Capillary Electrophoresis:
Beyond R&D and Towards High Volume Analysis

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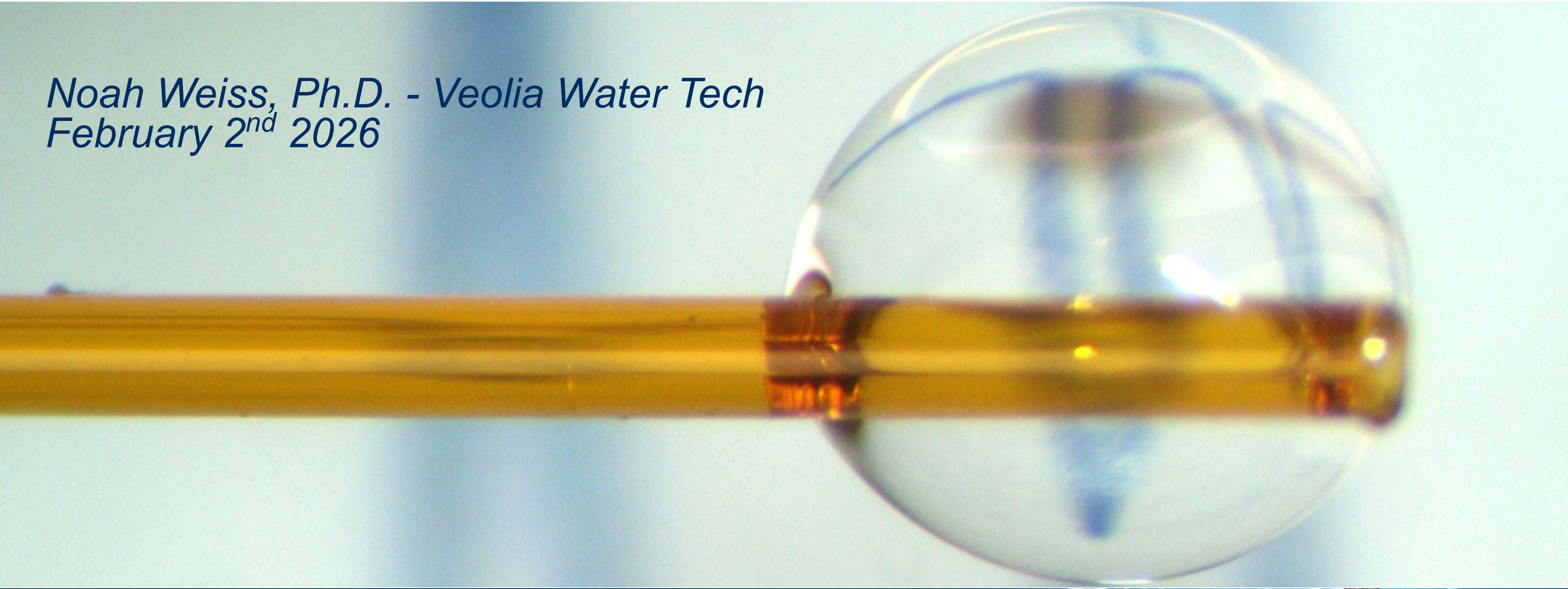


Distinctive Service & Innovation

Veolia Water Tech Tomball Technology Center

40+
scientists and engineers

200+
state-of-the-art scientific instruments

100,000+
samples processed annually

2 million
individual test results

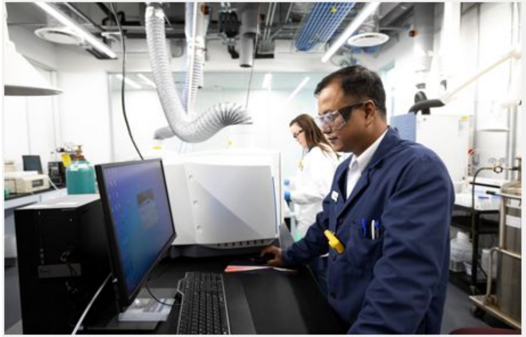
500+
years of combined laboratory and industry expertise

70+
patent families

ISO 9001:2015

Veolia Water Tech

Driving Support for Industrial Clients



Our Laboratories

Analytical

- Water & Oil
- Coupons & Metallurgy
- Deposits & Microbiology
- Membrane & Resin
- Advanced Analytical

