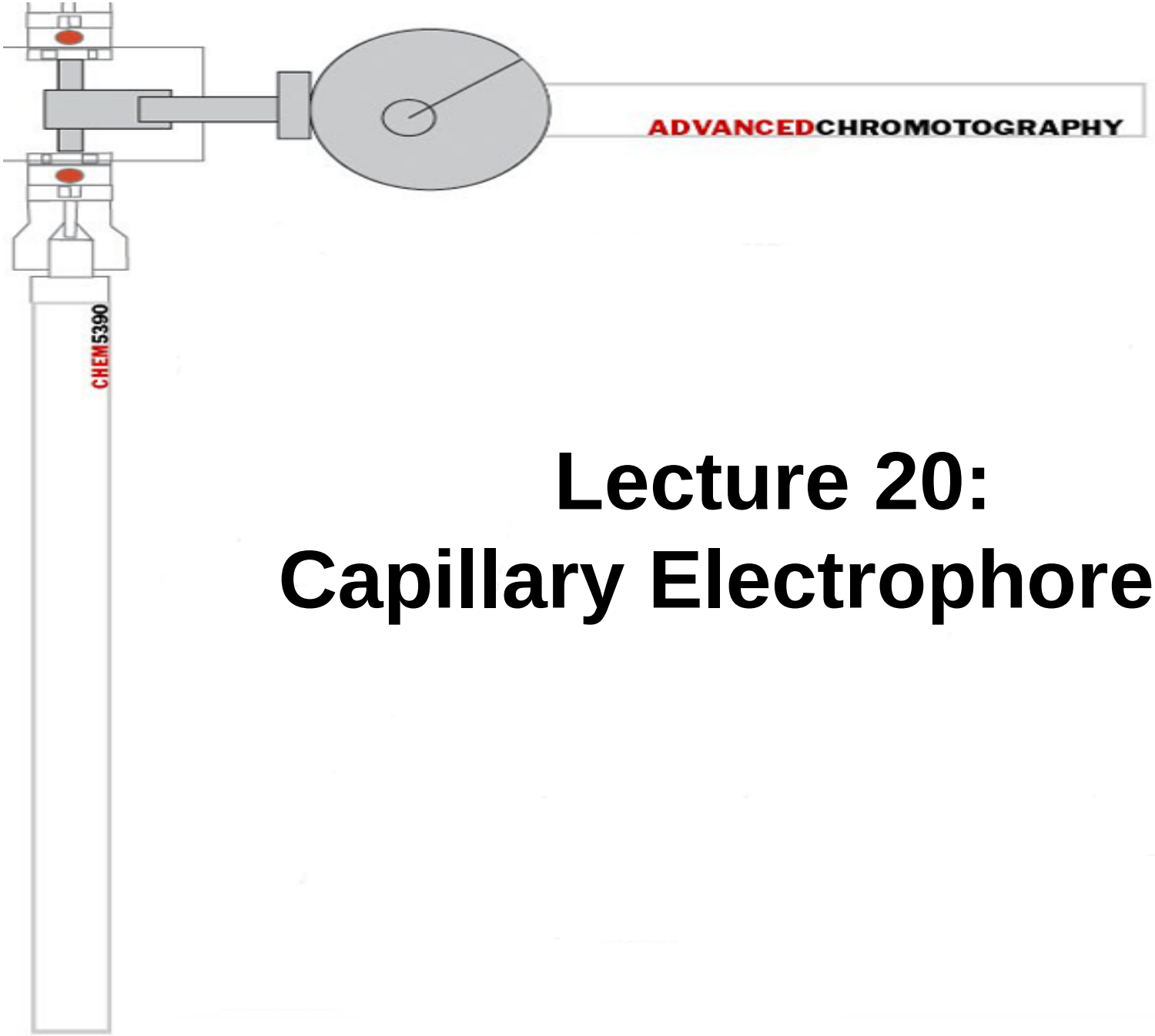
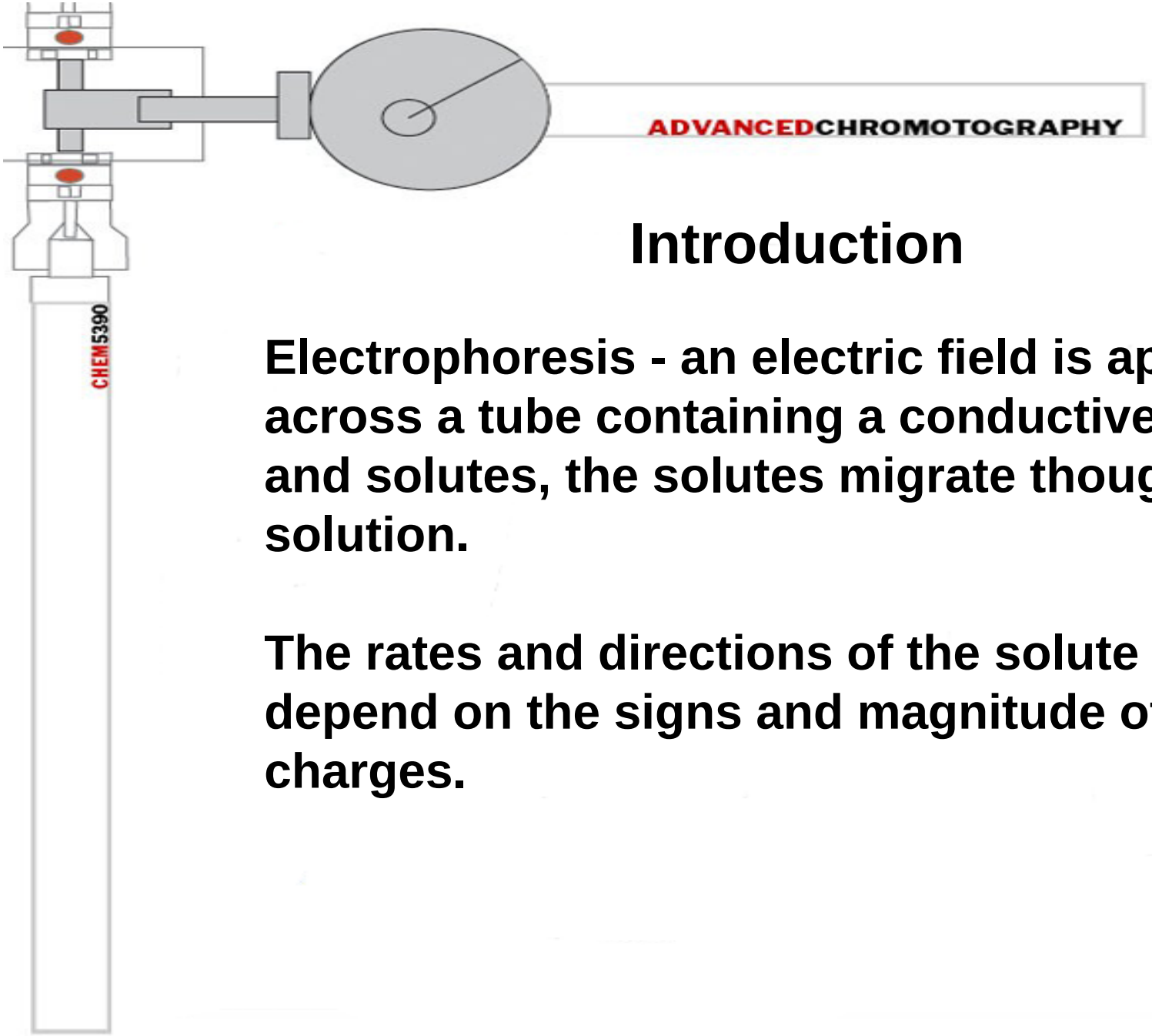


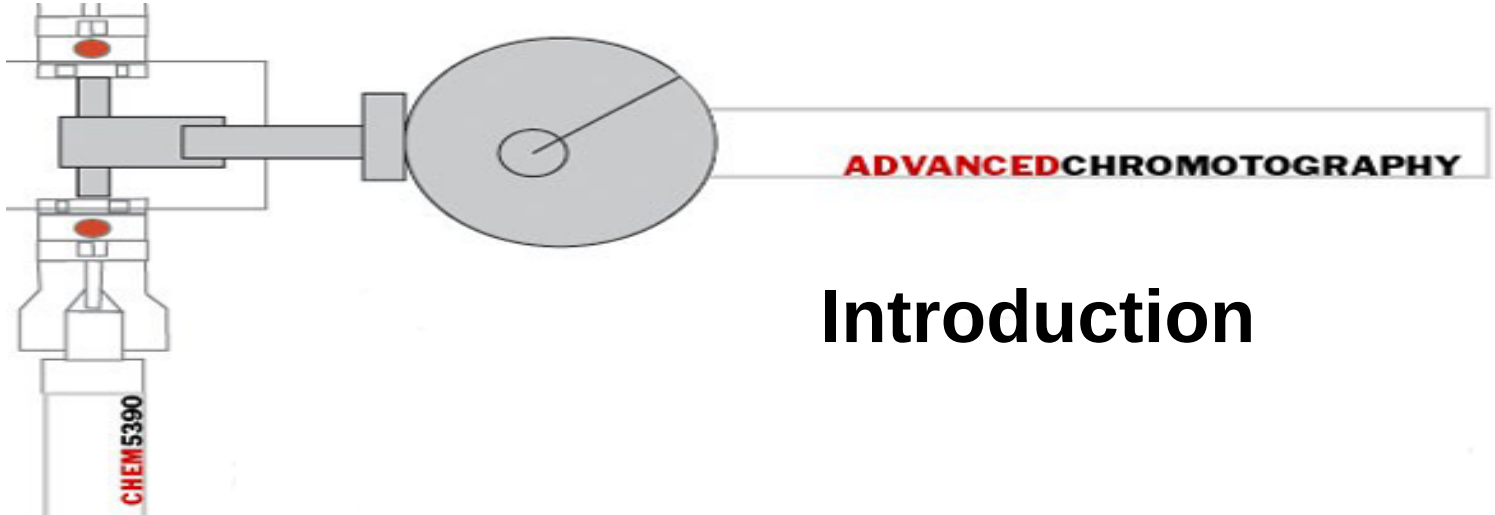
Lecture 20:
Capillary Electrophoresis



Introduction

Electrophoresis - an electric field is applied across a tube containing a conductive solution and solutes, the solutes migrate though the solution.

