sampling ports because contamination can leach from hoses or tubing and contaminate samples. To minimize contamination, do not touch the sampling port or allow the sampling bottle to touch the sampling port. Fill the sampling bottle nearly to the top to avoid gas headspace. Store the sample at 4 °C and analyze as soon as possible.

4. System preparation and setup

4.1 Autosamplers

It is important to minimize contamination from the sample introduction. Although the pressurized container method (a container with the sample is pressurized to fill the sample loop) has the least contamination to trace analysis, it lacks automation and is tedious. Using an autosampler for sample introduction is much more convenient, but it requires prior clean-up of the autosampler. Additionally, determinations of trace cations and anions should be run on separate systems and separate autosamplers to avoid cross contamination. The autosampler can be used to introduce samples to both systems, but the standards will cause cross-contamination.

4.1.1 Preparing the Thermo Scientific™ Dionex™ AS-AP Autosampler for trace ion analysis

Install and configure the Dionex AS-AP Autosampler in Push Mode for use with an ultra low pressure concentrator column, and Pull Mode or Push Mode when using a sample loop. Pull Mode is often recommended because it has less system contamination. For methods using a ultra low pressure concentrator column only use Push Mode. Follow the Dionex AS-AP Autosampler Operator's Manual (Document No. 065361)[12] or instructions on the Thermo Scientific™ Chromeleon™ console sampler panel to calibrate the sample transfer line to ensure accurate and precise sample injections. The Dionex AS-AP Autosampler has many features that improve sample introduction for trace analysis applications. However, additional steps are needed to ensure that accessories do not contaminate the system. Configurations are discussed for both direct large loop injections and large volume injections by concentration.

A. Tubing:

i. Replace any Teflon™ tubing, such as in the buffer loop or wash reservoir line, with new green (0.030 in i.d., and 0.75 mm i.d.) PEEK™ tubing.

ii. If the autosampler has been used to inject samples from vials other than polystyrene vials or polystyrene vials with red septa, replace the PEEK tubing from the sampling needle to the injection port with new PEEK tubing.

B. Transfer line calibration:

Prime the autosampler flush lines with 1,000 µL DI water. Calibrate the transfer lines according to TLV Calibration instructions on the Chromeleon Autosampler panel.

C. Specific for Large Loop Injections Using the Dionex AS-AP Autosampler:

i. Instrument configuration: On the Options page for the Dionex AS-AP Autosampler, enter the loop volume into the Loop Size field. Select *Push or Pull*.

ii. Instrument Method/Instrument Program Wizard:

a. Select *PullFull* or *PushFull* in the Inject Mode field based on method.

b. Enter *10.0* in the Loop Overfill field.

iii. Instrument Method/Instrument Program Wizard: On the second Sampler Options page:

a. Enter *500.0* in the Wash Volume field.

b. Select *Both* in the Injection Wash Mode field.

c. Use the recommended values for the remaining fields.

D. Specific for Concentrate Mode injections using the Dionex AS-AP Autosampler:

i. Server Configuration program: On the Options page for the Dionex AS-AP Autosampler, enter a large volume, such as 5 mL, to be loaded to the concentrator column.

ii. Instrument Method Wizard or Program Wizard:

a. Select *PushConcentrate* in the Inject Mode field.

b. Enter *5.0-10 (µL/s)* for the Draw and Dispense speeds (syringe). The sample must be delivered at low syringe speeds needed for the concentrator column to efficiently retain the anions.

c. Select *Both* in the Injection Wash Mode field.

d. Use the recommended values for the remaining fields.

E. Autosampler clean-up:

i. Soak the PEEK needle by positioning it in a previously cleaned vial or culture flask filled with fresh DI water and covered with food grade aluminum foil.

ii. Repeatedly flush and prime the syringe, needle, and buffer loop with 12 mL DI water. It is important to keep the buffer loop clean.

iii. Ensure that the needle assembly is properly drained so that no standing water can accumulate around it.

4.1.2 Preparing the Thermo Scientific™ Dionex™ AS-HV Autosampler for trace ion analysis

To set up the Dionex AS-HV Autosampler, connect one end of the RS-232 cable to the 9-pin connector on the Dionex AS-HV Host port and the other end to the 9-pin connector on the PC. Set the DIP switch, and connect the peristaltic rinse and sample pump, sample loop, and tubing in Pull Mode according to the installation guide in Appendix B of the Operator's Manual for the Dionex AS-HV Autosampler.[13] Install the spill tray, rack location mat, fixed rinse reservoir, and 15-position sample rack by following the instructions in Sections B.3.1–B.3.3, and B.3.6 in Appendix B of the Operator's Manual.[13] Soak the PEEK needle overnight in a previously cleaned vial or culture flask filled with fresh DI water.

Prepare the 4 L rinse fluid reservoir for the Dionex AS-HV Autosampler two or more days prior to use. Rinse the inside of the container five times with Type 1 DI water, fill it to just below the fittings, cap the container, and let it soak for two days. Discard the soaking water and fill the container with fresh Type 1 DI water to just below the fittings. Connect the bottle to the rinse fluid reservoir tubing on the peristaltic pump. As this bottle is open to the air, the DI water should be replaced daily if possible.

4.2 Connectors and ferrules

To minimize contamination from the connectors and ferrules, use only new parts and soak them in pre-cleaned polystyrene flasks containing fresh 18.2 MΩ·cm DI water.

4.3 Preparing the Thermo Scientific™ Dionex™ ICS-6000 system for trace ion analysis

The Dionex ICS-6000 HPIC system is configured with a CD Conductivity Detector, eluent generator, and a column and detector-suppressor compartment with temperature control.

4.3.1 Pre-installation system clean-up

Special system clean-up is typically needed for trace ion analysis. Typically, the injection valve, PEEK needle, and tubing may require additional cleaning. Fill the eluent bottle with fresh DI water daily to minimize microbiological contamination.

Fill the eluent bottle with fresh DI water, prime, and restart the pump.

A. For large loop injections, install the intended sample loop for the application. For concentrate mode injections, temporarily install a known clean 10–100 µL sample loop.

B. Install the backpressure coil from the pump to the six-port injection valve to ensure the pressure is at least 200 psi (lower pressure limit) and direct it to the waste container. Then pump DI water through the system with the injection valve in the inject position. Liquid flows through either the Load or Inject path, depending on the valve position. In the Inject position, eluent flows from the pump through the sample loop, thereby flushing the sample loop. The injection valve can be set to the Inject or Load position from the DC Detector/Chromatography front panel.

C. Flush overnight with DI water, with tubing installed rather than columns, before installing columns and other consumables. The newly cleaned tubing can be used in the installation.

4.3.2 Installation of Reagent-Free™ IC (RFIC™) consumables

Thermo Scientific™ Dionex™ Eluent Generator Cartridges (Dionex EGC):

Eluent generators allow automatic production of high purity IC eluents. The precise control of eluent concentration allowed by electrolytic eluent generation prevents baseline shifts, increases sensitivity, improves resolution, and ensures consistent peak integration. By eliminating trace contamination in eluents, electrolytic eluent generation provides outstanding run-to-run reproducibility. The Thermo Scientific™ Dionex™ EGC 500 KOH cartridges are the cartridges of choice for use with hydroxide-selective Dionex IonPac columns.

Install the Dionex EGC 500 KOH cartridge (P/N 075778) and Thermo Scientific™ Dionex™ CR-ATC 600 Continuously Regenerated Anion Trap Column (P/N 088662). Condition the devices according to instructions in the product manuals[14,15] and the Dionex ICS-6000 System Operator's manual.[16]

Electrolytically regenerated suppressor:

Electrolytically regenerated suppressors represent a major advance in eluent suppression technology, especially for trace-level IC. The suppressors make their own regenerant continuously and automatically from DI water. The suppressor provides excellent baseline stability, fast start up times, low background, and low noise.

The Thermo Scientific™ Dionex™ Anion Electrolytically Regenerated Suppressor for External Water (Thermo Scientific™ Dionex™ ERS™ 500e) and the Thermo Scientific™ Dionex™ Anion Dynamically Regenerated Suppressor (Thermo Scientific™ Dionex™ ADRS™ 600 Suppressor) are the latest suppressors for anion analysis. For trace analysis, the recommended suppressor is the Thermo Scientific™ Dionex™ AERS™ 500e suppressor run in external water mode as it provides low background and noise. Table 4 lists suppressor part numbers.

Table 4. List of anion suppressors with P/Ns

Suppressor	Format	P/N
Dionex ADRS 600	4 mm	088666
	2 mm	088667
Dionex AERS 500e	4 mm	302661
	2 mm	302662

Prepare the Dionex AERS 500e suppressor for use by hydrating the internal membrane. Refer to the instructions provided with the suppressor for step-by-step instructions on hydrating the 2 mm Dionex AERS 500e suppressor. Do not add any backpressure tubing coils after the suppressor. To complete the hydration step, wait an additional 20 min without eluent flow before installing the suppressor in the recycle mode. Connect Regen Out on the suppressor to Regen In on the Dionex CR-ATC 600 Anion Trap Column. DI water for the suppressor regen can be supplied by an additional pump (e.g., the second pump of a dual pump (DP) module) or by pressurizing the water reservoirs. Configure the pressurized water reservoirs to supply external water for suppressor regeneration. Fill the reservoir with DI water and apply 5–15 psi to the reservoir to deliver DI water through the regenerant channel. Ensure that the cap of the reservoir is sealed tightly. For more information on installation and operation of a Dionex AERS 500e suppressor, consult the product manual, Document No. 031956.[17]

Carbonate removal device:

It is advantageous to both increase sensitivity and decrease the baseline disturbance (i.e., contamination observed in the chromatographic blank analysis) when performing trace analysis. Typically, sensitivity is accomplished by injecting a large volume of sample or concentrating a larger volume of sample. Reducing baseline contamination is often the most challenging aspect of trace analysis. The carbonate peak is the largest in trace anion determinations. Ideally, carbonate should be removed before concentration to minimize carbonate acting as eluent on the concentrator column (i.e., carbonate takes too much of the concentrator's capacity and thus overloading it). The carbonate peak from the sample is always substantial and can interfere with the integration of some analyte peaks. Therefore, a Carbonate Removal Device, Thermo Scientific™ Dionex™ CRD 200 (CRD 200, 4 mm (P/N 062983) CRD 200, 2 mm (P/N 062986)), should be installed and plumbed inline. The Dionex CRD 200 device is positioned between the Dionex AERS 500e suppressor and the conductivity cell. Condition the Dionex CRD 200 device with DI water for 5 min before installing it in the system. Hydrate and install the device according to the instructions in the product manual.[18]

Table 5. Columns recommended for trace anion analysis

Column	Primary application
Dionex IonPac AS28-Fast-4µm (57.5 µEquiv-2 mm) 2 × 150 mm (P/N 088750) 4 × 150 mm (P/N 088747)	High capacity column for trace analysis of inorganic anions and low molecular weight organic acids, including glycolate, formate, and acetate in high purity water samples. This column is composed of supermacroporous resin particles.[19] Recommended replacement for Dionex IonPac AS15 and AS15-5µm columns as it has better resolution, higher capacity, and shorter analysis times.
Dionex IonPac AS17-C (7.5 µEquiv-2 mm) 2 × 250 mm (P/N 066294) 4 × 250 mm (P/N 066296)	Low capacity column for fast analysis of common (inorganic anions) using gradient elution. This column is composed of carboxylated supermacroporous resin particles to minimize the sulfate blanks during trace level anion analysis.[20]
Dionex IonPac AS15-5µm (17.5 µEquiv-3 mm) 3 × 150 mm (P/N 057594)	Fast run, high capacity column for trace analysis of inorganic anions and low molecular weight organic acids including glycolate, formate, and acetate in high purity water samples.[21] This column is composed of macroporous resin particles.