Energy & Chemicals Technology

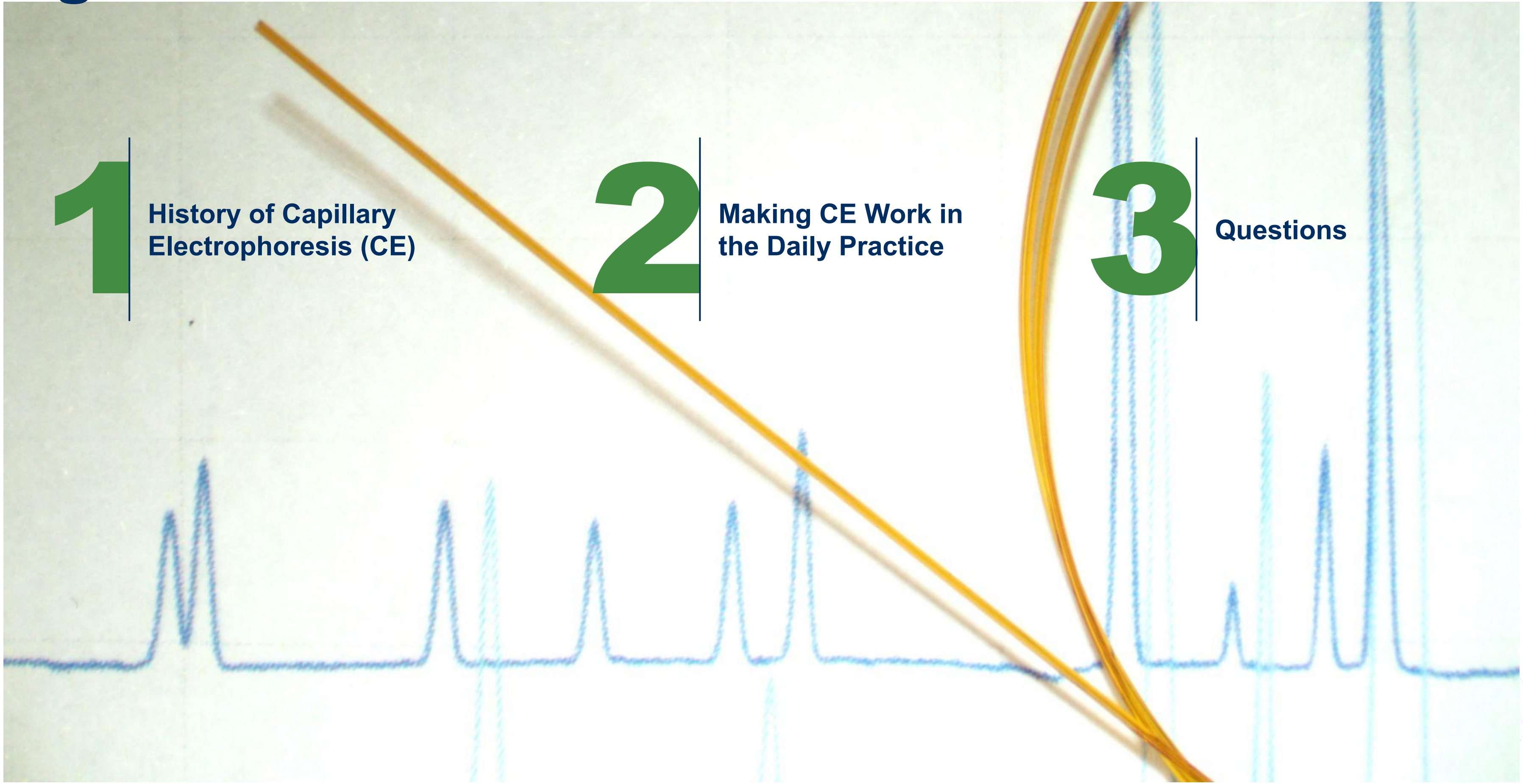
- Phase Separation
- Flow Assurance
- Corrosion Control
- Finished Product Additives & Scavengers
- Petrochemicals

4 Business Lines

- Technologies and Products
- Engineering and Procurement Projects
- Mobile Water and Integrated Services
- Chemical Solutions and Monitoring

Dozens of Industries

Agenda



1. History of Capillary Electrophoresis (CE)
2. Making CE Work in the Daily Practice
3. Questions

Part 1: History of CE

1. History of CE

300 Years of Development

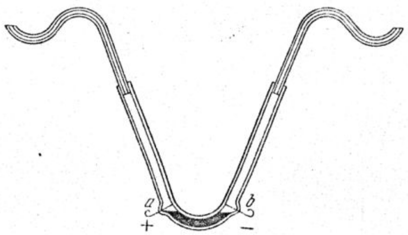


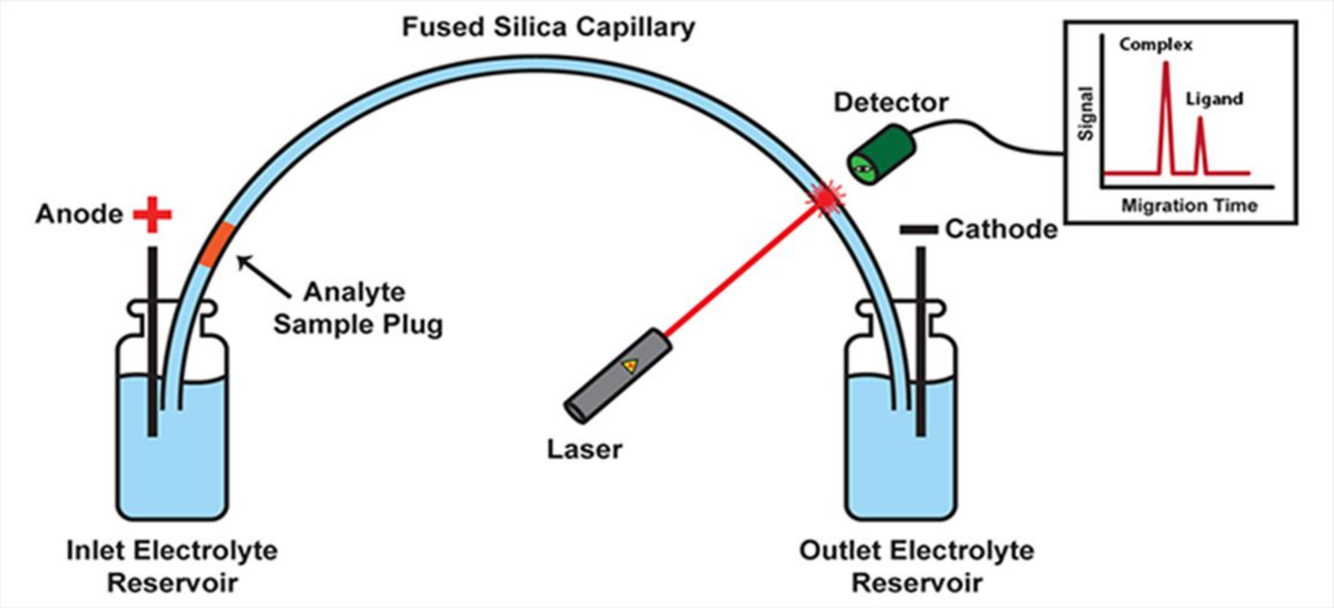
Figure 4. V-shaped quartz tube device used by Reuss in his first experiment on electroosmosis. The dimension of the tube was "*3 lignes de diamètre et de 7 pouces de lorgueur*", i.e. 3x2.26 mm in

- **1780 - 1910**: fundamental motion of charged particles in an electric field
- **1910 - 1990**: electrophoresis on paper/gels, >1 mm tubes down to 10 µm capillaries
  - **Tiselius 1948 Nobel Prize**: An electrical charge over a sheet of damp paper…
  - **Hjerten 1967**: The free zone electrophoresis method …in a horizontal tube which slowly rotates round its long axis.
  - **Jorgensen 1980**: Efficient heat transfer from small diameter capillaries permits application of unusually high voltages
- **1990 - 2000**: explosion in academic research, applications, new detectors → Human Genome Project
- **2000 +**: useful analytical tool with fading interest