The rates and directions of the solute migration depend on the signs and magnitude of their charges.

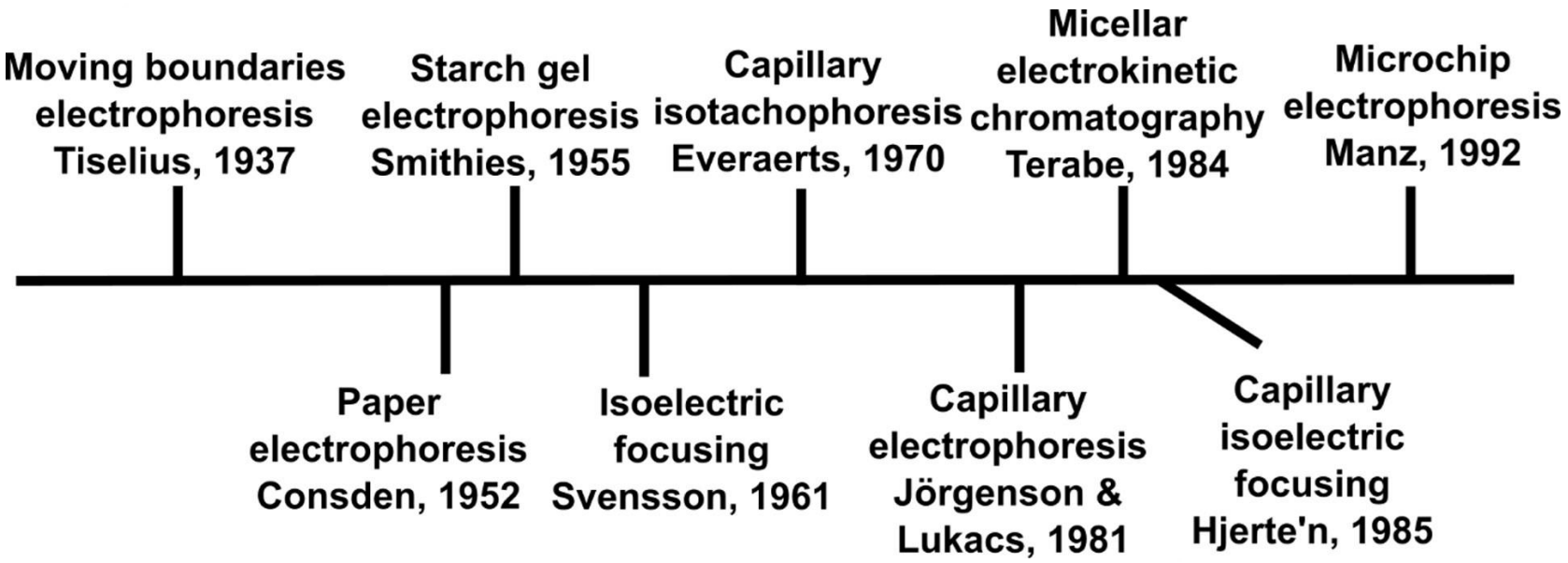


Introduction

Historically- electrophoresis has been done on a flat support such as a slab of gel or paper or cellulose acetate to provide mechanical stability for the fluid.

Capillary electrophoresis- uses a capillary wall as the mechanic support for the carrier electrolyte.