4.3.3 Anion exchange columns

The following columns (Table 5) are recommended for trace anion analysis in high purity water. These columns are optimized for hydroxide eluents that deliver lower backgrounds after suppression and thus better analyte sensitivity.

4.3.4 Post-installation system clean-up

After flushing the system overnight with DI water, install the Dionex EGC cartridge and flush with starting eluent concentration for 60 min. Install guard and analytical columns and flush them with starting eluent concentration to waste for 1–2 h. Install the suppressor and then CRD 200 as described above. Set the flow rate to 0.25–0.5 mL/min, the eluent concentration to 75 mM, and the suppressor current to 35 mA, and then monitor the baseline for 2–3 h. Toggle the injection valve between the load and inject positions every 15–30 min. Continue this process until both positions give a baseline conductivity of <0.5 µS/cm.

4.3.5 Achieving a low system blank

To start the system, turn on the pump and immediately turn on the Dionex EGC 500 eluent generator cartridge. Turn on the Dionex CR-ATC 600 trap and Dionex AERS 500e suppressor when liquid is flowing through the devices. Confirm that there are no leaks in the chromatographic pathway. Allow the system to equilibrate for 30 min and run a system blank. In all trace ion applications, the system and water blanks can often compromise detection limits of the analytical method and therefore are important parameters when qualifying a method. A system blank is a chromatographic run where no injection is made through the autosampler, but the system is operated for the whole run with the method conditions. To set a system blank injection in Chromeleon software, select a “blank” in the dropdown window in the “type of sample” column. Assess the quality of the blank by measuring the short-term noise. In a representative 1 min level portion of the chromatogram, a “peak-to-peak” measurement should be less than 5 nS/cm. It takes at least 4 h for the system to equilibrate to a stable background conductivity for trace analysis. At times there are brief increases in conductivity that minimize upon further operation of the system. The IC system’s flow path (eluent containers, injector, pump, valves, tubing, columns, suppressor, and conductivity cell) are potential contamination sources. Use caution when switching from a system setup that has previously seen significant concentrations of anions or cations. Rinse with high-purity water to reduce residual contamination. It is, therefore, a good practice to run a system until the baseline is stable, ±0.01 µS/cm. If an extremely low baseline is important for your analysis, this process could take from 1 to 4 weeks, depending on the initial system cleanliness. For the lowest detection limits, it is critical to achieve low system and DI water blanks.

5 Methods/approaches

5.1 Large volume direct injection

The direct-injection approach is easier to use than methods that use a concentrator column and loading pump but is limited by the amount of sample that can be loaded. Figure 1 displays the flow diagram of a system set up for a large-volume direct-injection method. Columns and suppressor are used in the microbore format (2 mm) due to the four-fold increase in mass sensitivity over the standard (4 mm) format. Injection volumes range from 1 to 2 mL. To execute large injection volumes, a sample syringe size of 5 mL (P/N 074308) and 8.5 mL buffer line size (P/N 075520) are required. To make a 1 mL sample loop, cut a 220 cm portion of the green 0.030 in. (0.75 mm) i.d. PEEK tubing. If a different loop or tubing with a different internal diameter is desired, refer to Table 6 to calculate the tubing length needed. The volume of a loop can be verified by measuring the weight difference between the sample loop filled with DI water and the empty loop. The internal diameter of tubing varies by as much as 20% (for example, 0.010 ± 0.002 in.).

Table 6. Volume per unit length for various tubing internal diameters

Material	Color	Internal diameter inches	Internal diameter mm	Estimated vol. (µL/cm)
PEEK	Red	0.005	0.125	0.126
PEEK	Black	0.010	0.250	0.506
PEEK	Orange	0.020	0.500	2.022
PEEK	Green	0.030	0.750	4.550

5.2 Preconcentration

Preconcentration is a trace enrichment technique that concentrates the desired analytes, which lowers detection limits. For the preconcentration method, a concentrator column is installed in place of the sample loop, as shown in Figure 2. Concentrator columns are short columns (typically 35–50 mm in length), which contain a stationary phase that is identical or similar to the analytical column used for the analysis. The function of a concentrator column is to "strip" ions from a measured volume of a relatively clean

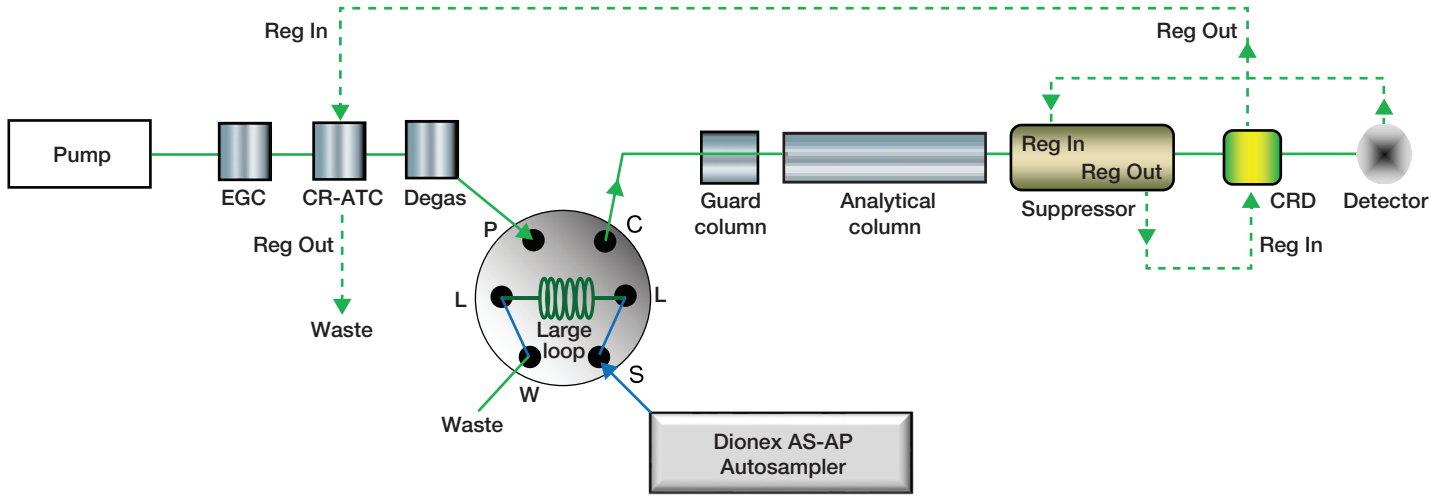


Figure 1. Flow diagram for large loop/direct injection

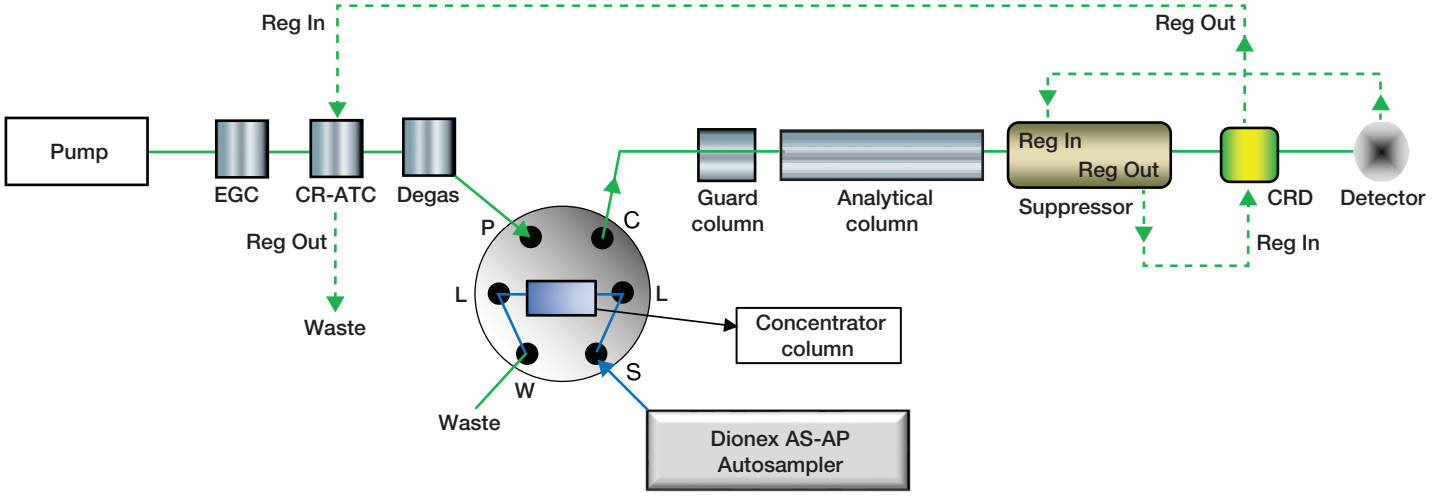


Figure 2. Flow diagram for preconcentration using the Dionex AS-AP Autosampler

aqueous sample matrix. This process “concentrates” the desired species, which leads to lower detection limits. The advantage of using concentrator columns is the ability to perform routine analysis for ions at µg/L (ppb) and sub-µg/L levels without extensive and laborious sample pretreatment. Table 7 lists the concentrator columns recommended for trace anion analysis.

For the best chromatography, install the concentrator column with a short piece of tubing into Port 4 (between Ports C and S) and a longer piece of tubing as needed in Port 1 (between Ports P and W). Set Valve 1 to Inject. Condition the concentrator column at 45 mM KOH, 0.25 mL/min for 10 min while temporarily directing the flow from the columns to a waste container. Align the direction of the column by pointing the arrow on the label of the concentrator column from Port 1 to Port 4. It is critical to minimize the effect of band broadening when using a preconcentration technique. To minimize the dead volume that causes band broadening, use the smallest length possible of red 0.005 in (0.125 mm) PEEK tubing between the outlet of the Dionex UTAC-LP2 column and Port 4.

The Dionex AS-AP (Figure 2) and Dionex AS-HV Autosamplers (Figure 3) can be used to load sample onto a concentrator column. When using the Dionex AS-HV Autosampler, a Thermo Scientific™ Dionex™ AXP Auxiliary Pump (P/N 063973) is used to pump DI water through a Thermo Scientific™ Dionex™ IonPac™ ATC-HC 500 trap column that removes trace anions, and then transfer the sample from the sample loop to the concentrator column. Additionally, the Dionex AXP pump should be modified to minimize contamination from the pump: Remove the elastomeric self-flush diaphragm, located between the Self Flush Housing and Piston Retainer (Figure 4),[22] and replace Teflon ¼” i.d. tubing with green PEEK 0.030 in i.d. (0.75 mm i.d.) tubing. After the sample has been loaded onto the Dionex UTAC-LP2 column in the direction opposite to the eluent flow, it is then eluted with the eluent onto the guard and analytical columns (Figure 5). Refer to the product manual for more information on concentrator columns.[23]

Table 7. Recommended concentrator columns for trace anion analysis

Preconcentration column	Backpressure	Recommended sample delivery method
Dionex IonPac UTAC-LP2, 4 × 35 mm (P/N 079917)	<60 psi, at 2 mL/min	Pressurized bottles, syringes, autosampler (Dionex AS-DV), single-piston sample delivery pump (Dionex AXP Auxiliary Pump)
Dionex IonPac UTAC-ULP2, 5 × 23 mm (P/N 079918)	<30 psi, at 2 mL/min	Pressurized bottles, syringes, autosamplers (Dionex AS-DV, Dionex AS-AP, and Dionex AS-HV), single-piston sample delivery pump (Dionex AXP Auxiliary Pump)
Dionex IonPac UTAC-XLP2, 6 × 16 mm (P/N 072781)	<15 psi, at 2 mL/min	Pressurized bottles, syringes, autosamplers (Dionex AS-DV, Dionex AS-AP, and Dionex AS-HV), single-piston sample delivery pump (Dionex AXP Auxiliary Pump)