[1] MLA style: Arne Tiselius – Facts. NobelPrize.org. Nobel Prize Outreach 2026. Tue. 6 Jan 2026. <https://www.nobelprize.org/prizes/chemistry/1948/tiselius/facts/>
[2] Kenndler E., Minárik M. (2021)Capillary Electrophoresis and its Basic Principles in Historical Retrospect -Part 1. The early decades of the "... Substantia 5(1) : 119-133. doi: 10.36253/ Substantia-1018

1. History of CE

Modern Instrumentation



1. History of CE

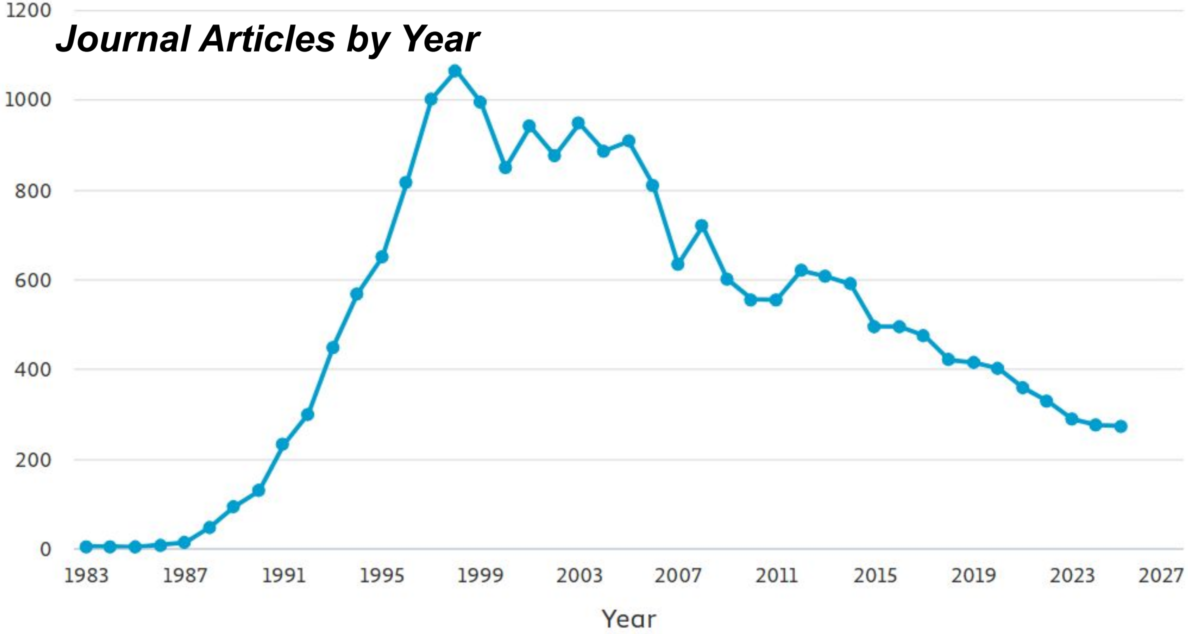
Background Electrolyte Buffers Drive Method Performance → Act As The "Analytical Column"

Category	Concentration	Examples
Buffers - change pH and analyte charge	mM	PO4, Citrate, Borate, etc.
Surfactants/Polymers - change EOF and MEKC	µM	SDS, TWEEN, PEG
Zwitterions - increase ionic strength without conductivity	mM	MES, TRIS, CHAPS
Organic solvents - change EOF, MEKC, and ion pairing	%	Methanol, Acetonitrile
Chiral/Ion Pair Additives - selective binding	mM	Cyclodextrins, crown ethers
Chromophore - improve sensitivity	mM	Transition metals, Aromatics