Introduction

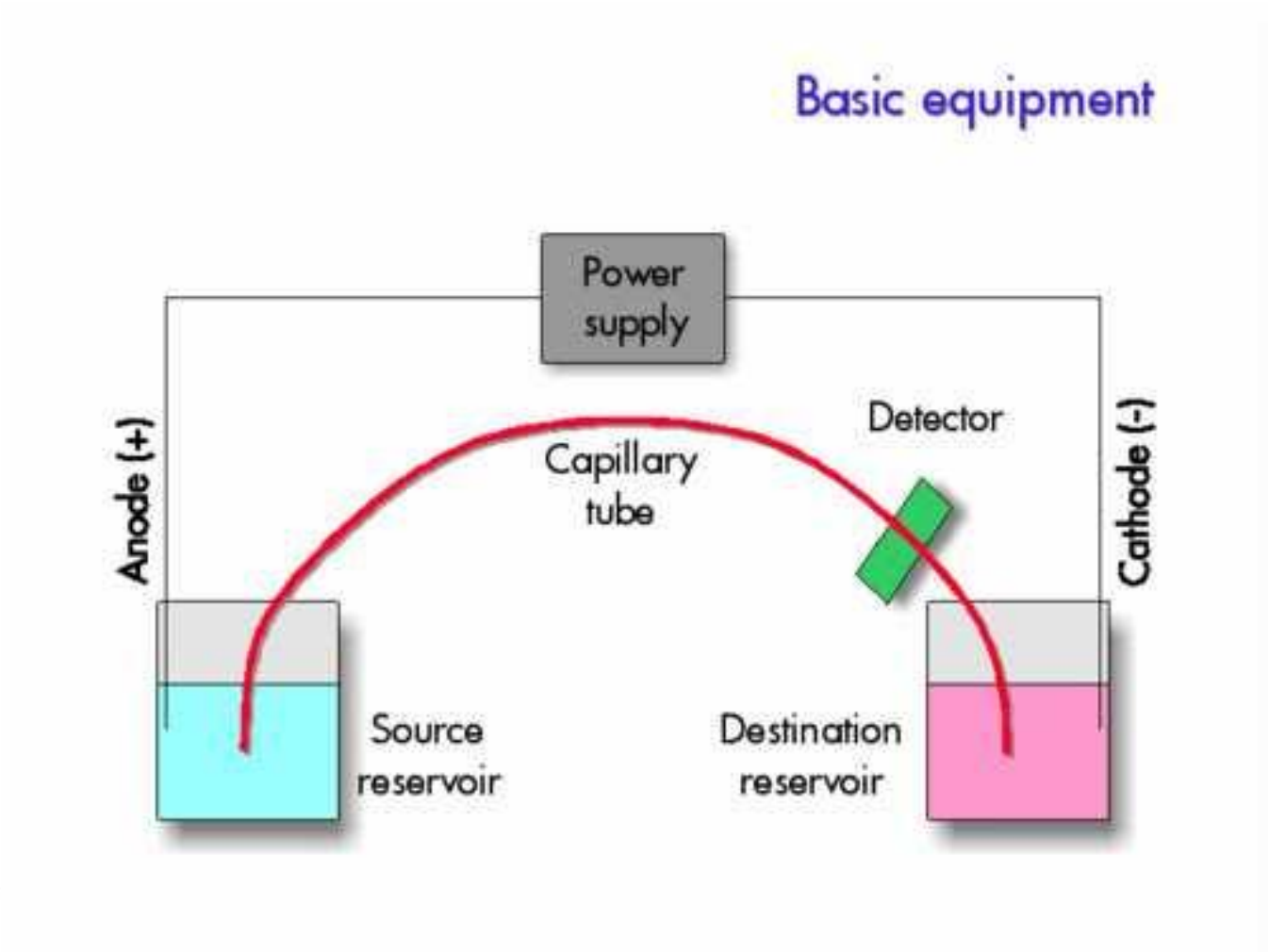


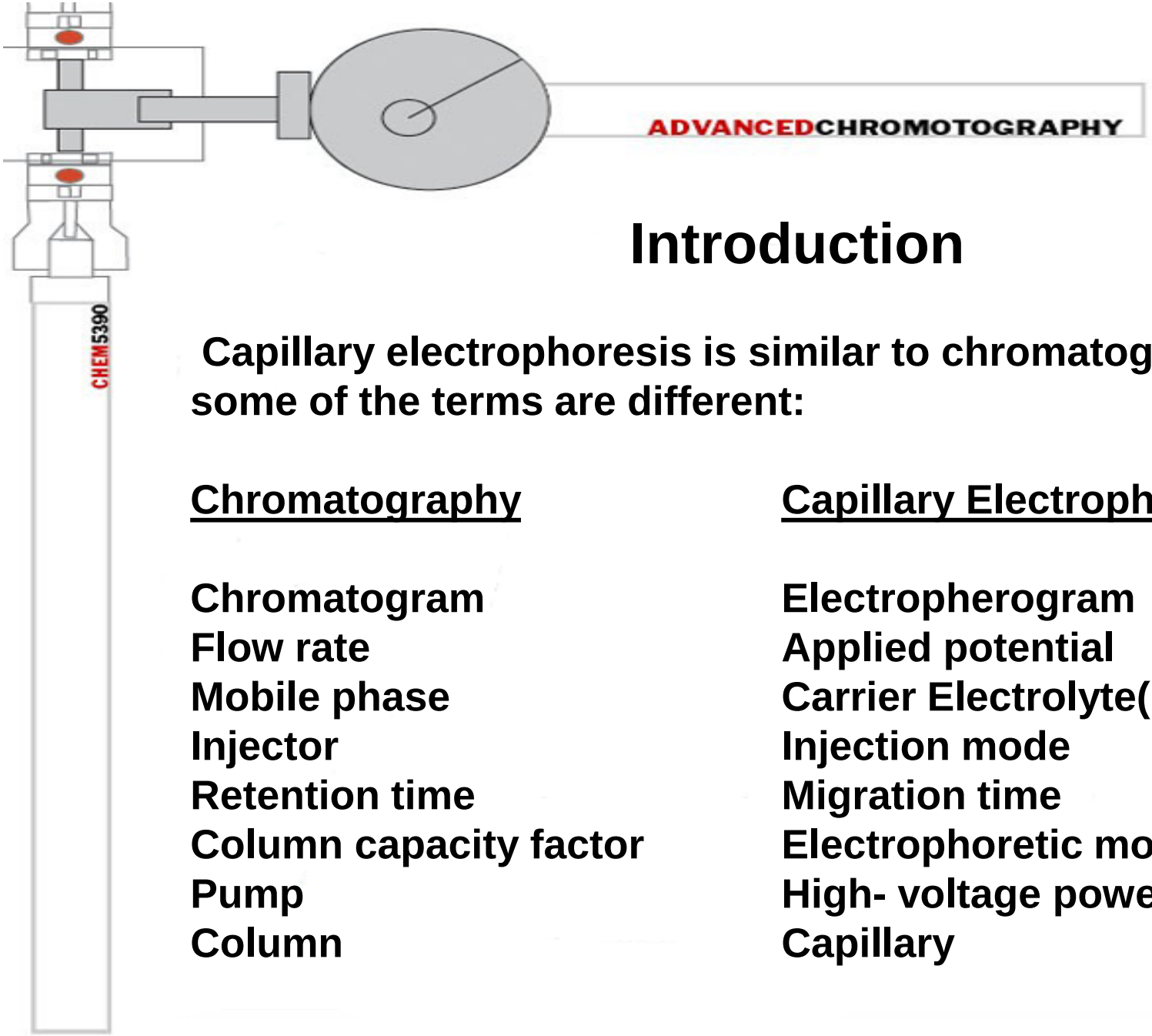
Introduction

ELECTROPHORESIS

Gel electrophoresis (GE)	Zone electrophoresis (ZE)	Free flow electrophoresis (FFE)	Capillary electrophoresis (CE)
- Agarose GE - SDS-PAGE - Native PAGE - Pulse field GE - DGGE & TGGE - Isoelectric focusing - 2D GE	- Paper electrophoresis - Cellulose acetate electrophoresis	- Microelectrophoresis - Moving boundary electrophoresis	- Capillary GE - Capillary ZE - Capillary isoelectric focusing - Capillary isotachophoresis - Micellar electrokinetic chromatography - Capillary electrochromatography

Introduction

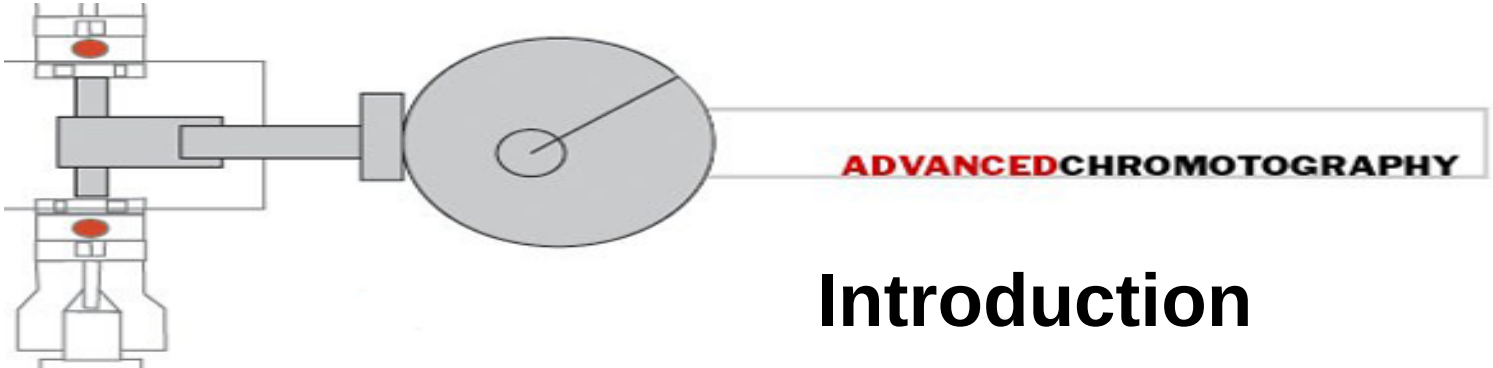




Introduction

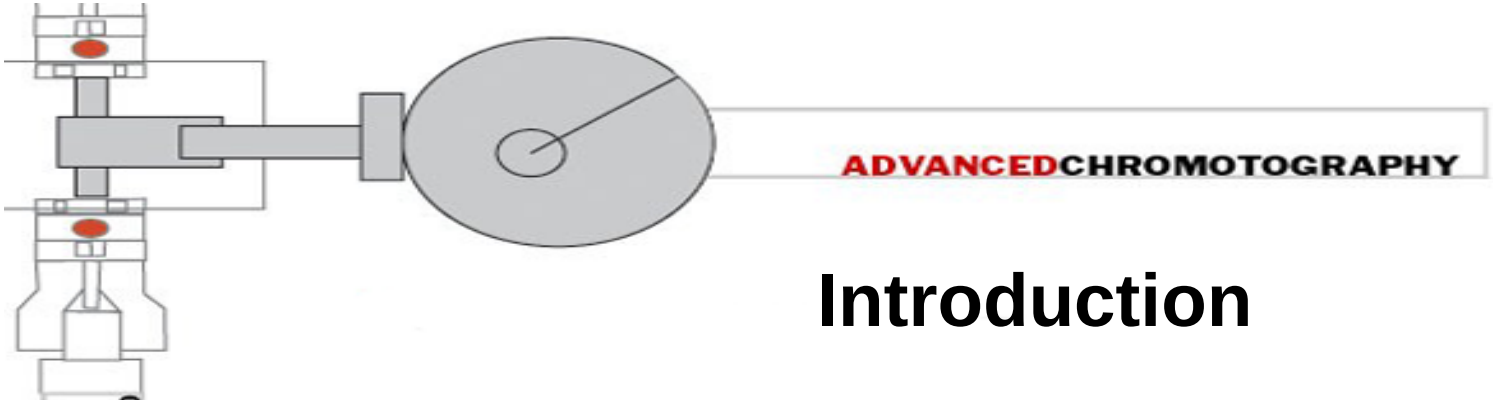
Capillary electrophoresis is similar to chromatography but some of the terms are different:

Chromatography	Capillary Electrophoresis
Chromatogram	Electropherogram
Flow rate	Applied potential
Mobile phase	Carrier Electrolyte(buffer)
Injector	Injection mode
Retention time	Migration time
Column capacity factor	Electrophoretic mobility
Pump	High- voltage power supply
Column	Capillary



Introduction

Technique	Advantages	Disadvantages
CE	- Minimal sample consumption and waste production. - High separation efficiency due to microscale dimensions and uniform flow front. - Rapid analysis and reduced run times. - Excellent for charged molecules and fast separations.	- Limited capacity for separating large molecules. - May require specialized equipment for certain applications. - Sensitive to changes in buffer composition.
LC	- Versatile separation of a broad range of molecules. - Enhanced control over separation conditions. - Suitable for complex samples and biomolecules. - Many mobile and stationary phases are available, as well as columns of different lengths and packings.	- Longer analysis times compared to CE. - Consumes large sample volumes. - Risk of column deterioration and band broadening. - More complex instrumentation.



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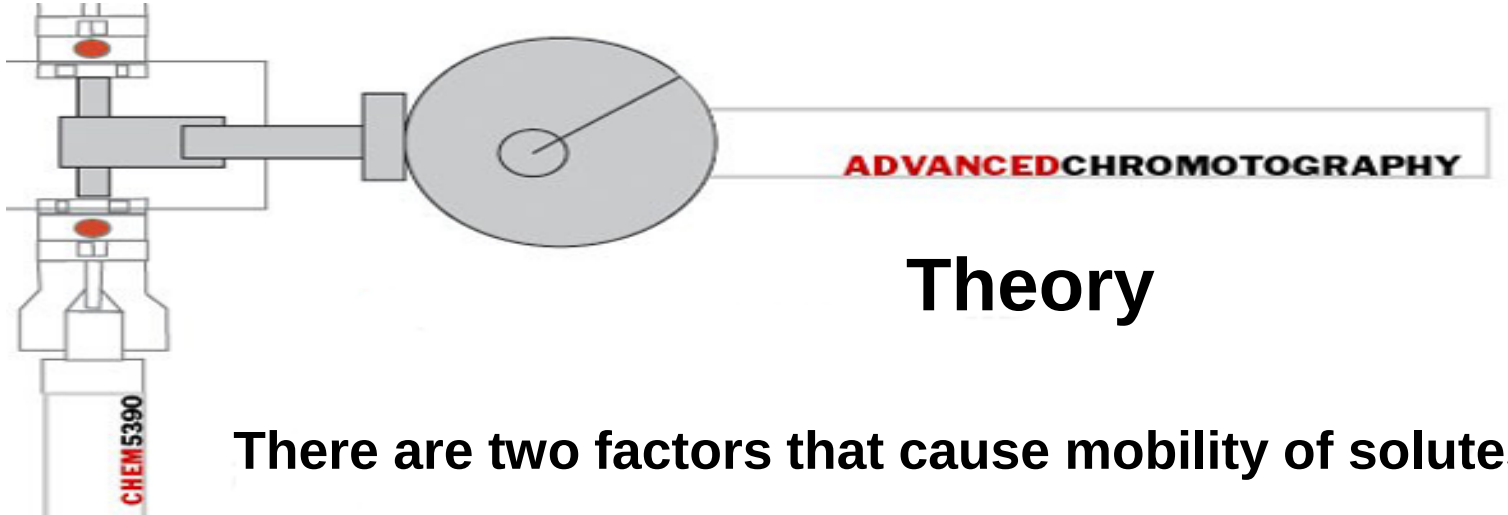
Introduction

Choose CE over LC when

- Analytes are charged or ionic in nature.
- Rapid analysis is crucial.
- High separation efficiency is required for small molecules.
- Minimal sample consumption is required.