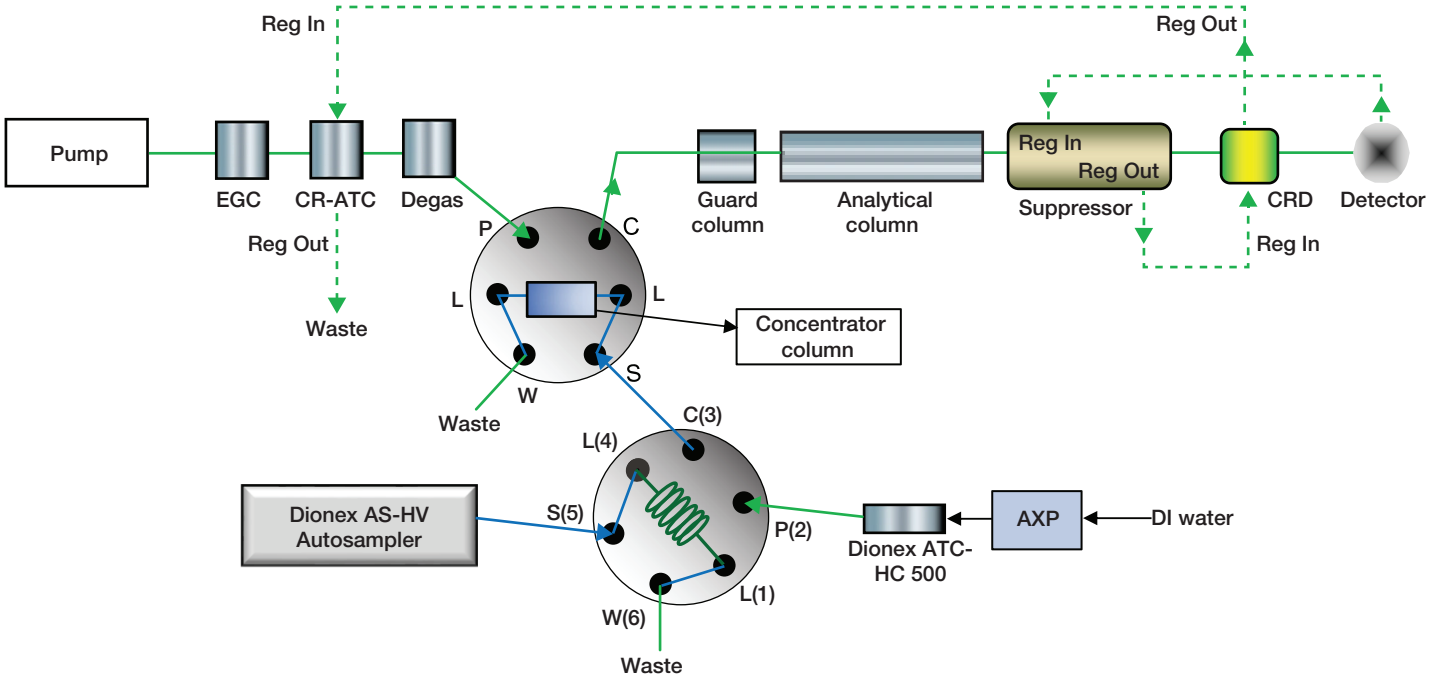


Figure 3. Flow diagram for preconcentration using the Dionex AS-HV Autosampler

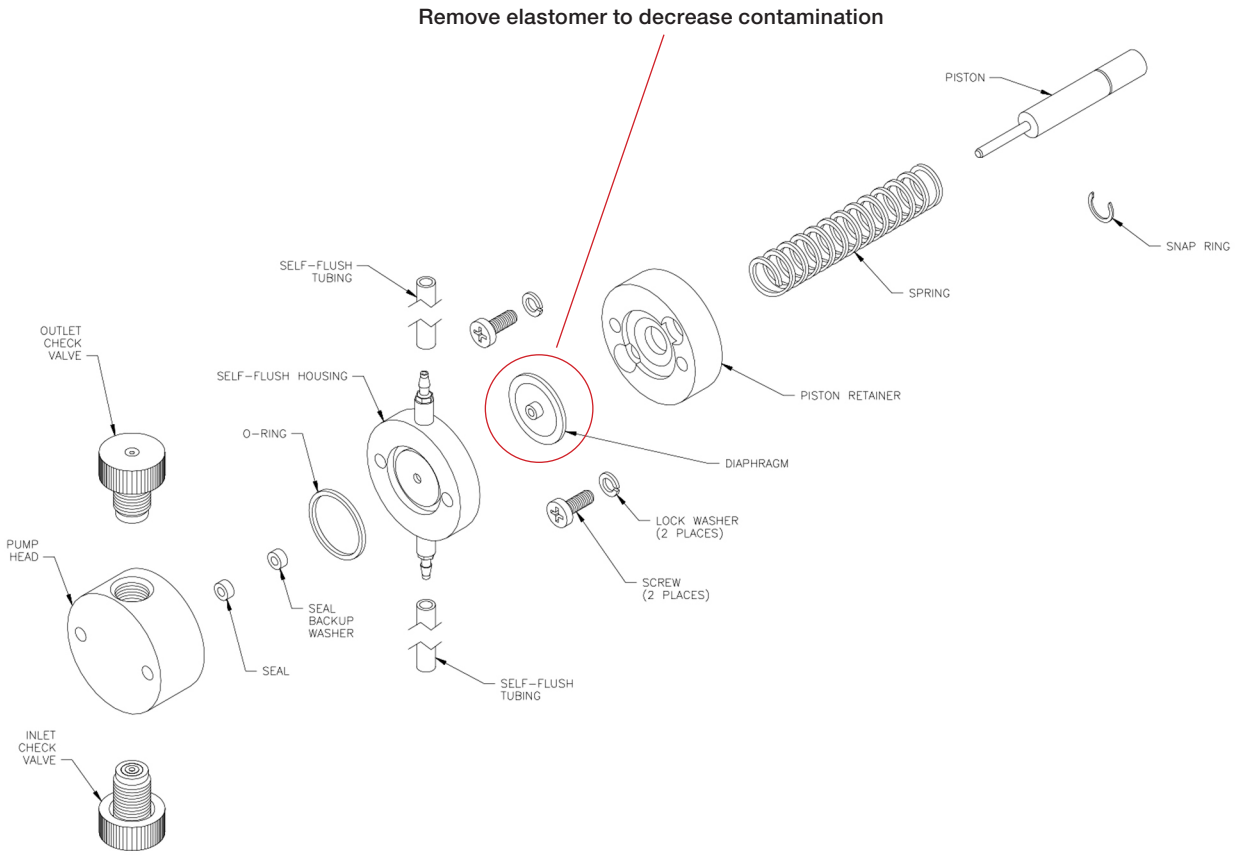


Figure 4. Remove diaphragm in Dionex AXP pump to reduce leachable contamination

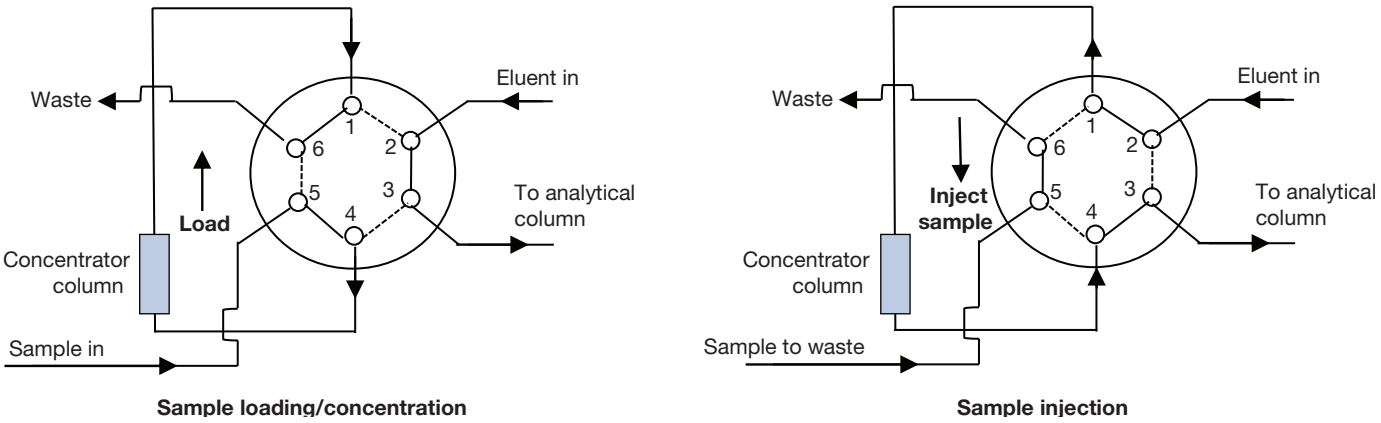


Figure 5. Configuration for 6-port valve and concentrator column

5.3 Dionex AutoPrep method

AutoPrep is an automated approach for trace ion analysis. Using the AutoPrep technique results in easier determinations of part per trillion (ppt, ng/L) concentrations in samples while using an easily prepared µg/L concentration standard. Typically, ppt concentration standards are challenging to prepare because of environmental contamination. AutoPrep has two sample loops, a large loop for samples (typically 10 mL) and a small loop for the standard (typically 10 µL). The flow path for the two sample loops is managed by the Dionex Automation Manager AM containing a 10-port valve. The sample is loaded into the large loop, transferred by DI water purified by the Thermo Scientific™ Dionex™ EWP-5000 Electrolytic Water Purifier to the concentrator column in load mode, and eluted in inject mode onto the guard and analytical columns. Similarly, the µg/L standard is loaded into the small loop, transferred to the concentrator column, and eluted onto the guard and analytical columns. Preconcentration of incremental aliquots of the standard is used to generate the calibration curve.

5.3.1 System configuration for Dionex AutoPrep module

To set up this application, connect the Dionex ICS-6000 HPIC system, Dionex AS-HV Autosampler, Dionex AutoPrep module (large loop, small loop, P/N 066342), Dionex EWP-5000 Electrolytic Water Purifier (P/N 072629), and Thermo Scientific™ Dionex™ ICS-6000 AM Automation Manager with a 10-port valve (P/N 075951) as shown in Figure 6. Notice that the flow path from the pump to the conductivity detector is similar to that of most IC systems. Install the Dionex AM Automation Manager with a 10-port valve into the Dionex ICS-6000 DC module (while the module is powered off). Table 8 lists the configuration of the Dionex ICS-6000 system with the Dionex AS-HV and the Dionex AutoPrep system.