1. History of CE

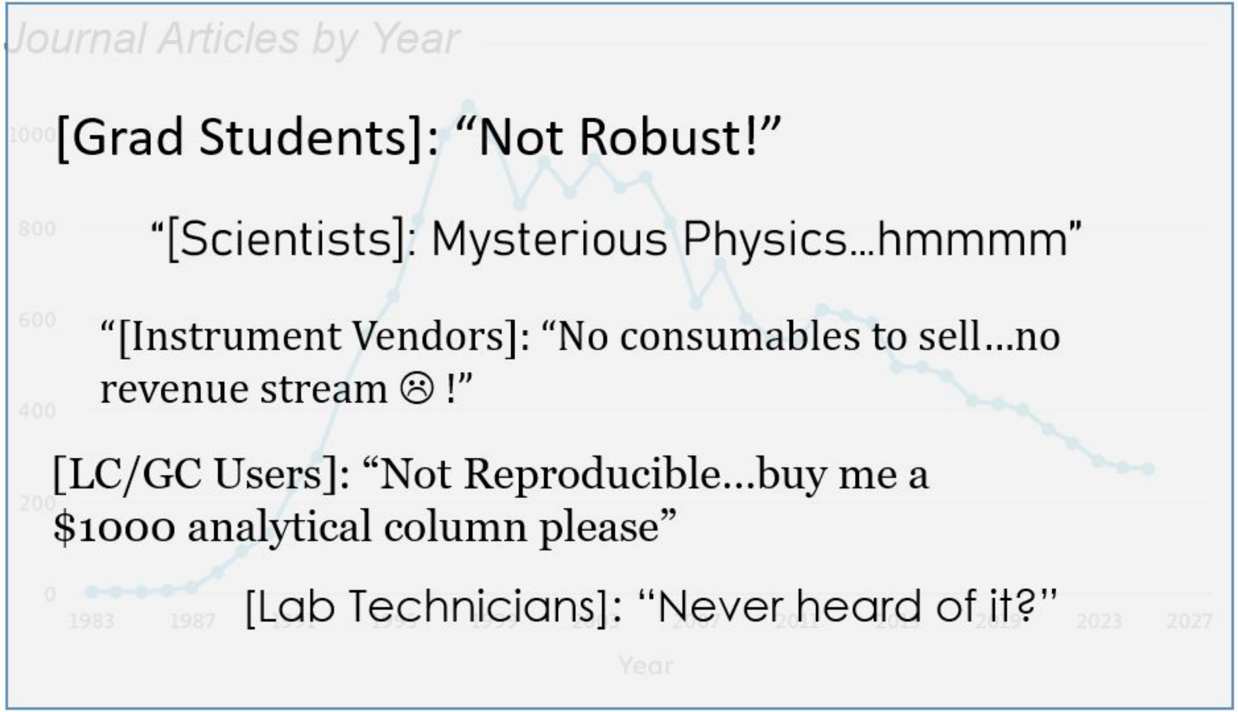
Fading Interest Since 2000

SCOPUS: Title (capillary AND electrophoresis) AND PUBYEAR 1982 -2026



1. History of CE

Some Reasons Why CE Has Faded?



1. History of CE

Reflecting on Qualities of "Good Methods"

Good Analytical Methods (7 S)

- ❑ Speed
- ❑ Sensitivity
- ❑ Selectivity
- ❑ Savings
- ❑ Simplicity
- ❑ Stability
- ❑ Safety

Characteristics of CE

- ❑ 10 minutes per run
- ❑ 0.01 - 10 ppm LOD
- ❑ 10^5 - 10^6 theoretical plates
- ❑ $1 / test
- ❑ Minimal mechanical parts
- ❑ >1 year shelf-life & matrix tolerant
- ❑ Microliter volumes

How to make it work in practice?!?!

1. History of CE

Reflecting on Qualities of "Green Methods"

Green Analytical Methods

- ❑ Low sample volume
- ❑ Low reagent volume
- ❑ Low waste
- ❑ Small Size & Miniaturizable
- ❑ Low power consumption
- ❑ Minimal maintenance
- ❑ Non-toxic reagents

Characteristics of CE

- ❑ 10 nL injections from 1 mL sample
- ❑ ~ 5 mL per day
- ❑ 2 L per year
- ❑ Handheld prototypes
- ❑ ~ 100 W
- ❑ Very few parts
- ❑ Customizable

How to make it work in practice?!?!

1. History of CE

Standard Test Methods Often Use Hazardous Reagents

EPA United States Environmental Protection Agency

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Home / Hazardous Waste Test Methods / SW-846

Hazardous Waste Test Methods / SW-846

- Which Method to Use
- Chapters and Methods
- Update VII to SW-846

SW-846 Test Method 6500: Dissolved Inorganic Anions in Aqueous Matrices by Capillary Ion Electrophoresis

7.5.1 Chromate concentrate (100 mM chromate) -- In a 1-L volumetric flask dissolve 23.40 g of sodium chromate tetrahydrate ($Na_2CrO_4 \cdot 4H_2O$) in 500 mL of water, and dilute to 1 L with water. This concentrate may be stored in a capped glass or plastic container for up to 1 year.

- H301 Toxic if swallowed.
- H340 May cause genetic defects.
- H350 May cause cancer.
- H360 May damage fertility or the unborn child.
- H372 Causes damage to organs through prolonged or repeated exposure.
- H410 Very toxic to aquatic life with long lasting effects.

Part 2: Making CE Work in Daily Practice

2. Making CE Work
Some Known Challenges

Peak Capacity is Limited	Analyte Identification is Difficult	System is Not Robust	Special Expertise
• *Develop better buffers* • *Explore > 20,000 literature publications* • *Micellar Electrokinetic Chromatography for non-ionic species* • *Capillary Gel Electrophoresis for Polymers* • *Trial and error*	• *Internal standard corrected migration times* • *Check migration times daily*	• *Modern instruments overcome most of this problems from heating, fittings, autosampling, etc.*	• *Simplify process steps and automate data processing*

2. Making CE Work

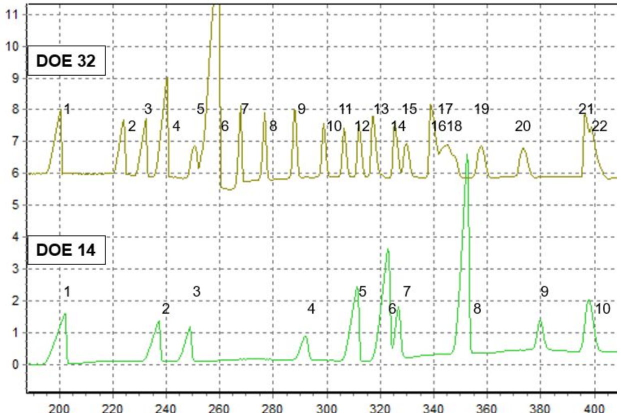
Development of Better Buffers

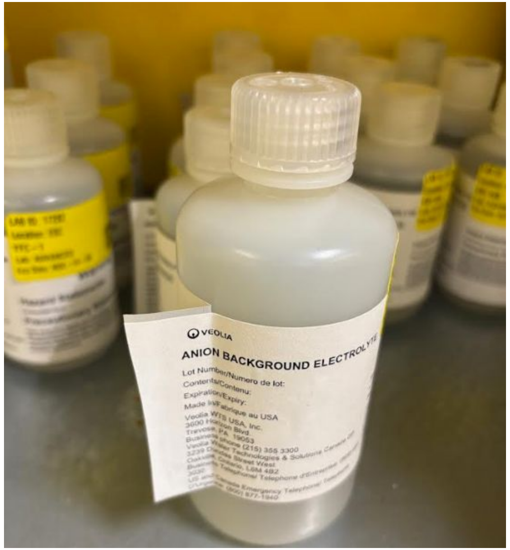
Review Literature

Electrolyte system
1 mmol/l 2,5-dihydroxybenzoic acid, 0.5 mmol/l lead(II) acetate, pH 4.3
5 mmol/l disodium 1,2-dihydroxy-3,5-disulfonate, pH 5.3
2.25 mmol/l PMA
5 mmol/l sodium chromate, 2.6 mmol/l TTAB, pH 8.8
(a) potassium phosphate, pH 2.5 (phosphoric acid)
(b) Tris, pH 8.75 (hydrochloric acid)
(a) 2 mmol/l sodium tetraborate, pH 9.2
(b) 4 mmol/l sodium glycinate, pH 10.5
(a) 2.5 mmol/l PMA, 6.5 mmol/l sodium hydroxide, 0.75 mmol/l HMOH, 1.6 mmol/l TEA, pH 7.7
(b) 2.5 mmol/l PMA, 6.5 mmol/l sodium hydroxide, 0.75 mmol/l HMOH, 1.6 mmol/l TEA, 15% methanol (v/v), pH 7 7
5 mmol/l sodium chromate, 0.5 mmol/l OFM-BT, pH 8.1