Choose LC over CE when

- Analytes vary in size, charge and hydrophobicity.
- Superior separation control and flexibility are needed.
- Complex samples with a diverse range of compounds are being analyzed.
- Longer separations times are acceptable.



Theory

There are two factors that cause mobility of solutes:

- **Electrophoretic Mobility**
  - **Response to the electric field**
  - **Cations migrate toward the cathode and anions toward the anode**

- **Electroosmotic Flow**
  - **Migration of solutes in response to the buffer's solution's movement in response to an electric field**
  - **The buffer moves towards the cathode and sweeps all species in that direction including anions and neutrals**

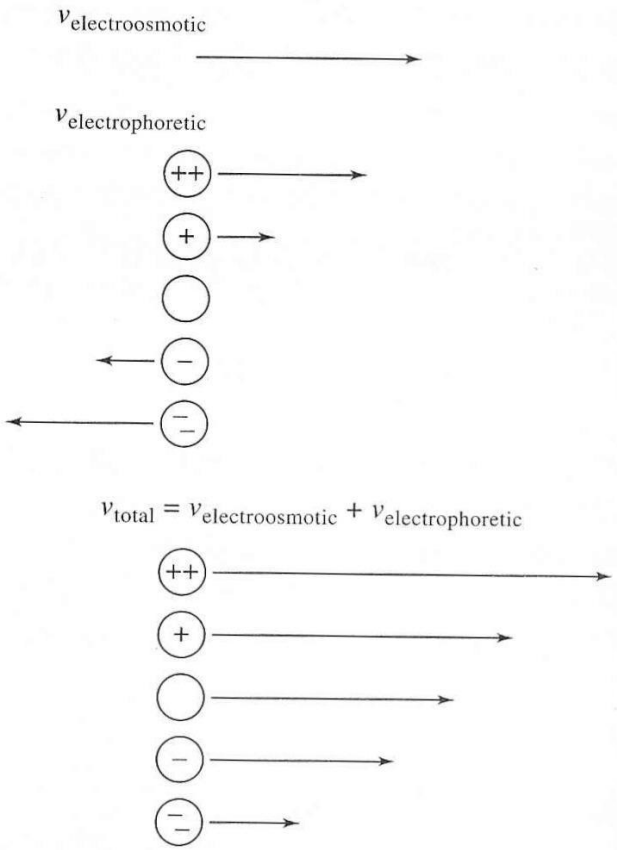
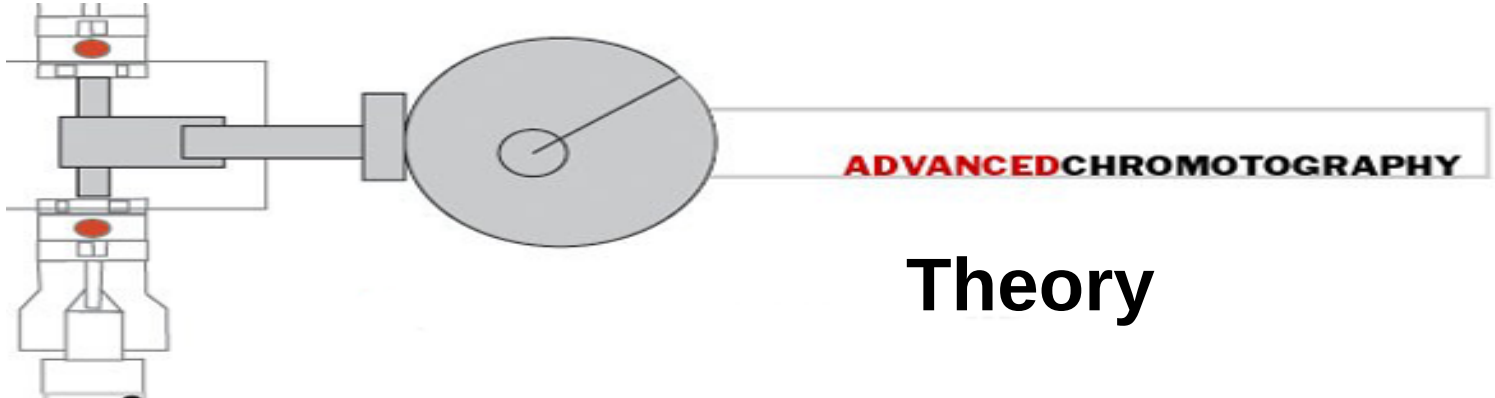


Figure 30-4 Velocities in the presence of electroosmotic flow. The length of the arrow next to an ion indicates the magnitude of its velocity; the direction of the arrow indicates the direction of motion. The negative electrode would be to the right, and the positive electrode to the left of this section of solution.



Theory

Electrophoretic mobility

The movement (migration) of a charge species under the influence of an applied field, μe(cm^2/sec V)

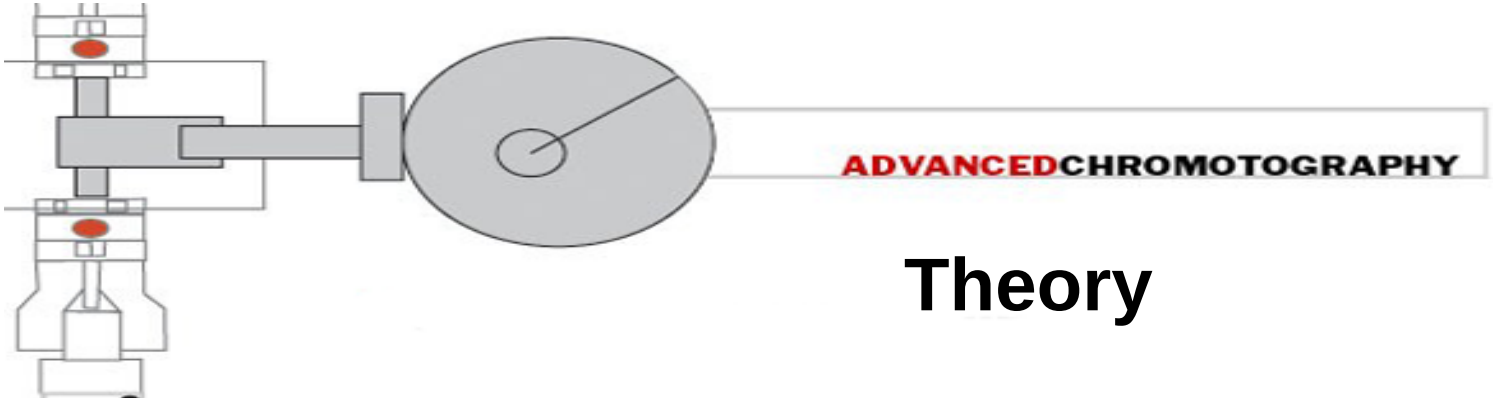
Mobility depends on the charge density of the solute (valence & size), the dielectric constant and viscosity of the electrolyte, and the temperature.

Under electroosmotic flow

$\mu = \mu_e + \mu_{eo}$

μ_e - electrophoretic mobility of the analyte

μ_{eo} - electroosmotic flow mobility



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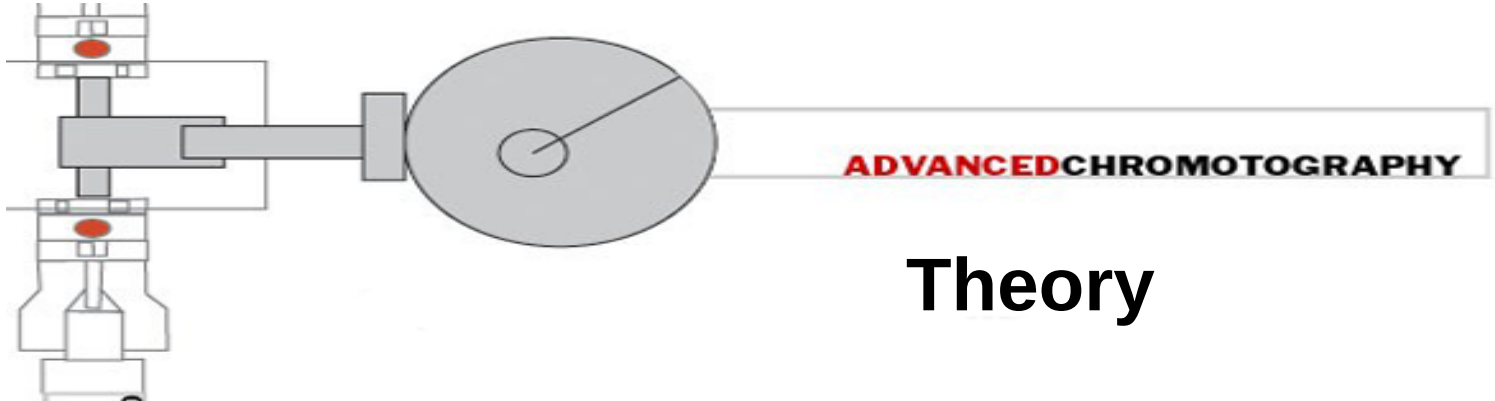
Theory

Electrophoretic mobility

$$\mu = \frac{l}{tE} = \frac{lL}{tV}$$

l - distance from point of injection to detector
t - time for the species to migrate to detector
E - electric field(V/L)
V - applied voltage
L - distance between two electrode(i.e. total length of the capillary)