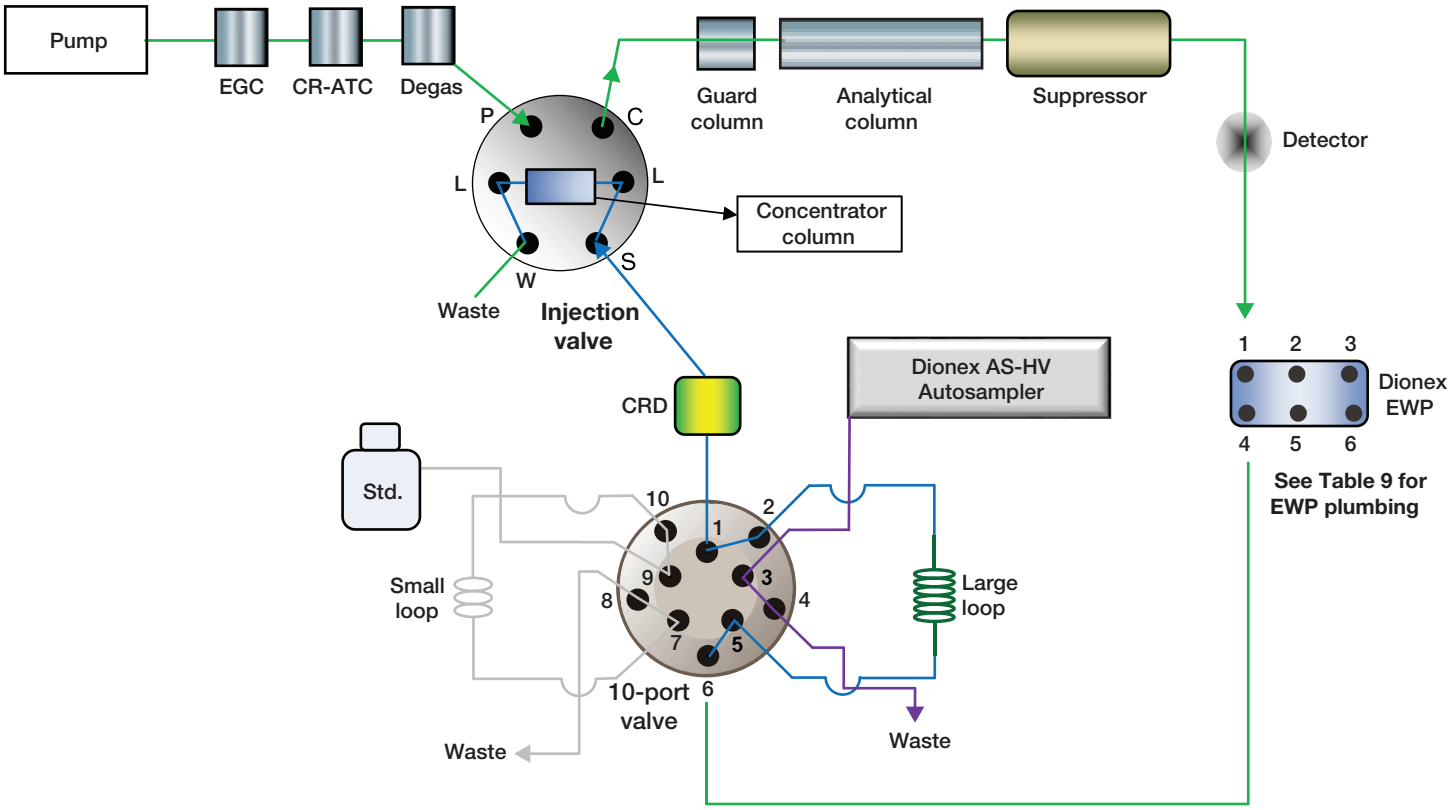


Figure 6. Flow diagram for Dionex AutoPrep using a large loop and a small loop

Table 8. Configuration for Dionex AutoPrep system

Module	Tab	Action
DP Dual Pump	General	Select module address in browse box
	Device	Link Pump_2 to instrument
EG Eluent Generator	General	Select module serial number
	Cartridges	Link to instrument, check EGC-2 box for one cartridge, link to Pump_2
DC Detector / Chromatography	General	Select instrument, select module serial number
	Detectors	Select CDet1, double-click on CDet1, link to Pump_2, Check CD_1 and CD_1_total signal boxes
	Thermal controls	Check Compartment_TC, and Column_TC
	Suppressors	Double click Suppressor2, link to Pump_2
	High pressure valves	Double click InjectValve_1, select Controlled by DC Double click AM-HP_1, select Controlled by DC
	Low pressure valves	Remove check marks
AS-HV Autosampler	General	Select COM7 for serial communication
	Options	Select Rack Type, internal peristaltic as the sample loading pump, Pull mode, Sample Loop
AutoPrep system		No entries needed

Table 9. Plumbing the Dionex EWP Electrolytic Water Purifier

Port	Incoming line	Function
1	From CD eluent out	Removes ionic contamination
2	From Port W of 6-port Injection valve	Provides water source to create clean Regen Water
3	From CR-ATC 500 Regen Out	Cleans Regen Water
Port	**Outgoing line**	**Function**
4	To Port 6 of 10-port valve	Delivers clean water as a carrier to transfer the content of the large loop to the concentrator
5	To Suppressor Regen in	Delivers clean water for the regenerant channels of the suppressor, then CRD 300, and CR-ATC 500 trap column
6	To waste	Sends cleaned Regenerant Out water to waste

5.3.2 Dionex EWP Electrolytic Water Purifier module

This device requires a constant-current power supply to power the device. The Dionex ICS-6000 HPIC system is a dual system with dual suppressor power ports. The second suppressor power can be used to power the Dionex EWP Electrolytic Water Purifier module. Table 9 lists the plumbing/connections for the Dionex EWP Electrolytic Water Purifier.

5.3.3 Calibrating the large loop with the small loop

The Dionex AutoPrep system module loads multiple 10 µL aliquots of a 50 ppb standard onto the concentrator column. The standard solution can be prepared at a thousand times the calibration concentrations because the small loop/large loop ratio (10 µL/10 mL) is 1/1,000. Using a higher concentrated calibration standard minimizes the effects of environmental contamination and inaccurate manual dilutions.

To determine the large loop/small loop ratio, gravimetrically determine the volume of the small loop by weighing the empty loop and the loop filled with DI water in triplicate. Determine the average difference (mg) between the empty and filled small loop. Record the average weight (mg) as the calibrated small loop volume (µL). Prepare a freshly made 5 ppb bromide working standard. Bromide is used to determine the Dionex AutoPrep system large loop to small loop ratio because it is not typically found as an airborne environmental contaminant, and therefore would not be compromised during calibration. Concentrate 10 mL of the working standard by overfilling the Dionex AutoPrep system large loop with ~12 mL total volume.

Then concentrate 10 µL in the Dionex AutoPrep system small loop by overfilling ten times. Record the peak area responses by repeating both measurements in triplicate. Determine the peak area ratio by comparing the average peak area response for each loop.

Dilution factor = Peak area ratio = (average peak area using large loop) / (average peak area using small loop)

Volume of large loop = Peak area ratio × Calibrated volume of small loop

Enter the dilution factor in the “Dilution” column in the Chromeleon sequence. As described above, the dilution factor is typically ~1,000 when using a 10 mL large loop and a 10 µL small loop.

5.3.4 Creating Chromeleon instrument programs using the Dionex AS-HV Autosampler and AutoPrep

Programming for a single aliquot injection of the small loop:
The injection of the µg/L calibration standard is accomplished by preconcentrating a single aliquot as described in Table 10.

Table 10. Timing for loading, concentrating, and injecting a single standard aliquot

Time (min)	Valve	Position	Command
-11.5	Inject Valve	Load	DC.InjectValve_2.LoadPosition
-10.5	AM_HP1	B	DC.AM_HP1.B
-10.3	AM_HP1	A	DC.AM_HP1.A
0	AM_HP1	B	DC.AM_HP1.B
	Inject Valve	A	DC.InjectValve_2.LoadPosition

Programming for multiple aliquot injections of the small loop:
Similarly, preconcentration of multiple aliquots of the µg/L calibration standard is accomplished in the same way as a single aliquot, as described in Table 11 for four aliquots.

Table 11. Timing for loading, concentrating, and injecting four standard aliquots

Time (min)	Valve	Position	Command
-11.5	Inject Valve	Load	DC.InjectValve_2.LoadPosition
-10.5	AM_HP1	B	DC.AM_HP1.B
-10.3	AM_HP1	A	DC.AM_HP1.A
-10.1	AM_HP1	B	DC.AM_HP1.B
-9.9	AM_HP1	A	DC.AM_HP1.A
-9.7	AM_HP1	B	DC.AM_HP1.B
-9.5	AM_HP1	A	DC.AM_HP1.A
-9.3	AM_HP1	B	DC.AM_HP1.B
-9.1	AM_HP1	A	DC.AM_HP1.A
0	AM_HP1	B	DC.AM_HP1.B
	Inject Valve	Inject	DC.InjectValve_2.InjectPosition

The three methods/approaches discussed above typically require different autosamplers. The recommended autosamplers for the three methods are listed in Table 12.

6 Calibration and limit of detection

6.1 Calibrating using large volume direct injections

Calibration of large loop injections is done in the usual way, using standards of different concentrations to create a calibration curve of peak area response versus concentration. Typically, this curve is established using single or multiple injections of 3 to 5 standards covering a concentration range from slightly above the limit of detection to slightly above the expected highest unknown sample concentration.

6.2 Calibrating using concentrate mode

To calibrate using a concentrator column, concentrate different volumes of the same working standard from the same vial, such as 50, 100, and 200 µL of ~0.5 µg/L mixed standard. Using this method, the calibration validates both the linearity of the peak responses and the efficiency of the concentrator column. This method eliminates the possible errors made during the preparation of multiple standards. However, it has a systematic bias if there is any error in the working standard's concentration, so special care should be taken to ensure that its concentration is accurate.

6.3 Calibrating using Dionex AutoPrep method

To determine linearity, one to five 10 µL aliquots of the working standard are incrementally loaded into the Dionex AutoPrep system small loop, concentrated, and separated according to the method conditions.

Table 12. Summary of three methods/approaches for trace ion analysis

Approach/method	Trace level	Autosampler	Comments
Large volume / Direct injection	Low ppb levels	Dionex AS-AP (Sample volume 1–2 mL)	Simple and direct method
Preconcentration	Low ppb levels	Dionex AS-AP (Sample volume 1–5 mL)	Increased sensitivity over Large Volume direct injection method
	ppt levels	Dionex AS-HV (Sample volume >5 mL)	Need extra pump, extra valve, and Dionex ATC-HC 500 trap column
Dionex AutoPrep	Low ppt levels	Dionex AS-HV (Sample volume >10 mL)	Need Dionex EWP 500 device, extra power at suppressor connection for EWP device, DC Automation Manager with 10-port valve

6.4 Method detection limit (MDL)

There are various methods for calculating detection limits. We recommend the method based on three times the signal-to-noise (S/N) ratio. In this method, baseline noise (N) is determined by measuring the peak-to-peak noise in a representative one-minute segment of the baseline where no peaks elute but close to the analyte peak. The signal (S) is determined from the average peak height of three injections of the lowest level standard (3–5 times the estimated MDL). This MDL calculation method cannot always be used when the anions are found as contaminants in the DI water blanks. In such cases, if the contamination amount is more than MDL, then the amount of contamination can be effectively considered the MDL. MDLs vary from lab to lab depending on water quality and lab environment, and ultimately each lab must decide how they handle MDLs in case of low-level contamination.

For more rigorous determination of detection limit, the Hubaux-Vos Limit of Detection (H-V LOD) can be used. H-V LOD is a value that represents the minimum amount of an analyte that can be detected by a method with a specified level of certainty. The H-V LOD is calculated from the calibration data using selected values of α and β, where α represents the probability of a false positive (reporting detection when no analyte is present) and β represents the probability of a false negative (reporting nothing detected when the analyte is actually present). The selected α and β values are used to calculate upper and lower prediction intervals, respectively. From the prediction intervals, the H-V LOD is determined by constructing a horizontal line through the intersection of the upper prediction interval (defined by α) and the response axis, then finding the amount that corresponds to the point where the constructed horizontal line intersects the lower prediction interval (defined by β). The H-V LOD can be easily graphed and calculated in Chromeleon software, version 7.2 and above. For more information on H-V LOD calculations, please refer to Thermo Scientific Application Note 1116.[24]

7 Application examples

7.1 Trace anion determinations using large-volume direct injection

Thermo Scientific application notes, recent AN73852[25], and previous AN146[26] and AN153[10] (discussed in Section 7.2), describe using large-volume direct injections to determine trace anions in ultrapure water (UPW). In Application Note 73852, which updates Application Update 142,[27] anions at sub-µg/L levels were determined using a large-volume direct injection (50% of the sample loop volume (0.5 mL)) by the Dionex AS-AP autosampler and facilitated by the Dionex ICS-6000 HPIC modular system. This method highlights trace anion determinations with the column selectivity to resolve glycolate and acetate. The separation column is updated from the Dionex IonPac AS15 anion-exchange column composed of macroporous resin to the Dionex IonPac AS28-Fast-4µm column composed of supermacroporous resin. The eluent generation was upgraded to the newest format. The total background conductance, ~0.4–0.6 µS/cm, was reduced considerably from that reported in AN146 (~1.2 µS/cm) due to the improved technology of the Dionex CR-ATC trap column over the packed bed trap column and two generations of suppressor improvement. Figure 7 (AN73852, Figure 1) shows the chromatogram demonstrating the separation of 12 anions at sub-µg/L concentrations (except phosphate at 1.25 µg/L) using a 0.5 mL large-loop direction injection. MDLs were determined as 3× S/N. Fluoride, acetate, formate, chloride, and sulfate were detected in DI water blanks, limiting the method detection. As most of the contaminant peaks were greater than 3× S/N, the MDL for each analyte with a contamination peak was defined as the average concentration of each contamination peak (Table 13).