Select Less Toxic & More Biodegradable

DOE Performance Screening of 50+ Buffers

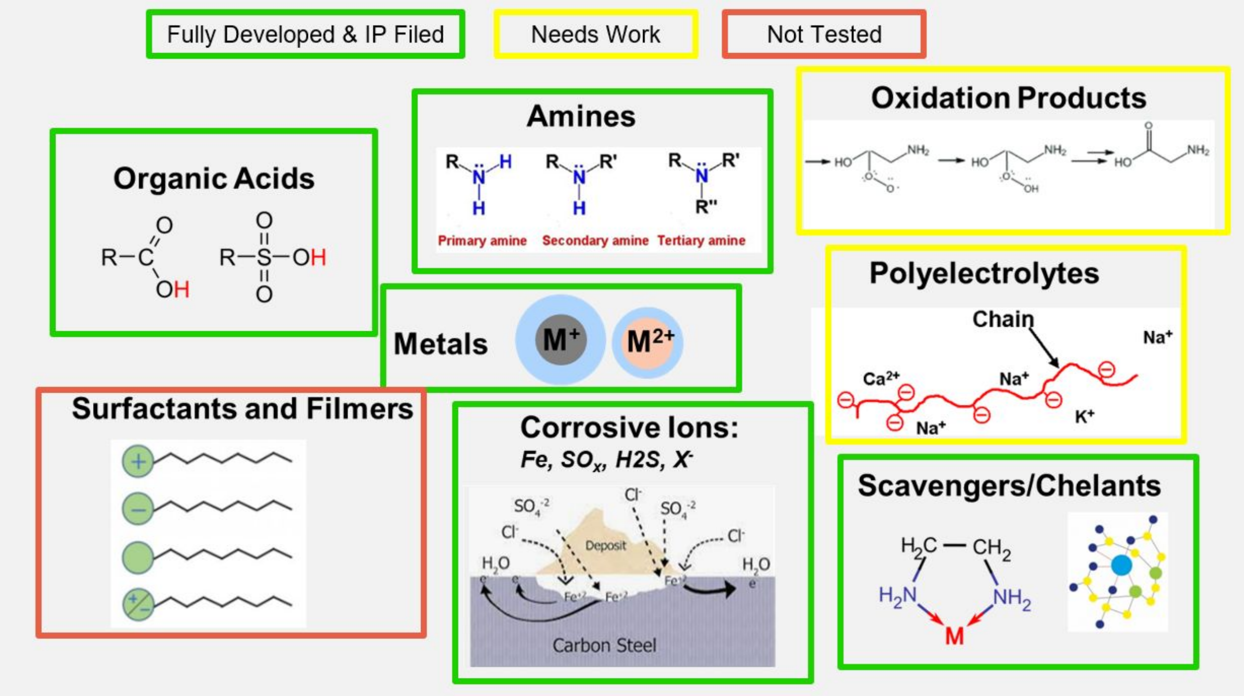




Shelf Stability Evaluation

- **Chemical stability -** resisting UV and thermal degradation
- **Microbiological stability -** inhibits MB growth
- **Air stability -** resisting even subtle changes due air intrusion

2. Making CE Work
Amenable Compound Classes



Providing Key Insights for:

- Corrosion
- Product reliability
- Wastewater toxicity
- Chemical quality
- Process stability
- End fate studies