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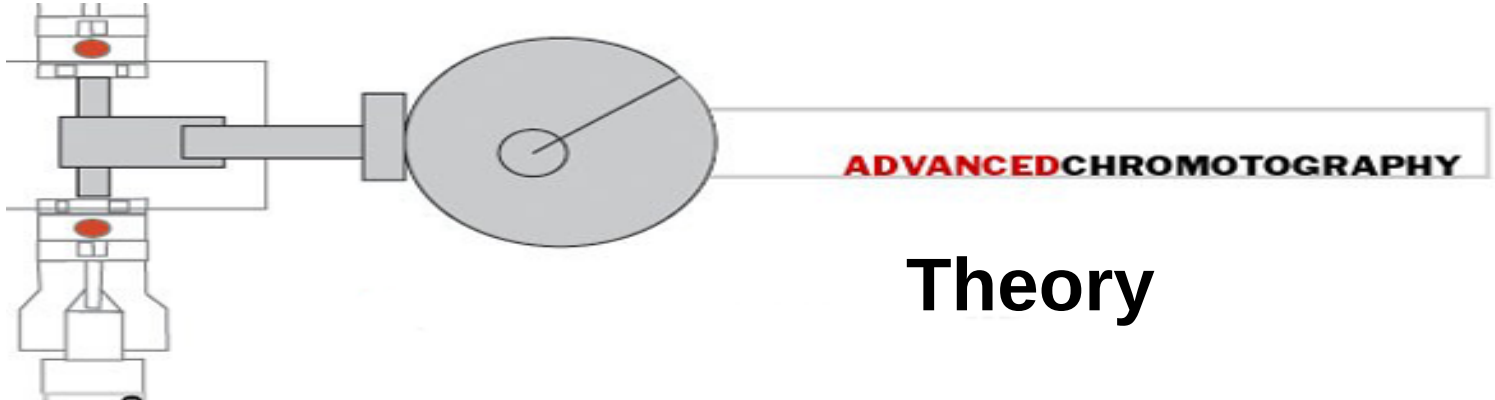
Theory

Electrophoretic mobility

$$\mu_e = \frac{q}{6\pi\eta r}$$

q - charge on the ionic solute
η - viscosity of the electrolyte
r - radius of the solute

Highly charged - small molecule have the highest velocity & move through capillary fastest.



Theory

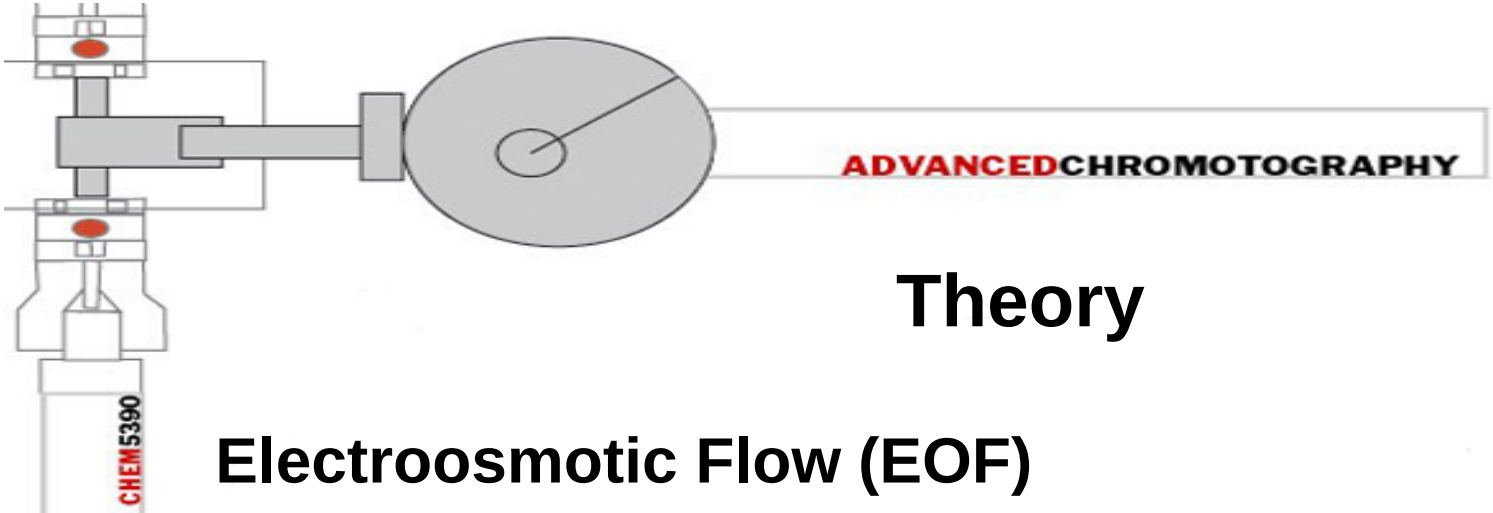
Velocity

Separation is based on the difference in solute velocity in the applied electric field

$$\upsilon = \mu_e E = \mu_e \frac{V}{L}$$

With electroosmotic flow:

$$\upsilon = \mu E = \mu \frac{V}{L}$$



Theory

Electroosmotic Flow (EOF)

EOF - is the movement of a liquid in contact with a solid surface when an electric field is applied.

EOF can be used to increase the speed of the analytes flowing in the same direction (co-electroosmosis) or to improve resolution when flowing in opposite direction (counter-electroosmosis).

Theory

Electroosmotic Flow (EOF)

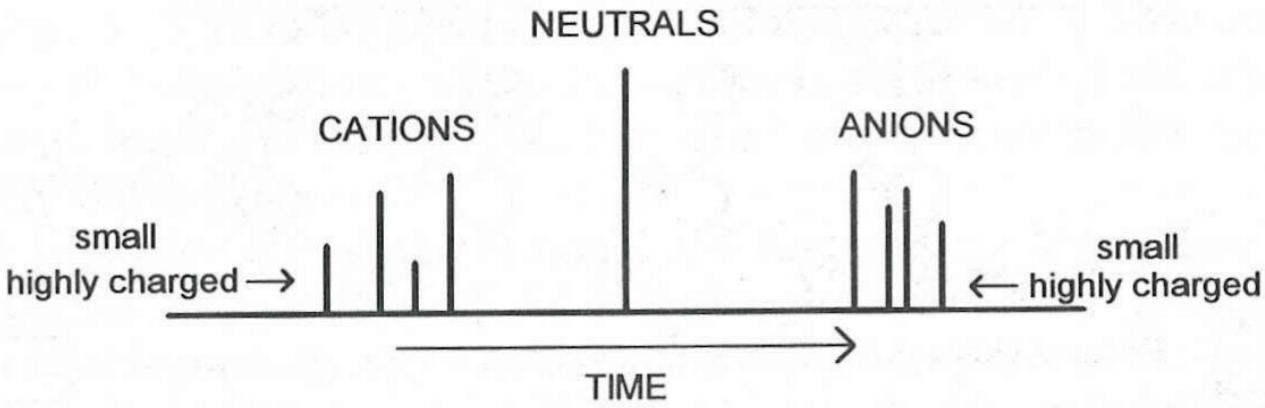
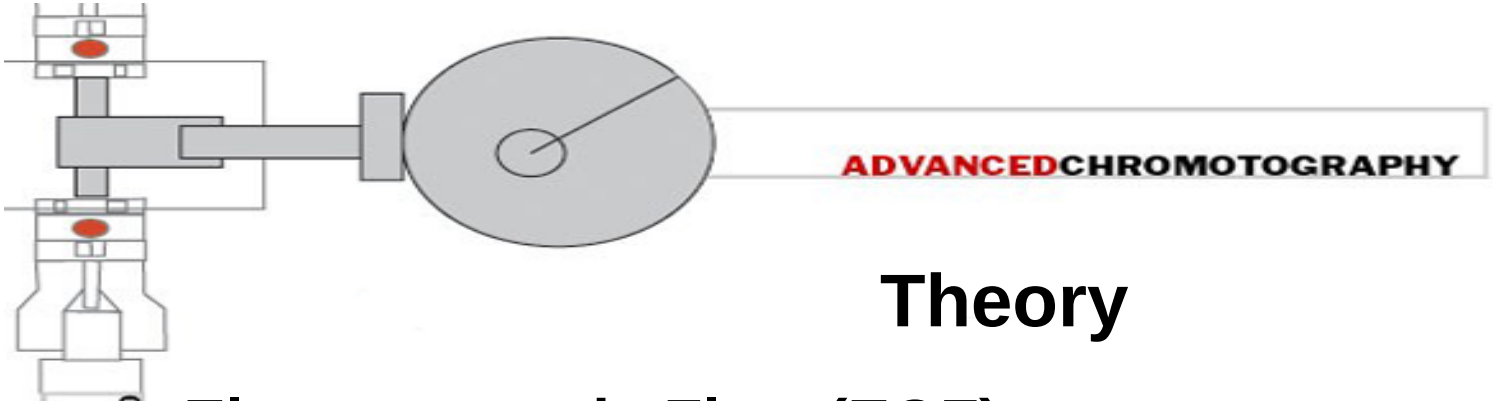


Fig. 2.2. Drawing of an electropherogram showing the order of migration due to electroosmotic flow and electrophoretic mobility. Small, highly charged cations are the first to elute from the capillary. Neutral solutes are not separated from each other. In this example, the outlet of the capillary is at the negatively charged cathode.



Theory

Electroosmotic Flow (EOF)

For fused silica capillaries - acidic silanol groups on the surface dissociate when in contact with an electrolyte solution:

SiOH(s) → SiO-(s) + H+(aq)

Hydrated cations in the electrolyte are attracted to the negatively charged SiO- groups.

When an electric field is applied - diffuse layer breaks away and moves toward the cathode - dragging with it the bulk solution of electrolyte (viscous drag).

This flow of the bulk solution is called electroosmosis.