Table 13. Method detection limits (from AN73852)

Analyte	MDL (µg/L)	Analyte	MDL (µg/L)
Fluoride*	0.030	Sulfate*	0.313
Acetate*	0.271	Oxalate	0.156
Glycolate	0.127	Bromide	0.066
Formate*	0.303	Nitrate	0.044
Chloride*	0.156	Phosphate	0.085
Nitrite	0.015		

* Found as contaminants in DI water blanks

Column:	Dionex IonPac AG28-Fast-4µm, Dionex IonPac AS28-Fast-4µm, 2 mm
KOH gradient:	7 mM (-5–6 min); 7–20 mM (6–8 min); 20–72 mM (8–13 min); 72 mM (13–25 min)
Eluent source:	Dionex EGC-500 KOH cartridge with Dionex CR-ATC 600 trap column
Flow rate:	0.3 mL/min
Inj. volume:	500 µL
Column temp.:	30 °C
Detection:	Suppressed conductivity, Dionex ADRS 600, 4 V constant voltage, recycle mode

1. Fluoride	0.125 µg/L (ppb)	7. Carbonate	-
2. Acetate	0.313	8. Sulfate	0.625
3. Glycolate	0.313	9. Oxalate	0.313
4. Formate	0.313	10. Bromide	0.625
5. Chloride	0.313	11. Nitrite	0.625
6. Nitrite	0.625	12. Phosphate	1.250

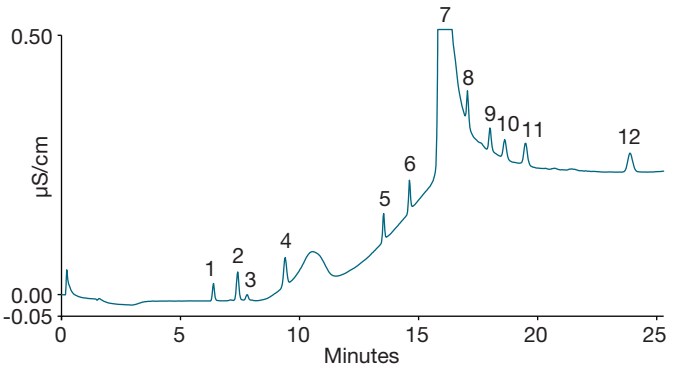


Figure 7. Trace anion determination on a Dionex IonPac AS28-Fast-4µm column using large volume direct injection (from AN73852, Figure 1)

In AN146, a 1 mL sample is directly injected, using a pressurized container delivery method, onto a 2 mm i.d. Dionex IonPac AS17 anion-exchange column. A pressurized container in place of an autosampler is used to deliver the sample and to minimize contamination. The anions are separated using an electrolytically generated gradient from 0.3 mM to 40 mM KOH over 36 min using electrolytic eluent generation and a trap column (used before the introduction of the Dionex CR-ATC). The anions are detected by suppressed conductivity, using an earlier generation electrolytic suppressor. Figure 8 (AN146, Figure 2) shows the chromatogram of 15 anions using this method. The carbonate peak dominates the 14 µg/L anion peaks in the chromatogram. The total conductivity baseline, approximately 1.2 µS/cm, is higher than those in newer methods with recent suppressors. MDLs of <1 µg/L were achieved.

Column:	Dionex IonPac AG17, Dionex IonPac AS17, 2 mm
KOH gradient:	0.3 mM (6 min); 0.3-1 mM (6–8 min); 1–10 mM (8–19 min); 0–40 mM (19–36 min)
Eluent source:	Dionex EG40 KOH cartridge
Trap column:	Dionex IonPac ATC-3 trap column
Flow rate:	0.5 mL/min
Inj. volume:	1 mL
Column temp.:	30 °C
Detection:	Suppressed conductivity, Dionex ASRS ULTRA, gas-assisted recycle mode

Peaks:

1. Fluoride	0.24 µg/L	9. Nitrate	1.3
2. Acetate	0.82	10. Benzoate	2.5
3. Formate	0.57	11. Carbonate	--
4. Acrylate	1.9	12. Sulfate	1.2
5. Methacrylate	1.9	13. Oxalate	1.0
6. Chloride	0.72	14. Phthalate	6.3
7. Nitrite	0.90	15. Phosphate	1.6
8. Bromide	1.8		

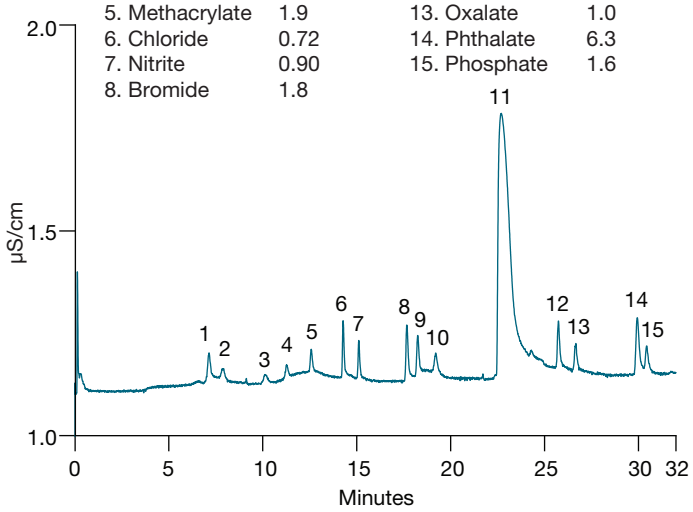


Figure 8. Determination of trace anions using large volume direct injection (from AN146, Figure 2)

7.2 Trace anion determinations using large-volume, direct injection/preconcentration

In Thermo Scientific Application Note 153, large-volume direct injection and large-volume preconcentration were compared for trace contamination in extracts of electronic components. In the large-volume direct injection, 1 mL of sample was directly injected on a 2 mm i.d. Dionex IonPac AS17 anion-exchange column with a similar KOH gradient as in AN146. Technological advancements have been made from conventional trap columns to electrolytically continuously regenerated trap columns. As a result, the total conductivity baseline was reduced from 1.2 µS/cm, previously reported in AN146, to ~0.9 µS/cm, shown in chromatogram A in Figure 9 (AN153, Figure 3).

Column:	Dionex IonPac AG17, Dionex IonPac AS17, 2 mm
KOH gradient:	0.3 mM (6 min); 0.3-1 mM (6–8 min); 1–10 mM (8–19 min); 10–40 mM (19–36 min)
Eluent source:	Dionex EG50 KOH cartridge Dionex CR-ATC trap column
Flow rate:	0.5 mL/min
Inj. volume:	A: 1 mL direct injection B: 5 mL preconcentrated
Concentrator:	B: Dionex IonPac TAC-LP1
Column temp.:	30 °C
Detection:	Suppressed conductivity, Dionex ASRS ULTRA, recycle mode

Peaks:	A µg/L	B µg/L		A µg/L	B µg/L
1. Fluoride	1.1	1.2	9. Nitrate	0.9	1.3
2. Acetate	1.4	4.8	10. Benzoate	5.6	10
3. Formate	1.5	6.6	11. Carbonate	--	--
4. Acrylate	3.1	1.9	12. Sulfate	3.1	3.8
5. Methacrylate	1.5	2.1	13. Oxalate	2.3	2.4
6. Chloride	1.6	2.6	14. Phthalate	3.6	5.6
7. Nitrite	1.3	3.1	15. Phosphate	2.9	4.1
8. Bromide	0.7	1.0			

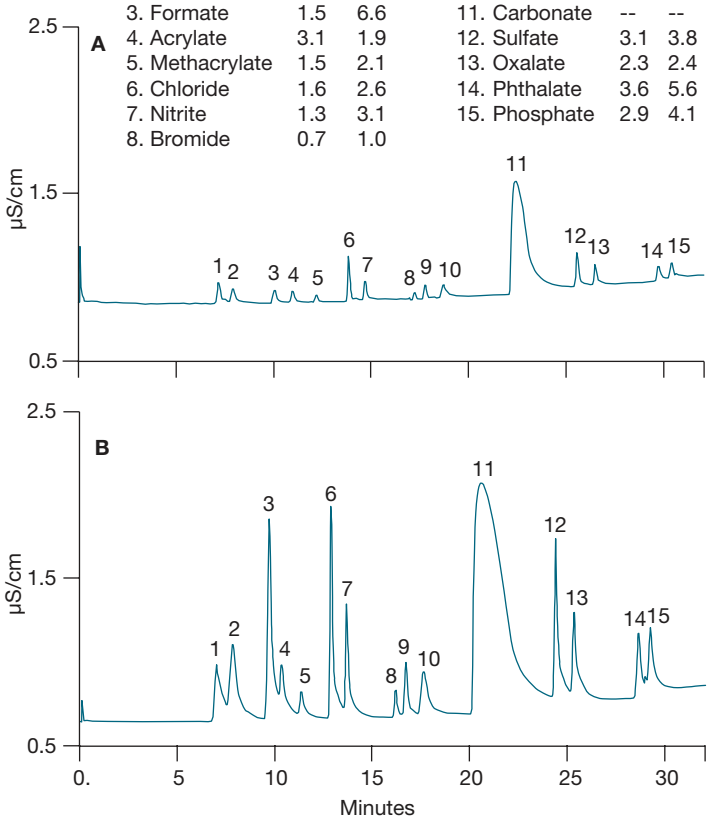


Figure 9. Comparing trace anion determination using direct injection vs. preconcentration (from AN153, Figure 3)

The anions are detected by suppressed conductivity, using the same suppressor (the Dionex ASRS ULTRA electrolytic suppressor) as used in AN146, but in recycle mode to simplify the method. Another improvement in technology was the sample introduction. The samples were introduced automatically using the Dionex AS40 Autosampler (the predecessor of the Dionex AS-DV Autosampler), using 10 mL HDPE sample vials with plain caps. Chromatogram A in Figure 9 (AN153, Figure 3) shows the separation of 15 anions using large volume direct injection. The carbonate peak has a slightly lower response but still dominates the chromatogram. The µg/L concentration peaks have baseline resolution that is an improvement on the results in AN146.

AN153 also demonstrates that preconcentration allows more sample volume injected on-column by eliminating much of the sample matrix (water). As a result, higher peak responses are achieved using sample preconcentration. In the preconcentration method, the trace anions in 5 mL of sample are captured on the Thermo Scientific™ Dionex™ IonPac™ TAC-LP1 concentrator column (Table 14). The anions are retained while the water matrix flows to waste. The resultant concentrated sample is eluted onto a 2 mm i.d. Dionex IonPac AS17 anion-exchange column. The results shown in Figure 9 (AN153, Figure 3) comparing the large volume direct injection (Chromatogram A) and a large volume preconcentration (Chromatogram B) demonstrate a total conductivity baseline reduced from ~0.9 µS/cm to ~0.7 µS/cm and significant increases in peak responses, which improves peak integration and reporting.