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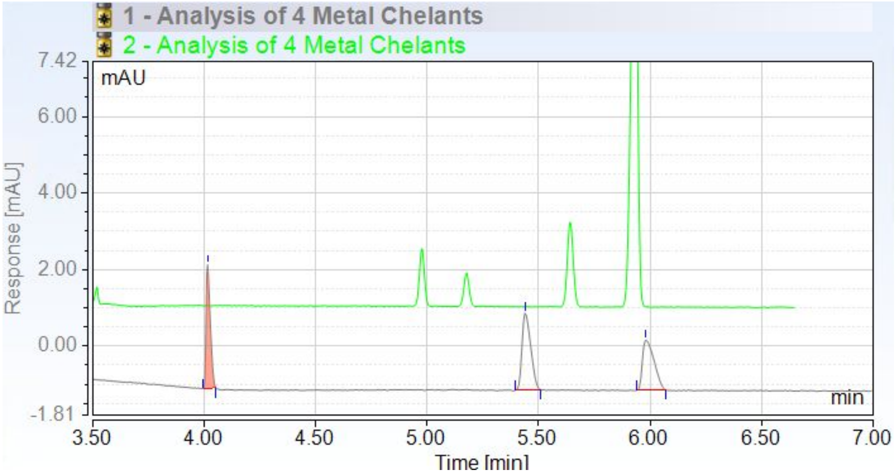
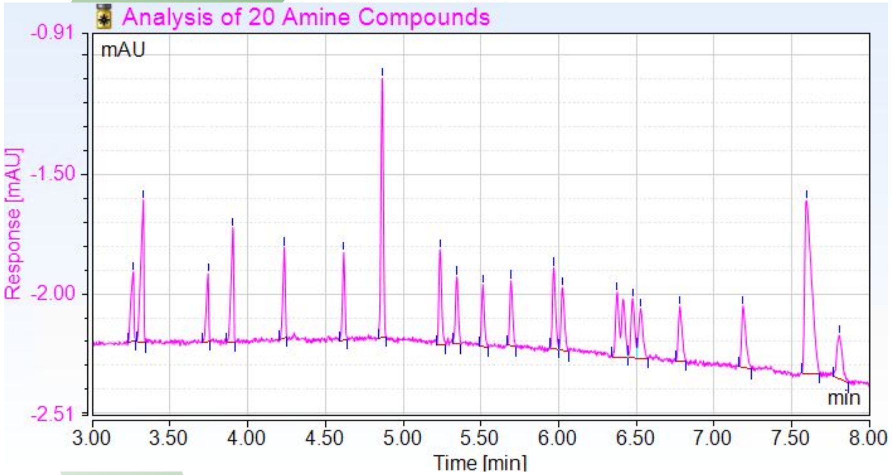
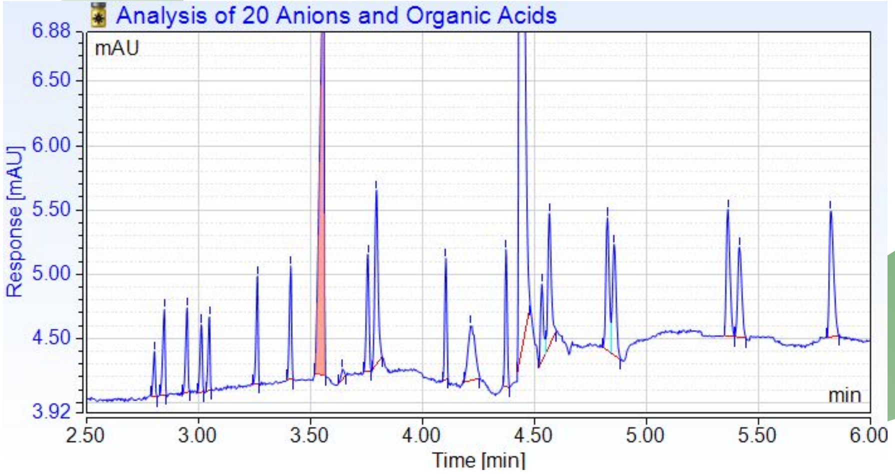
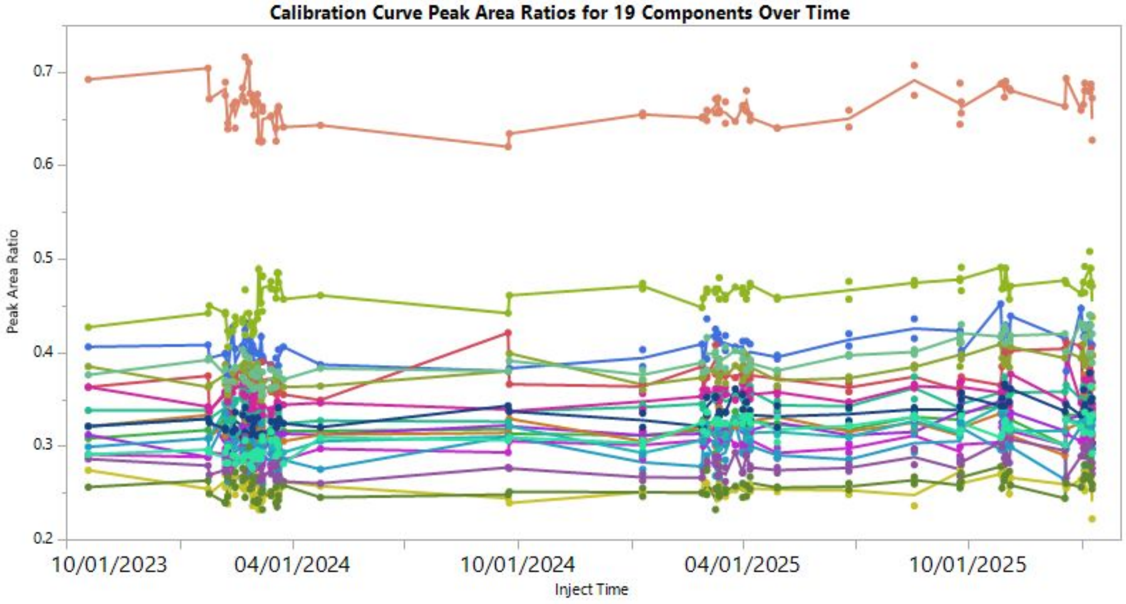
2. Making CE Work
Established Routine Methods