Theory

Electroosmotic Flow (EOF)

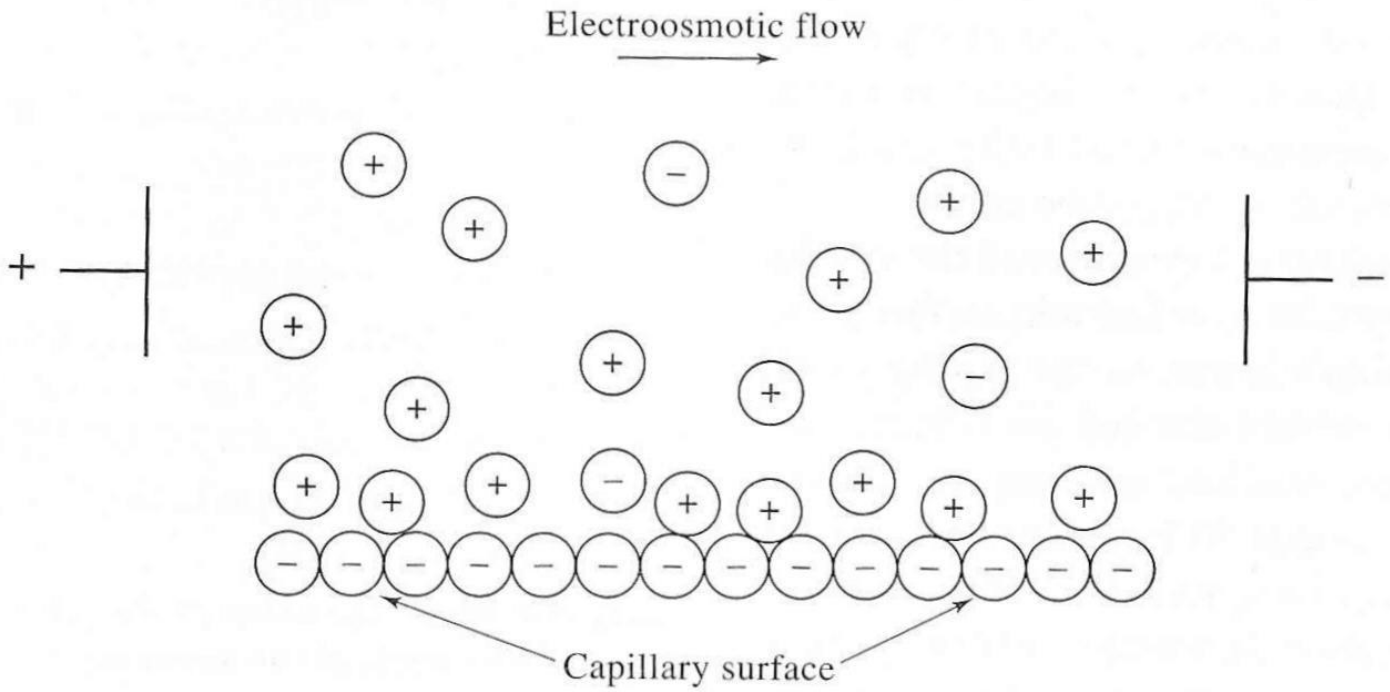


Figure 30-2 Charge distribution at a silica/capillary interface and resulting electroosmotic flow. *(From A. G. Ewing, R. A. Wallingford, and T. M. Olefirowicz,* Anal. Chem., ***1989,*** 61, *294A. With permission.)*

Theory

Electroosmotic Flow (EOF)

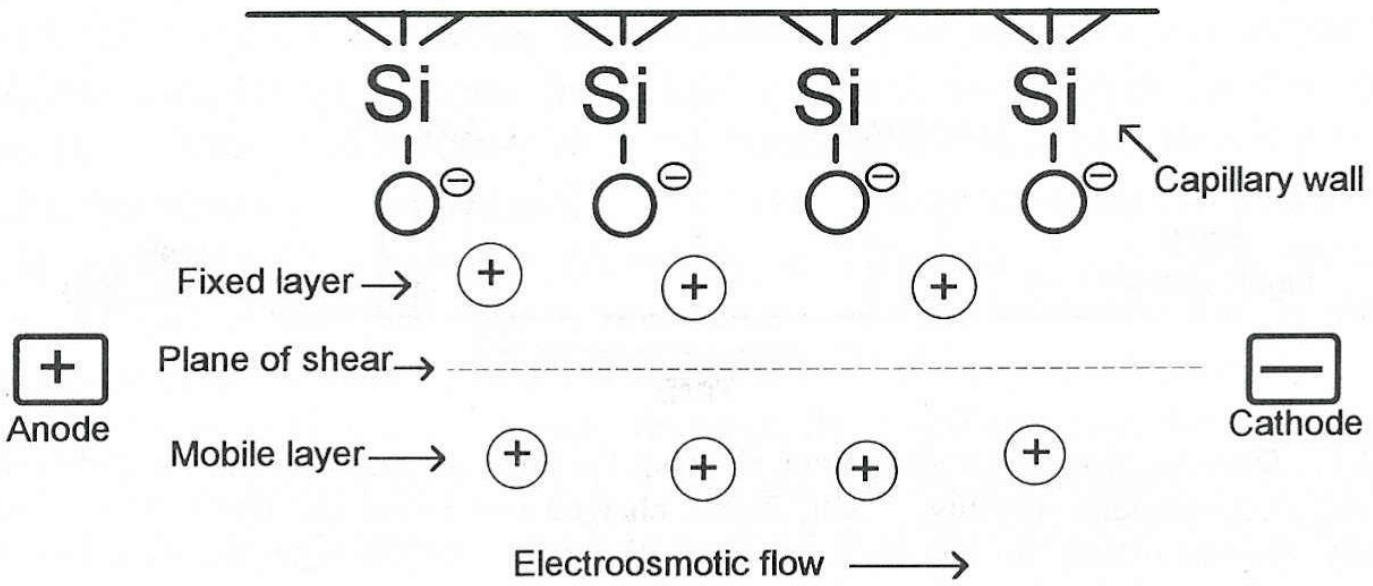
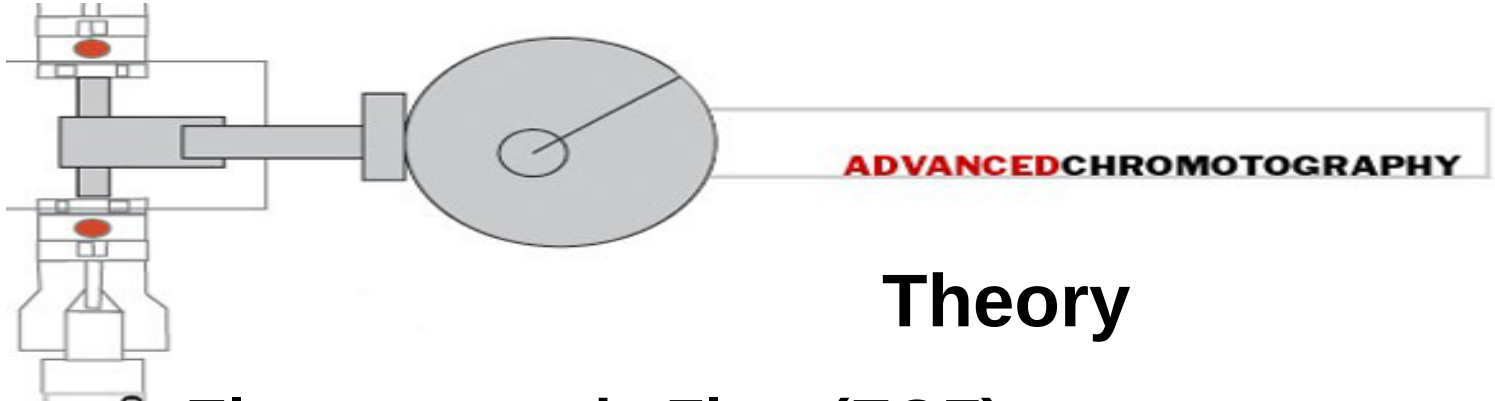


Fig. 2.3. Representation of electroosmotic flow in a capillary. Electroosmotic flow is caused by the negatively charged Si–O^- groups on the inner wall of the capillary attracting the positively charged cations, represented by the circled +'s, forming the fixed layer. The mobile layer of cations is pulled toward the cathode, dragging the bulk buffer solution with it. The anions and the solvation of the cations are not shown.



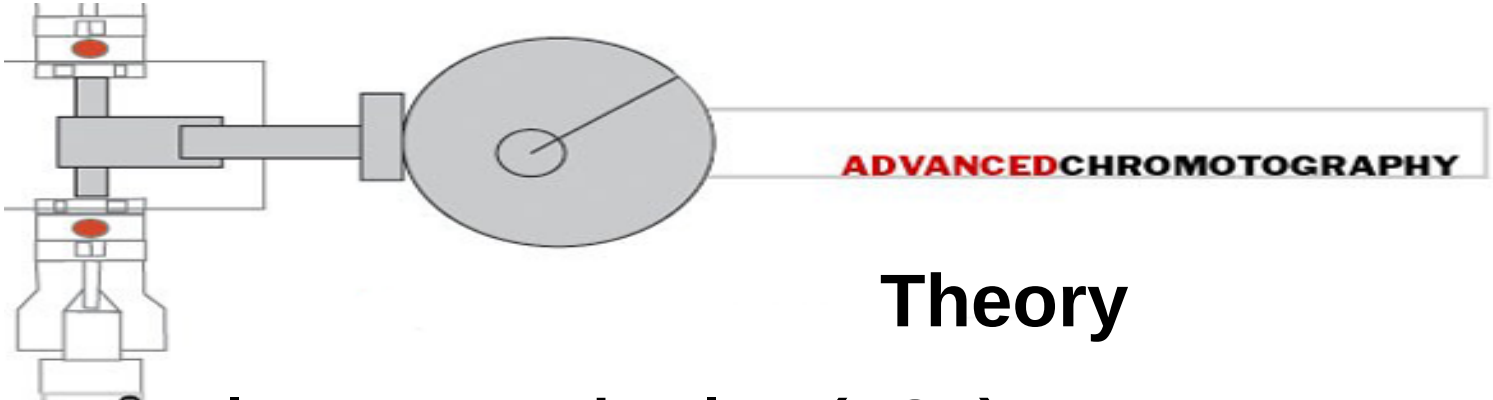
Theory

Electroosmotic Flow (EOF)

Between the 2 layers is the shear plane where there is a potential difference known as the zeta potential.