Table 14. MDLs for analysis of DI water extracts of disk drive components (from AN153, Table 5)

Analyte	1 mL direct injection MDL,* (µg/L)	5 mL preconcentration MDL,* (µg/L)
Fluoride	0.08	0.024
Acetate	0.16	0.072
Formate	0.17	0.038
Acrylate	0.45	0.12
Methacrylate	0.35	0.11
Chloride	0.05	0.014
Nitrite	0.10	0.031
Bromide	0.16	0.043
Nitrate	0.11	0.028
Benzoate	0.71	0.27
Sulfate	0.13	0.028
Oxalate	0.17	0.035
Phthalate	0.37	0.10
Phosphate	0.28	0.076

*Calculated based on three times signal-to-noise

A slight variation on the previous method using preconcentration is to load the large volume sample into a sample loop by the Dionex AS-HV High Volume Autosampler. Another pump with a packed bed trap column is used to transfer the sample to the concentrator column. This method is demonstrated in Thermo Scientific Dionex Application Update 163 to determine trace anions in organic solvents.[28]

7.3 Trace anion determinations using AutoPrep, large loop/small loop

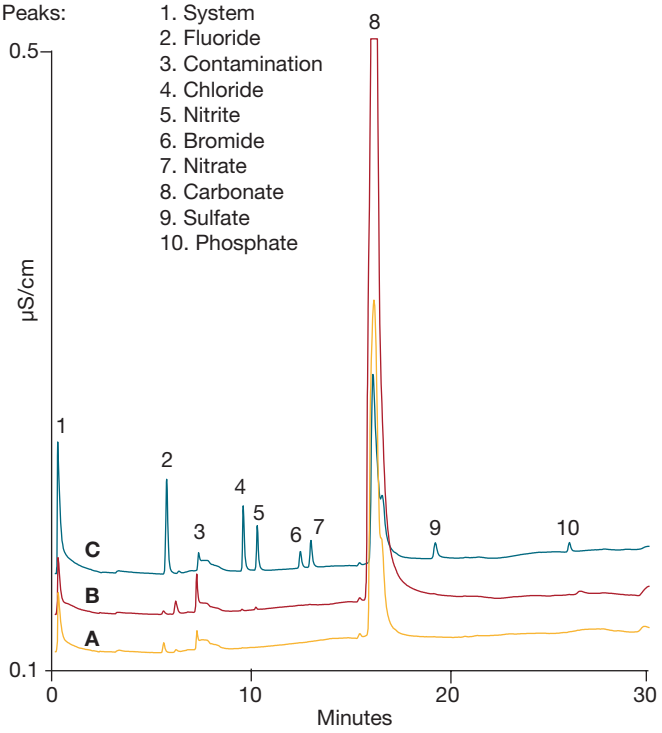
The lab environment, the IC system cleanliness, and the standard preparation can significantly impact the contamination observed in the system blank, and thus limit the analytical sensitivity in trace analysis methods, particularly as analytical needs approach ng/L and sub-ng/L. Environmental cross contamination increases the baseline and causes erratic and unreliable results. As a result, these samples may provide misleading results. In some cases, the contamination may be higher than the analyte concentrations. Calibration standards at ng/L and sub-ng/L are more easily contaminated from the air, and difficult to prepare in an accurate and precise manner without contamination.

To overcome these challenges, a technique named AutoPrep in combination with a closed loop IC system using an inline electrolytic water purifier (EWP) is used. The method uses two pumps including the inline water purifier, two suppressor positions, one 10-port valve, and one 6-port injection valve. AutoPrep, as described in Thermo Scientific Technical Note 72206, uses preconcentration of a 1,000-fold larger injection volume of samples (large loop) than of standards (small loop) on a Dionex ICS-6000 HPIC modular IC system.[29] As a result, the calibration curve is generated by preconcentration of 10 µL incremental injections of a single µg/L (ppb) standard. The anions are separated on a Dionex IonPac AS17-C column optimized for trace anion determinations.

This method uses a µg/L standard, which is easier to prepare without contamination than a ng/L standard. Additionally, the incremental small loop injections reduce variations in preparing diluted standards for calibration. To achieve high sensitivity, 10 mL of the sample is preconcentrated, creating a 1,000-fold higher volume loading than the calibration standard. To reduce the background and environmental contamination, an inline water purifier (Dionex EWP-5000 Electrolytic Water Purifier) is used to create a closed cycle. The inline water purifier removes the ionic content leaving the CD conductivity detector and returns the newly deionized water to transfer the sample from the sample loop to the concentrator column.

This process minimizes the contamination contributed by the transfer DI water. In addition, the inline water purifier deionizes the waste stream after the concentrator column to use as Regen water for the suppressor, thereby reducing baseline contamination. Figure 10 (TN72206, Figure 12) shows chromatograms of blanks and standards. Table 15 shows MDLs.

Column:	Dionex IonPac AG17-C, Dionex IonPac AS17-C, 4 mm
KOH gradient:	50 mM wash (4.5 min); 1 mM (-7–4 min); 1–12.5 mM (4–10 min); 12.5–20 mM (10–12 min); 20–35 mM (20–30) min
Eluent source:	Dionex EGC-500 KOH cartridge, with Dionex CR-ATC 500 trap column, Dionex high pressure degasser
Flow rate:	1 mL/min
Column temp.:	30 °C
Det. compart.:	15 °C
Detection:	Suppressed conductivity, Dionex AERS 500e, 4 mm, 109 mA, recycle mode
Sample prep.:	Dionex CRD 300 inline degassing, Dionex AutoPrep, EWP, 20 mA
Concentrator:	Dionex UTAC-LP2, 4 mm
Sample:	A: EWP system blank; B: Sample blank* C: 50 ppt standards
Vol.:	B: 10 mL for container sample, C: 10 µL for standards
Peaks:	1. System 2. Fluoride 3. Contamination 4. Chloride 5. Nitrite 6. Bromide 7. Nitrate 8. Carbonate 9. Sulfate 10. Phosphate



* Sample run time includes 21.5 min pre-injection time

Figure 10. Comparing the system and container baseline contamination with the 50 ppt trace anion standard (from TN72206, Figure 12)

Table 15. Estimated method detection limits (from TN72206, Table 10)

Analyte	Standard (ng/L)	MDL, 3× S/N (ng/L)
Fluoride	8.6*	0.024
Chloride	6.5*	20
Nitrite	8.0*	24
Bromide	50.0**	7
Nitrate	6.2*	19
Sulfate	51.7**	19
Phosphate	53.1**	43

*Calculated based on three times signal-to-noise
**Calibration standard 50 ng/L

8. Trace cation determinations

8.1 Introduction

Trace cation contamination is a serious concern in the power industry. Specifically, trace sodium concentrations in boiler amine cooling solutions can cause corrosion in the boiler and turbines.[30] Issues from trace cation contamination are a lesser-known concern in the electronics industry. However, sodium can cause high leakage failures in semiconductor devices.[31] Ammonia and other amines can cause undesirable neutralization in chemically assisted (Deep UV, DUV) photolithography processes. These processes are used to create the device patterns, thus any damage to the patterning is unacceptable and costly. Ammonia and amine contamination are considered so critical that the photolithography room is often isolated from other processes, and air and water quality are continually monitored by inline monitoring, rather than batch sampling.[32] More commonly, determination of trace cations, including dissolved metals, are monitored in incoming reagents to minimize future contamination.

8.2 System preparation and system setup

Follow the same guidelines for system preparation and setup as described in sections for trace anion determinations (Sections 4.1, 4.2, and 4.3).

8.2.1 Installation of RFIC consumables

Dionex Eluent Generator Cartridges (Dionex EGC): The Thermo Scientific™ Dionex™ EGC 500 MSA Methanesulfonic Acid cartridges are used for separations with cation exchange columns.

Install the Dionex EGC 500 MSA cartridge (P/N 075779) and Thermo Scientific™ Dionex™ CR-CTC 600 Continuously Regenerated Cation Trap Column (P/N 088663). Condition the devices according to instructions in the product manuals[14,15] and the Dionex ICS-6000 System Operator's manual.[16]

Electrolytically regenerated suppressor:
The Thermo Scientific™ Dionex™ CERS™ 500e Cation Electrolytically Regenerated Suppressor for External Water and the Thermo Scientific™ Dionex™ CDRS™ 600 Cation Dynamically Regenerated Suppressor are the latest suppressors for cation analysis. For trace analysis, use the Dionex CERS 500e suppressor in external water mode, as it provides low background and noise. Table 16 lists suppressor part numbers.

Table 16. List of cation suppressors with P/Ns

Suppressor	Format	P/N
Dionex CDRS 600	4 mm	088666
	2 mm	088667
Dionex CERS 500e	4 mm	302663
	2 mm	302664

Follow the same instructions described above in Section 4.3.2 for the preparation and installation of the Dionex CERS 500e suppressor.

8.2.2 Cation exchange columns

The columns listed in Table 17 are recommended for trace cation analysis in high purity water.

8.2.3 Trace cation concentrator columns

The function of the trace cation concentrator is to strip ions from a measured volume of a relatively clean aqueous sample matrix. As described in Section 5.2, in trace anion preconcentration, this can be accomplished by replacing the sample loop with a concentrator column, then pumping (and concentrating) large volumes of the sample onto a concentrator column. The sample should be pumped into the concentrator column in the opposite direction of the eluent flow, otherwise the chromatography will be compromised. This process "concentrates" all cationic analyte species onto the Thermo Scientific™ Dionex™ IonPac™ Trace Cation Concentrator (TCC) column leading to a lowering of detection limits by 2–5 orders of magnitude. The unique advantage of the Dionex IonPac Trace Cation Concentrator column is the capability of performing routine trace analyses of sample matrix ions at ng/L levels without extensive and laborious sample pretreatment. Table 18 lists the concentrator columns[35] recommended for use with Dionex IonPac CS12A, Dionex IonPac CS16-4µm, and Dionex IonPac CS16-Fast-4µm columns.

8.3 Trace-level cation application examples

Similar to trace anion determination methods (Section 5 of the document), trace cation determinations can be determined using a 1) large-volume direct injection, 2) preconcentration of large sample volume, and 3) the AutoPrep method using preconcentration of a large loop volume for samples and preconcentration of a small loop volume for standards.

Table 17. Columns recommended for trace cation analysis

Column	Comments
Thermo Scientific™ Dionex™ IonPac™ CS16-4µm (2 × 250 mm, P/N 088582); 4 x 250 mm, P/N 088584)	Higher cation exchange capacity per gram of resin than the Dionex IonPac CS12A and other Dionex cation exchange columns.
Thermo Scientific™ Dionex™ IonPac™ CS16-Fast-4µm (2 × 150 mm, P/N 088601); 4 x 150 mm, P/N 088599)	Shorter run times than the Dionex IonPac CS16-4µm (250 mm long)[33]
Thermo Scientific™ Dionex™ IonPac™ CS12A-5µm (3 × 150 mm, P/N 057185)	Low capacity for fast analysis of common inorganic cations using isocratic elution.[34]

Table 18. Recommended concentrator columns for trace cation analysis

Preconcentration column	Backpressure	Recommended sample delivery method
Dionex IonPac TCC-LP1 (4 × 35 mm) (P/N 046027)	<70 psi, at 0.5 mL/min	Pressurized bottles, syringes, autosampler (Dionex AS-DV)
Dionex IonPac TCC-ULP1 (5 × 23 mm) (P/N 063783)	<45 psi, at 0.5 mL/min	Pressurized bottles, syringes, autosamplers (Dionex AS-DV and Dionex AS-AP), single-piston sample delivery pump (Dionex AXP Auxiliary Pump)
Dionex IonPac TCC-XPL1 (6 × 16 mm) (P/N 063889)	<30 psi, at 0.5 mL/min	Pressurized bottles, syringes, autosamplers (Dionex AS-DV and Dionex AS-AP), single-piston sample delivery pump (Di-onex AXP Auxiliary Pump)

Thermo Scientific Application Update 155 applied the large-volume direct injection technique for determining trace sodium in platinum-treated hydrogen peroxide. A 1 mL sample volume was injected onto a 4 mm i.d. Thermo Scientific™ Dionex™ IonPac™ CS17 cation-exchange column optimized for the resolution of alkylamines. The cations and amines were separated using an electrolytically generated MSA gradient.[36] The seven inorganic cations and ammonium were detected in the sample by suppressed conductivity using an earlier generation electrolytic suppressor in recycle mode. Figure 11 shows the chromatogram of seven µg/L cations using this technique. MDLs were determined using the standard deviation of seven injections of a low-level standard times the Student's t-test value of 3.14 (Table 19). The MDLs of the inorganic cations, ammonium, methylamine, dimethylamine, and trimethylamine are <1 µg/L.