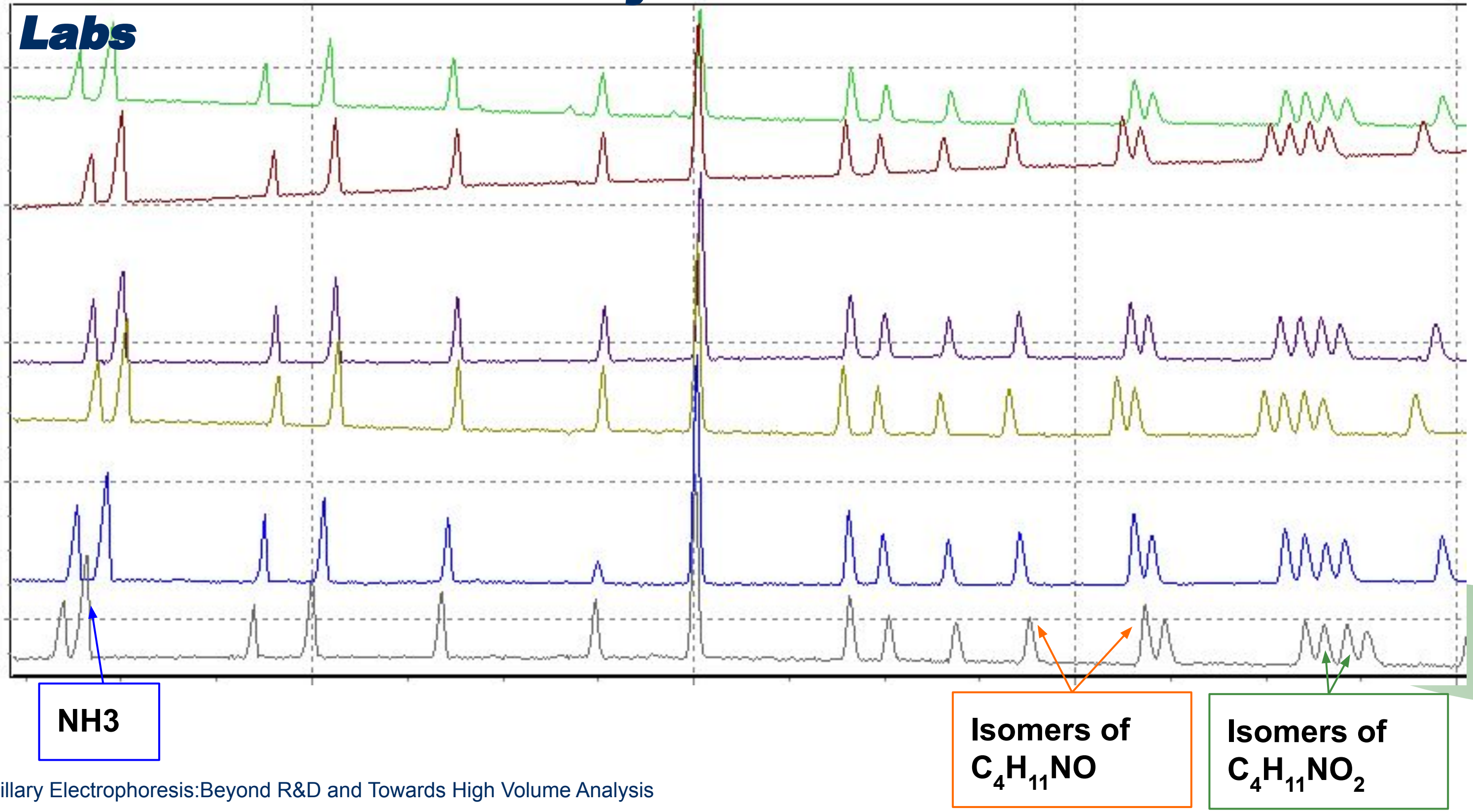
2. Making CE Work
Quantitative Response is Very Precise Over Years