Electroosmotic flow is proportional to the thickness of the double layer.

The thickness of the double layer is inversely proportional to the concentration of the buffer, 10 mM concentration gives a 1nm thick layer.



Theory

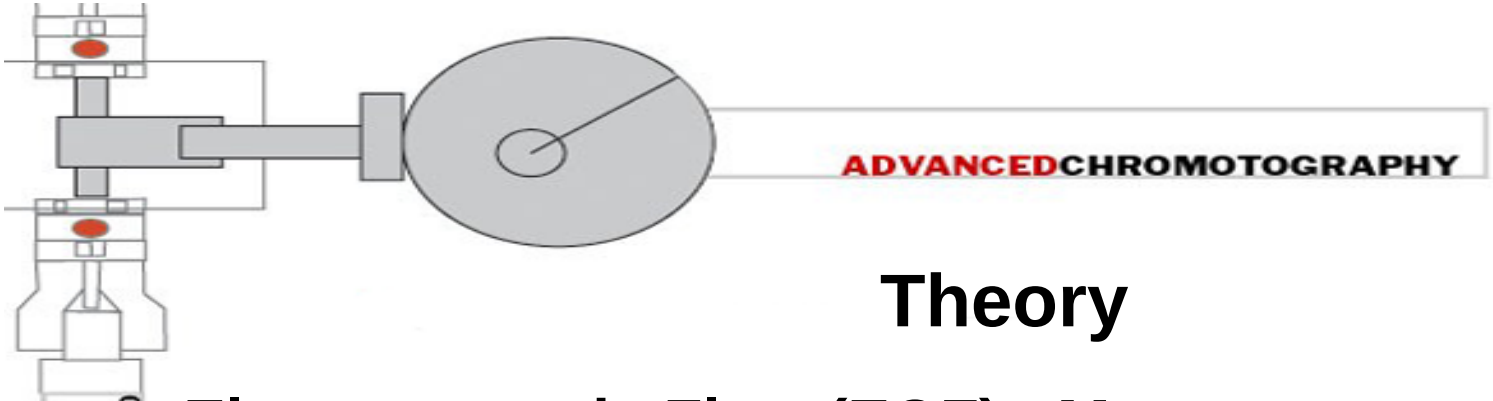
Electroosmotic Flow (EOF) - Measurement of Electroosmosis Flow

To calculate electrophoretic mobility of an analyte - need to know contribution from the electroosmotic flow to the mobility.

Common way - record the migration time of an injected uncharged marker solute - which is carried to detector only under EOF.

For a neutral marker: $\mu_{eo} = 1/Et$

t - time for the marker to migrate to the detector
E - electric field

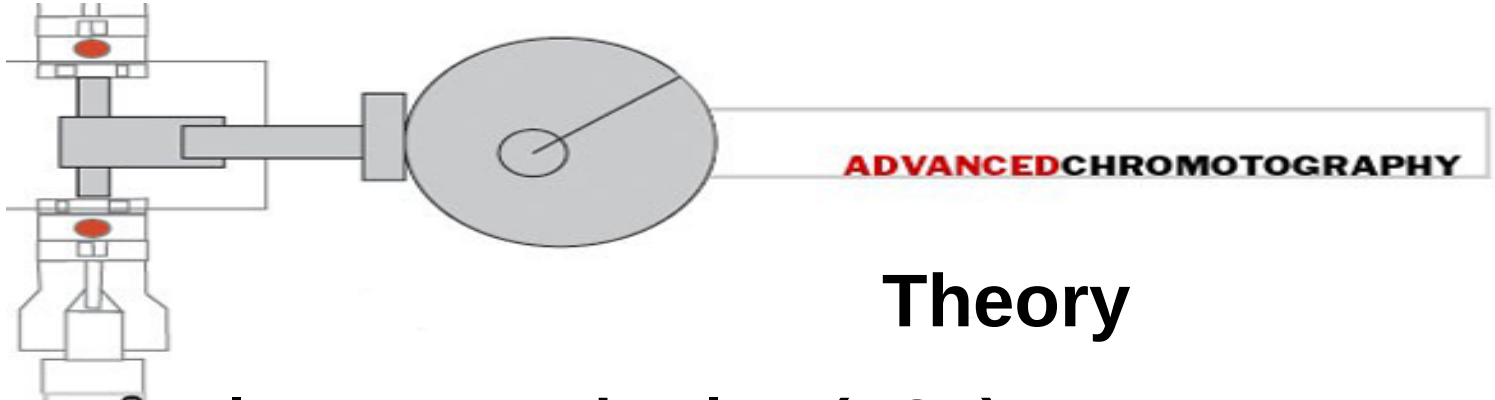


Theory

Electroosmotic Flow (EOF) - Measurement of Electroosmosis Flow

Example of neutral markers: methanol, acetone, benzene, dimethyl sulfoxide

Disadvantage: may have adsorption of marker on wall.



Theory

Electroosmotic Flow (EOF) - Measurement of Electroosmosis Flow

Alternative method:

-Fill capillary & receiving vial with buffer at concentration ,C

-Injection vial filled with buffer at 0.95C is pulled into capillary by applied voltage.

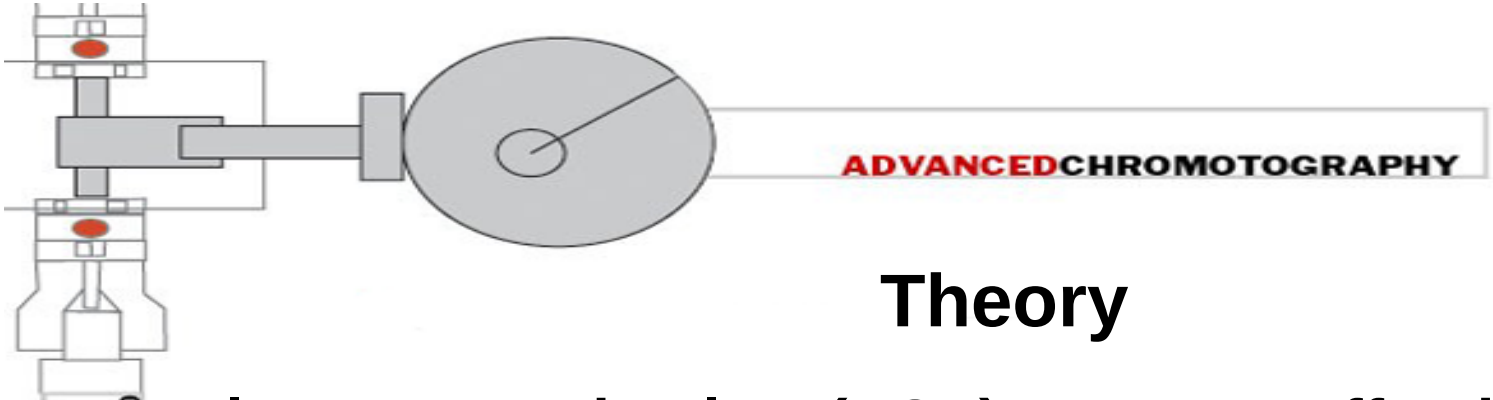
-since injection buffer is more dilute, the current will fall as buffer fills capillary.

-time for current to stabilize, Δt, represents the complete filling of the capillary.

$$\upsilon_{eo} = L/\Delta t$$

L - length of capillary

υ_{eo} - electroosmotic flow rate.



Theory

Electroosmotic Flow (EOF) - Factors affecting Electroosmotic Flow

Speed of EOF is related to the magnitude of the "zeta potential"

ξ-- potential at the sheer plane

Zeta potential depends on the nature of the solid surface and the ionic state of the liquid.

Polar solvents-i.e. - water-give a high ξ value (~100 mV) when in contact with polar surfaces.

Non-polar, non-conducting solvents-
i.e. heptane – do not exhibit zeta potentials

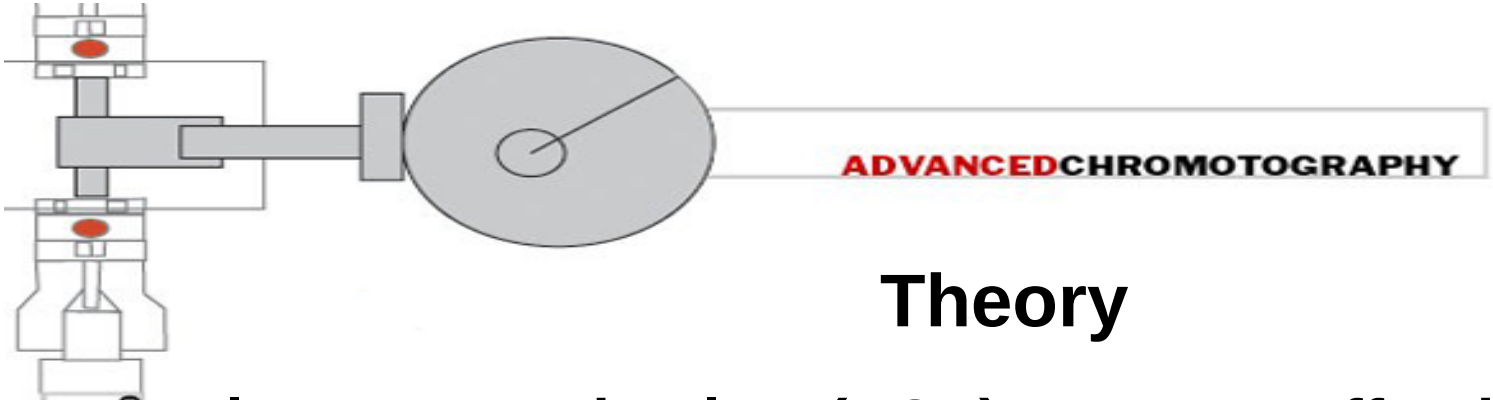
Theory

Electroosmotic Flow (EOF) - Factors affecting Electroosmotic Flow

Effect of pH

Acidic silanol groups at surface of capillary wall dissociate when in contact with solution.