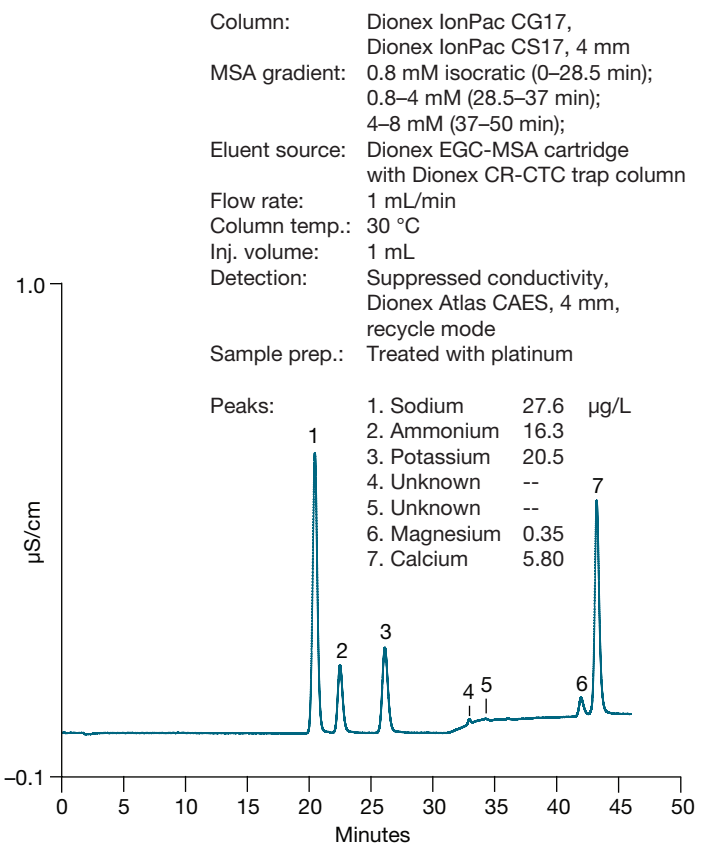


Figure 11. Analysis of hydrogen peroxide sample (from AU155, Figure 2)

Table 19. Method detection limits (from AU155)

Analyte	MDL[a] (µg/L)	Analyte	MDL[a] (µg/L)
Lithium	0.005	Ethylamine	0.108
Sodium	0.025	Dimethylamine	0.330
Ammonium	0.066	Trimethylamine	0.138
Methylamine	0.105	Magnesium	0.059
Potassium	0.068	Calcium	0.148

[a] MDL = $\sigma_{s,99}$ where $t_{s,99}$ = 3.14 for n = 7

8.3.1. Trace cation determination using large volume injection and preconcentration

Thermo Scientific Dionex Application Update 137 (AU137) and Application Notes 86 (AN86) and 152 (AN152) demonstrate the advantages of using preconcentration of a large sample volume.[37-39] In AU137, 7.5 mL of UPW or borated industrial water was preconcentrated on an earlier generation concentrator column, the Dionex IonPac TCC-LP1 column. The preconcentrated cations were separated on a 2 mm i.d. Dionex IonPac CS12A column selected for its fast separation of cations. The cations were separated using an eluent step change of manually prepared sulfuric acid eluent. The current eluent recommendation for this application is MSA produced by an electrolytic eluent generator. Figure 12 shows that sub-ppb concentrations of lithium were determined.

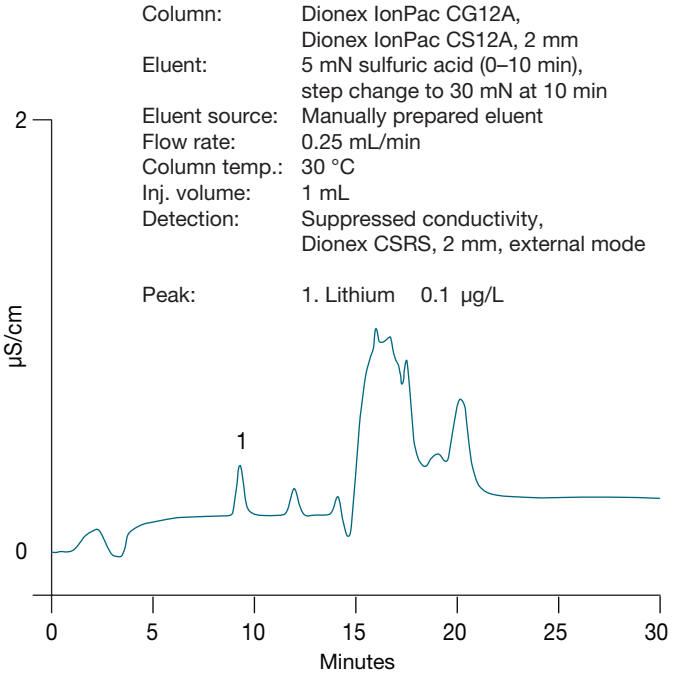


Figure 12. Trace lithium in high-purity DI water (from AU137, Figure 2)

The applications in AN152 and AN86[39] were optimized for power plant boiler cooling solutions. In AN152, which updates AN86, ng/L sodium was determined in 1 g/L ethanolamine using matrix elimination by preconcentration. A 10 mL volume of diluted ethanolamine (1 g/L), loaded by an auxiliary pump, is preconcentrated onto a 5 mm i.d. Thermo Scientific™ Dionex™ IonPac™ CG16 cation-exchange guard column selected for the resolution of disparate concentrations of ammonium and sodium. The cations are retained on the concentrator column and the preconcentrated sample was eluted onto the same chemistry, 3 mm i.d. Dionex IonPac CG16 cation-exchange guard and Dionex IonPac CS16 analytical column. The cations were separated using electrolytically generated 20 mM MSA. Figure 13 shows 5 ng/L sodium resolved from 3,000 µg/L ethanolamine. The MDL of sodium was determined using the standard deviation of seven injections of a low-level standard times the Student's t-test value of 3.14. The calculated MDL was 3.2 ng/L.

Column:	Dionex IonPac CG16, Dionex IonPac CS16, 3 mm
Eluent:	20 mM MSA
Eluent source:	Dionex EG40 cartridge with Dionex CR-CTC trap column
Eluent flow rate:	1 mL/min
Column temp.:	60 °C
DXP flow rate:	2 mL/min
Sample vol.:	10 mL
Concentrator:	Dionex IonPac CG16, 5 × 50 mm
Detection:	Suppressed conductivity, Dionex Atlas CAES, 4 mm, 34 mA, recycle mode

Peaks:	1. Sodium	0.005 µg/L
	2. Unknown	--
	3. Ethanolamine	3000

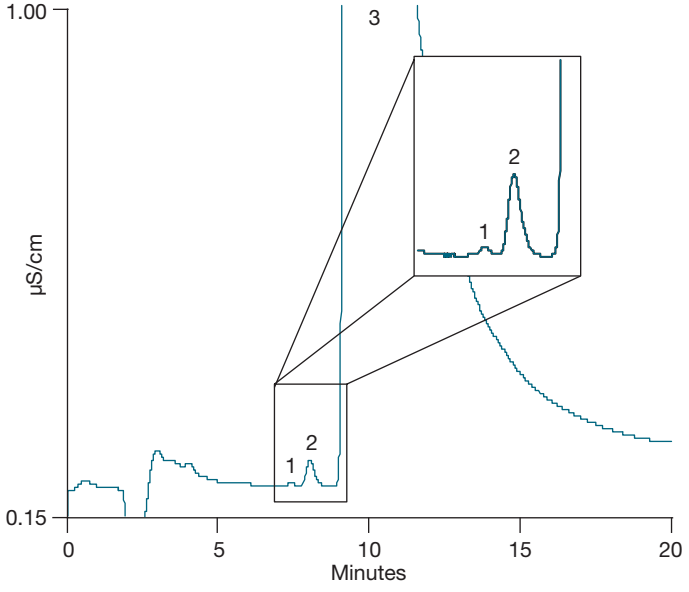


Figure 13. A representative chromatogram of 3,000 µg/L ethanolamine (from AN152, Figure 5)

In AN86, 1 mL of diluted morpholine 2,000 mg/L with low mg/L cation additives was concentrated on a Dionex IonPac CG14 guard column. Methods were demonstrated using acetonitrile or DI water to rinse the matrix from the guard column. The addition of acetonitrile to the eluent was shown to improve the morpholine peak shape and resolution, permitting quantitative analysis of morpholine. Figure 14 shows the separation of mg/L cations in 2,000 mg/L morpholine on a Dionex IonPac CS14 cation exchange column using MSA eluent at 0.25 mL/min.

Column:	Dionex IonPac CG14, Dionex IonPac CS14, 2 mm
Eluent:	8 mM MSA
Eluent source:	Dionex EG40 cartridge with Dionex CR-CTC trap column
Eluent flow rate:	0.25 mL/min
Rinsing flow rate:	1 mL/min, acetonitrile (6-8 min) prior to injection
Sample vol.:	1 mL
Concentrator:	Dionex IonPac CG14, 2 × 50 mm
Detection:	Suppressed conductivity, Dionex CSRS, 2 mm, external water mode (when using acetonitrile)

Peaks:	1. Lithium	0.5	mg/L
	2. Sodium	2.0	
	3. Ammonium	150	
	4. Potassium	2.0	
	5. Morpholine	2000	
	6. Magnesium	2.0	
	7. Calcium	10.0	

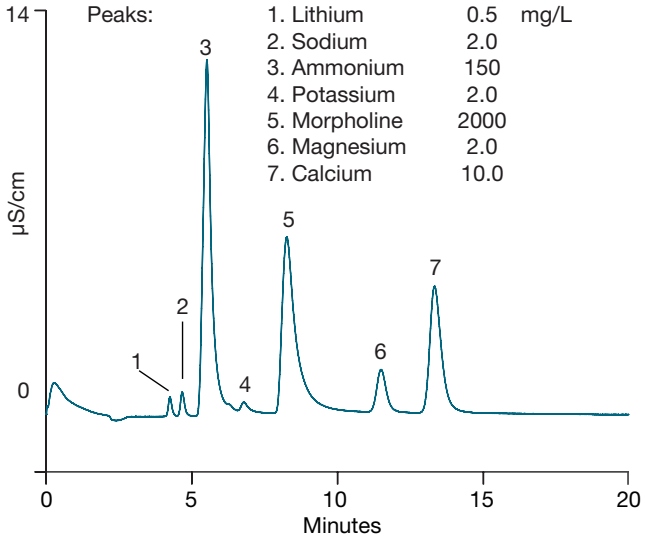


Figure 14. Trace cations in morpholine mix: Method 2 (from AN86, Figure 5)

8.3.2 Trace cation determination using Dionex AutoPrep

Trace concentrations of dissolved transition metals can cause contamination issues on semiconductor wafers, thereby impacting yields and device performance. These dissolved metals can cause an improper or weak interface in the resulting deposition of layers, and ultimately cause a p-n junction leakage.[40] In Thermo Scientific Dionex Application Note 131, determinations of trace transition metals (low ng/L) are demonstrated in HPW and semiconductor bath solutions.[41] A large injection volume (30 mL) is preconcentrated on a Thermo Scientific™

Dionex™ IonPac™ TCC-LP2 concentration column using an auxiliary pump. The transition metals are eluted using chelating, pyridine-2,6-dicarboxylic acid (PDCA) eluent, and separated by anion-exchange chromatography on the Thermo Scientific™ Dionex™ IonPac™ CS5A column. This column is a mixed ion-exchange column optimized for transition metal separations, as either anions or cations. As the metal-complexes elute from the column, the PDCA is replaced (post column using a knitted reaction coil) with 4-(2-pyridilazo)resorcinol (PAR) to create a highly absorbing metal-complex and detected at 520–530 nm. Figure 15 shows the determination of ng/L concentrations of transition metals in a semiconductor cleaning (SC2) solution sample.