- Absolute Peak Area ~10% CV
- **Peak Area Ratio ~5% CV !**

2. Making CE Work

Resolution and Sensitivity is Consistent Across Time and Labs



Lab 1: Calibrations 1 Year Apart

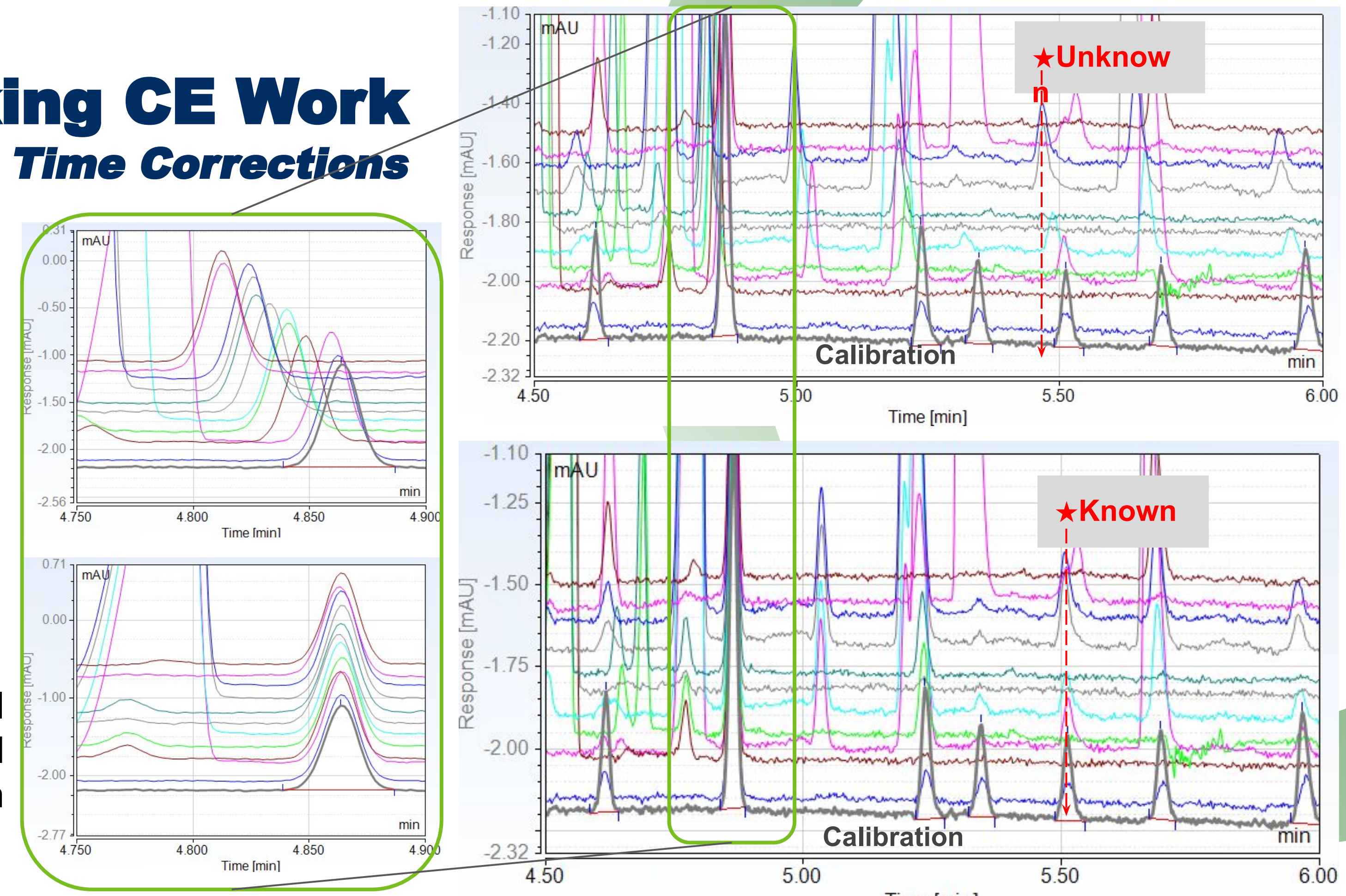
Lab 2: Calibrations 2 Years Apart

Lab 3: Calibrations 5 Years Apart

2. Making CE Work
Migration Time Corrections

Before Correction

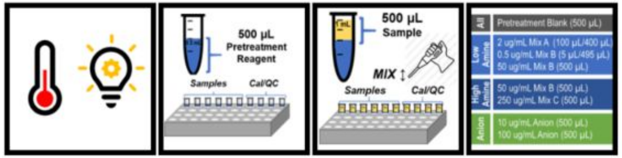
After Internal Standard Correction



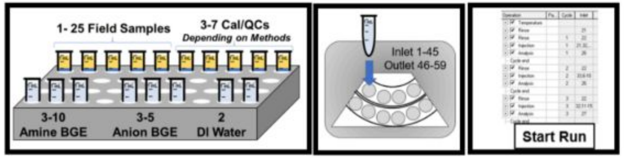
2. Making CE Work

Simplify and Automate

Field Operator Instructions



1. Install capillary cartridge cassette, verify coolant level, turn on capillary temperature to 20 °C, and turn on lamp in software. Allow 15 min. warm up time.
2. Place one vial in rack for each sample (plus 3-7 extra vials for QC/Cal standards), label them, and pre-load them with 500 µL pretreatment reagent.
3. Add 500 µL sample to each sample vial. Mix 3x with pipette. Use DI water for dilutions as follows: *500/0 µL (1x) 50/450 µL (10x) 5/495 (100x)*.
4. Prepare QC/Cal. Stds. with 500 µL pretreatment reagent. The PT Blank and 50 µg/mL Mix B standards may be used across methods. Mix 3x with pipette.

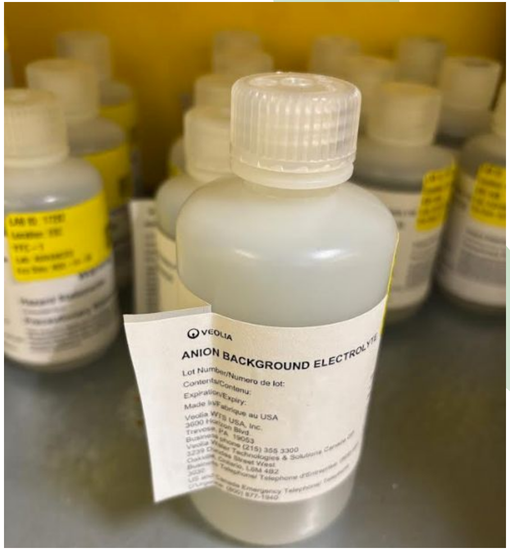


5. Place the following number of vials in rack to hold Background electrolyte (BGE) and DI Water. Add 1 mL of reagent to each vial.
   - *DI Water = 2 vials*
   - *Amine BGE = 3 – 10 vials*
   - *Anion BGE = 3 – 5 vials*

   1-10 samples require 3 BGE vials, 10-20 samples require 5 BGE vials for each method (low-level amine, high-level amine, and anions).
6. Discard old sample vials and load new sample vials (including waste collection vials) in autosampler following the pre-defined autosampler template. Inspect for any leaks, dirt on O-Rings, salt on electrodes, etc. Create a Sample ID log. Close the lid on instrument.
7. Load the amine method template program. Edit as necessary. Create and save under directory: C:Lumex/Elforun205/Amines/yyyy-mm-dd.

   → **Start Run!**

Shelf Stable and Greener Reagents



Automate Data Processing with Modern CDS Software

#	Variable Wavelength Detec	Name	Processing Method	Dilution	Type
1		260102_1605_BLANK_T-691626...	AMINES_CE_T_PM_1	1.0000	Matrix
2		260102_1618_Amine Cal 2ppm_...	AMINES_CE_T_PM_1	1.0000	Matrix
3		260102_1630_LLCCV_T-691627...	AMINES_CE_T_PM_1	1.0000	Matrix
4		260102_1643_TW251230.42.16...	AMINES_CE_T_PM_1	1.0000	Matrix
5		260102_1655_TW251230.42.16...	AMINES_CE_T_PM_1	10.0000	Matrix
6		260102_1708_TW251230.42.17...	AMINES_CE_T_PM_1	10.0000	Matrix
7		260102_1721_TW251230.42.17...	AMINES_CE_T_PM_1	1.0000	Matrix
8		260102_1733_TW251230.42.17...	AMINES_CE_T_PM_1	1.0000	Matrix
9		260102_1746_TW251230.42.17...	AMINES_CE_T_PM_1	10.0000	Matrix
10		260102_1759_TW251230.42.17...	AMINES_CE_T_PM_1	1.0000	Matrix

	A	B	C	D	E	F	G	H	I	J	K
1–2	SampleID	Dilution Factor	Amount ppm	Amount ppm	Amount ppm	Amount ppm	Amount ppm	Amount ppm	Amount ppm	Amount ppm	Amount ppm
5	TW251212.23.143	1	2.12	1.67	0	0	0	1.61	41.59	0	0
6	TW251212.23.144	1	2.40	1.05	0	0	0	1.60	12.20	0	0
7	TW251212.24.145	1	1.74	0.74	0	0	0	1.48	26.99	0	0
8	TW251212.24.146	1	1.38	1.63	0	0	0	1.53	39.36	0	0
9	TW251212.25.147	1	2.04	1.97	0	0	0	1.96	39.50	0	0
10	TW251212.25.148	1	2.03	1.11	0	0	0	1.67	11.32	0	0
11	TW251215.15.083	1	1.59	0	0	0	0	0	8.70	0	0
12	TW251215.15.084	1	1.58	0	0	0	0	0	8.56	0	0
13	TW251217.31.187	1	4.33	22.98	0	0	0	6.19	*	0	*
14	TW251217.31.188	1	6.23	43.28	0	0	0	8.61	*	0	*
15	LCS_T-691633	1	9.86	10.99	0	0	0	10.96	9.35	0	10.33
16											

Part 3: Questions

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