9. Common errors and troubleshooting

To assist analysts doing trace ion determinations, here is a table summarizing symptoms, likely causes, experiments, and suggested processes for troubleshooting (Table 20).

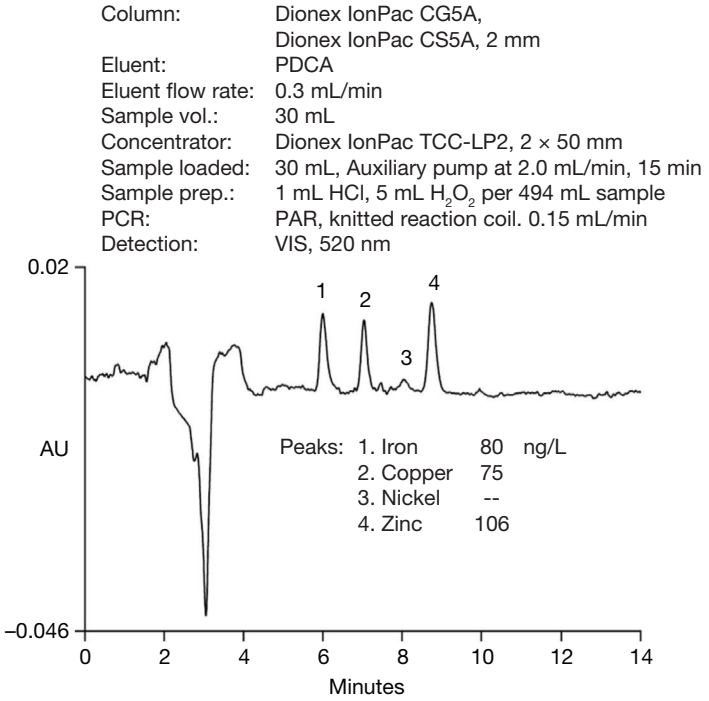


Figure 15. Trace metals in (30 mL preconcentrated) SC2 batch solution pH-adjusted (1 mL HCl, 5 mL H_2O_2 per 494 mL sample) (from AN131, Figure 5)

Table 20. Troubleshooting common symptoms in trace ion determinations

Symptom	Likely cause	Verifying experiment	Suggested processes
Ghost peaks	System contamination	Present in a "no injection blank"	Run baseline for 2–3 h at maximum eluent concentration with periodic rotations of injection valve. Re-equilibrate at starting concentration.
Periodic ghost peak	Carryover of late eluting peak	Not present in first standard or sample injection	Extend run or extend time at the high concentration in the gradient.
High baseline	Contaminated DI water, eluent bottle	Baseline shows dramatic change after changing DI water.	Dump out DI eluent bottles and refresh with new fresh DI water. Cover any open connections on the eluent bottle with a small sheet of food-grade aluminum foil to prevent particles from dropping into the bottle.
Unstable water blank	Unstable baseline	Expand scale of 0–2 min run time of water blanks to view the baseline.	Run baseline for 2–3 h at maximum eluent concentration with periodic rotations of the injection valve. Re-equilibrate at the starting concentration.
	Contamination of sample vials	Prepare a new DI water blank using a recently cleaned container. Rapid improvement is observed.	Use same vial for experiments, rinse 10x. Avoid splashing from gloves or sink because of cross-contamination. Analyze DI water blank.
	Buffer loop	Use freshly cleaned DI water blank after washing buffer loop. Rapid improvement is observed.	Use manual F8 commands: wash buffer loop, 12 mL.
	Autosampler DI wash solution	Use freshly cleaned DI water blank after washing buffer loop. Rapid improvement is observed.	Option 1: Change autosampler wash bottle with fresh DI water every day.
		Use freshly cleaned DI water blank after washing buffer loop. Rapid improvement is observed.	Option 2: Draw autosampler water directly through second pump on the Dionex ICS-6000 system by a tee after the proportioning valve. (Re-plumb autosampler wash line.)
	Contaminated TLV line	Use freshly cleaned DI water blank after washing buffer loop. Rapid improvement is observed.	Remove autosampler TLV line from injection valve. Inject 10× concentration of eluent to waste, 3×. Inject water, 3×. Re-install TLV tubing into the injection valve.
Poor linearity	Cross-contamination of standards during preparation or storage	Rapid improvement is observed after preparing new standards.	Re-clean sample vials, standard containers. Prepare working standards using the "weigh, pour, and weigh" method.

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11. Appendix

This section covers trace ion determinations in matrices other than high purity water (Table A1) and other columns that have been used previously for trace ion analysis (Table A2). Some of these applications may require suppressors other than those specified in Tables 4 and 16. For these applications, such as AN1119 -Determination of borate in cosmetics, use the decision tree in the Suppressor Selection Guide to determine the best suppressor.

Table A1 (part 1). Trace ion analysis in other matrices

Matrix	Method	Application	AppsLab link
Anions and organic acids			
Caustic reagents	AutoNeutralization	AN72481	https://appslab.thermofisher.com/App/3899/single-pass-autoneutralization-anions-di-water
Solvents	Matrix elimination	AU163	https://appslab.thermofisher.com/App/1672/race-anions-organic-solvents
		AN85	https://appslab.thermofisher.com/App/2003/an85-determination-trace-anions-nmethylpyrrolidone-organic-solvents
DI water extraction solutions	Standard injection volumes	AU157	https://appslab.thermofisher.com/App/2182/anions-extracts-electronic-components
Lithium borated water	Standard injection volumes	AU191	https://appslab.thermofisher.com/App/1051/anions-lithiumcontaining-borated-waters
	Large-volume direct injection.	AU175	https://appslab.thermofisher.com/App/2218/anions-licontaining-boric-acidtreated-water
Borated water	Large-volume/ preconcentration	AN185	https://appslab.thermofisher.com/App/1872/an185-determination-trace-organic-acids-inorganic-anions-boric-acidtreated-power-plant-waters-using-an-automated-reagentfree-ion-chromatography-system
	Large-volume direct injection.	AN166	https://appslab.thermofisher.com/App/1871/an166-application-eluent-generation-for-trace-anionanalysis-borated-waters
Concentrated phosphoric acid	Matrix elimination (using ion exclusion Thermo Scientific™ Dionex™ IonPac™ ICE-AS6 or ICE-AS1 column) and preconcentration	TN44	https://appslab.thermofisher.com/App/2289/tn44-determination-trace-anions-concentrated-phosphoric-acid
Concentrated hydrofluoric acid		TN45	https://appslab.thermofisher.com/App/2300/tn45-determination-trace-anions-hydrofluoric-acid-ammonium-fluoride-a-buffered-oxide-etchant
Concentrated glycolic acid		TN46	https://appslab.thermofisher.com/App/2342/tn46-determination-trace-anions-concentrated-glycolic-acid
Concentrated nitric acid	Dilution and direct injection	AN137	https://appslab.thermofisher.com/App/1414/anions-high-nitrate-samples
Concentrated sulfuric acid	Dilution and direct injection	AN72751	https://appslab.thermofisher.com/App/4163/anions-sulfuric-acid

Table A1 (part 2). Trace ion analysis in other matrices

Matrix	Method	Application	AppsLab link
Trace silicate			
UPW	AutoPrep	AN170	https://appslab.thermofisher.com/App/1615/an170-determination-silicate-highpurity-water-using-ion-chromatography-online-sample-preparation
Trace borate			
Extract of cosmetics	Ion exclusion using an acid mannitol eluent	AN1119	https://appslab.thermofisher.com/App/4506/boric-acid-cosmetics
Ultrapure water (UPW)	Preconcentration of large sample volume on borate concentrator. Ion exclusion separation using a Thermo Scientific™ Dionex™ IonPac™ ICE-Borate column.	Dionex IonPac ICE-Borate column specification sheet	https://www.thermofisher.com/order/catalog/product/053945?SID=srch-hj-053945#/053945?SID=srch-hj-053945
Cations and metals			
Concentrated acids	AutoNeutralization	AN94	https://appslab.thermofisher.com/App/2009/an94-determination-trace-cations-concentrated-acids-phosphoric-acid-using-autoneutralization-pretreatment-ion-chromatography
Ammonium and amine solutions	Chelation	AN277	https://appslab.thermofisher.com/App/1485/determination-transition-metals
Lithium borated water	Large-volume preconcentration	AN250	https://appslab.thermofisher.com/App/1874/an250-determination-trace-nickel-zinc-borated-power-plant-waters-containing-lithium-hydroxide-using-nonsuppressed-conductivity-detection
HPW, semiconductor cleaning (SC2) solution sample	Large-volume preconcentration	AN131	https://appslab.thermofisher.com/App/1870/an131-determination-transition-metals-at-ppt-levels-highpurity-water-sc2-dclean-baths

Table A2. Other columns used for trace anion analysis

Column	Method	Description	Application
Dionex IonPac AS11	High volume/direct injection	Manually prepared hydroxide eluent for the determination of trace anions in high-purity water as well as power plant high-purity waters containing corrosion inhibitors, morpholine.	AN113
		Electrolytically generated KOH for the determination of trace anions in high-purity waters	TN48
Dionex IonPac AS14	Large-volume/direct injection	Manually prepared borate eluent for the determination of trace anions in high-purity waters	AN114
		50 mM boric acid with EGC II KOH for the determination of trace anions in borated waters	AN166
		Manually prepared borate eluent for the determination of trace anions in lithium-containing borated waters	AU191
		50 mM boric acid with EGC 500 KOH for the determination of trace anions in lithium containing borated waters	AU73866
Dionex IonPac AS15	Direct injection	Electrolytically generated KOH gradient for the determination of trace anions in 0.7% (V/V) nitric acid	AN137
	Matrix elimination/ preconcentration	Electrolytically generated KOH gradient for the determination of trace anions in borated water.	AN185
	Large-volume/direct injection	Electrolytically generated KOH for the determination of trace anions in high-purity waters	TN48
Dionex IonPac AS15-5µm	Large-volume/direct injection	Electrolytically generated KOH for the determination of trace anions in high-purity waters	AU142
Dionex I onPac AS18	Matrix elimination and preconcentration	Electrolytically generated KOH for the determination of trace anions in organic solvents	AU163
	AutoNeutralization and preconcentration	Electrolytically generated KOH for the determination of trace anions in basic solutions such as tetramethylammonium hydroxide (TMAOH), sodium hydroxide (NaOH), tetrabutylammonium hydroxide (TBAOH)	AN72481
Dionex IonPac ICE-Borate	Ion-exclusion	Determination of borate in UPW and cosmetics	AN1119
	Preconcentration of large volume, ion-exclusion	Manually prepared MSA and mannitol eluent with suppressor designed for ion-exclusion and chemical regeneration	Specs document, LPN 1001

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