At high pH – silanol groups are fully ionized, generating a dense compact layer and increasing zeta potential.



Theory

Electroosmotic Flow (EOF) - Factors affecting Electroosmotic Flow

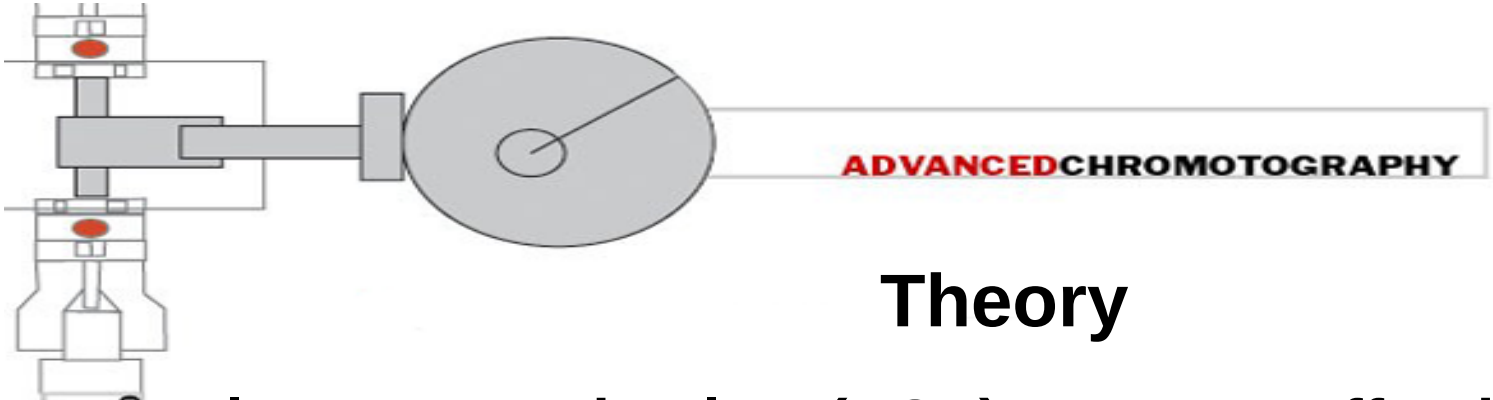
Effect of Ionic Strength

Dependence of mobility on ionic strength (or concentration):

$$\mu = e/(3x10^7)\,|z|\,\eta C^{1/2}$$

z - # of valence electrons
e - total excess charge in solution per unit area
C - buffer concentration
η - viscosity

As buffer concentration mobility of EOF ↓



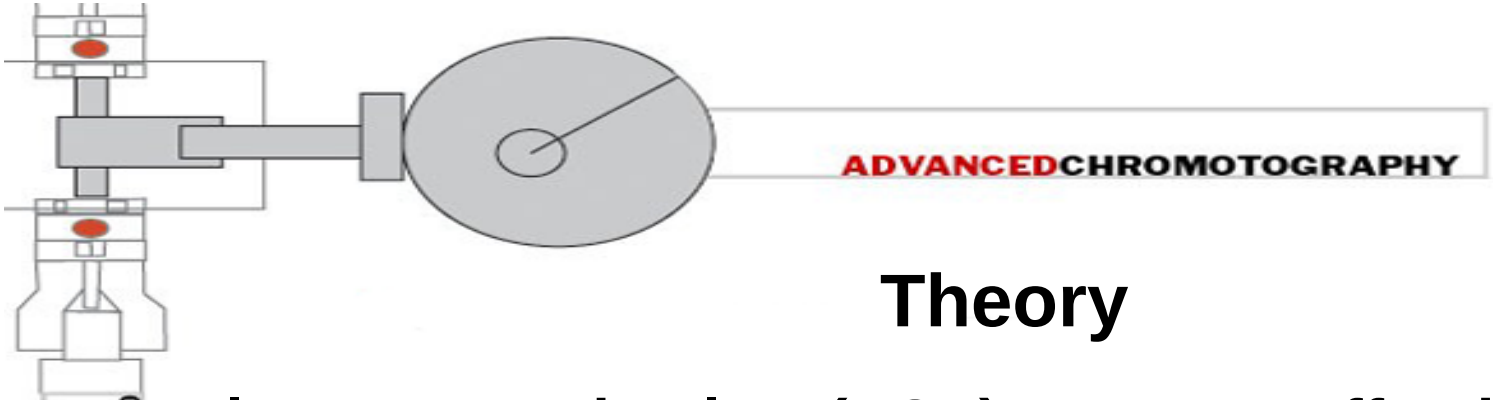
Theory

Electroosmotic Flow (EOF) - Factors affecting Electroosmotic Flow

Effect of organic solvent

Addition of organic modifier alters the viscosity of the buffer.

Tends to $\downarrow \mu_{eo}$



Theory

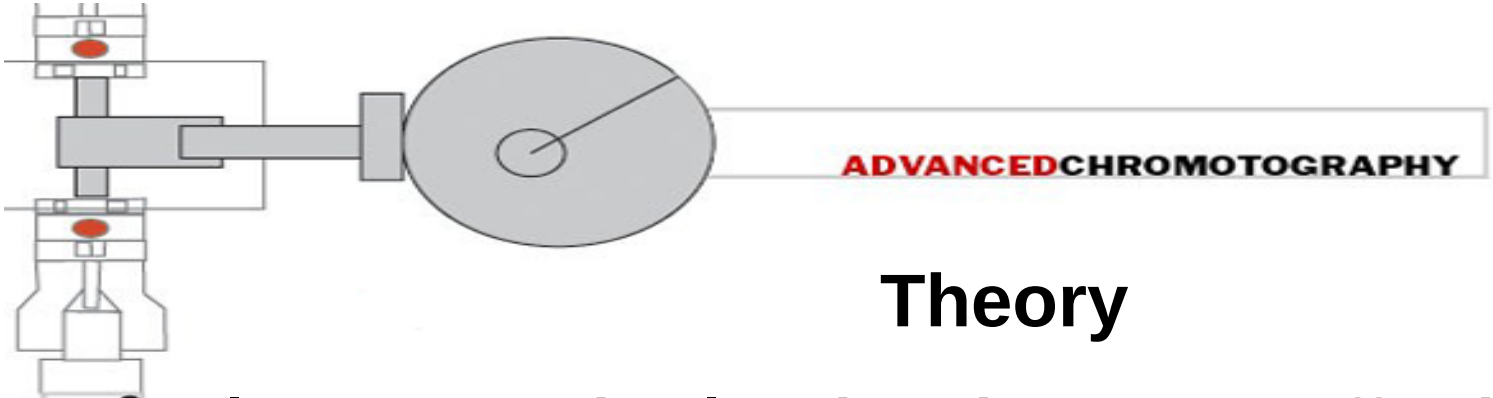
Electroosmotic Flow (EOF) - Factors affecting Electroosmotic Flow

Effect of Buffer cation & Buffer anion

EOF is proportional to potential drop across the diffuse layer of counterions.

Highest mobility obtained with smallest cations.

Buffer anions affect mobility but do not seem to show any trend.



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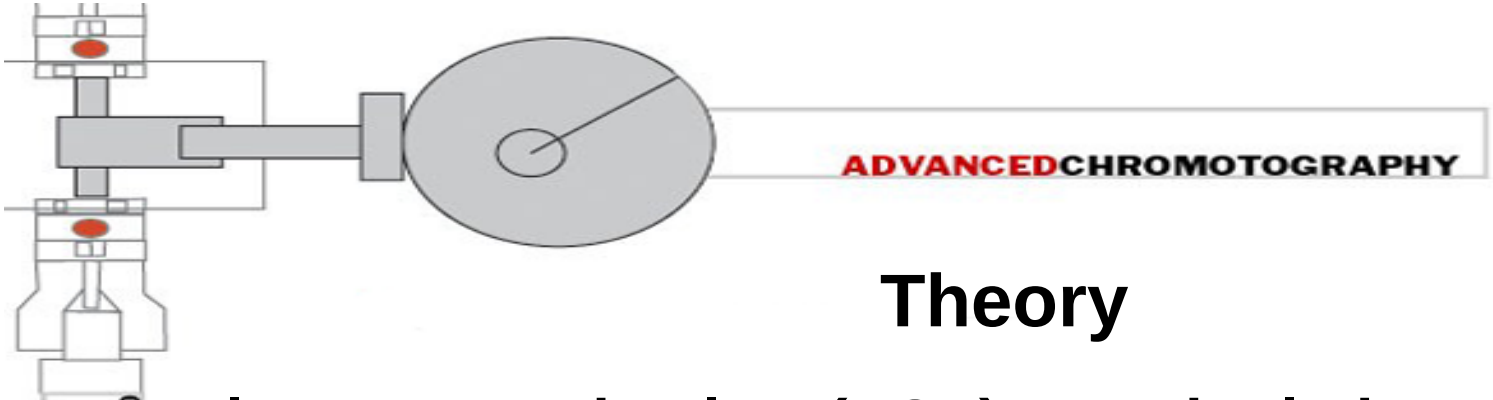
Theory

Electroosmotic Flow (EOF) - Factors affecting Electroosmotic Flow

Applied Voltage

Mobility of EOF increases with increasing applied voltage.

But this affect is due mainly to increasing temperature (joule heating).

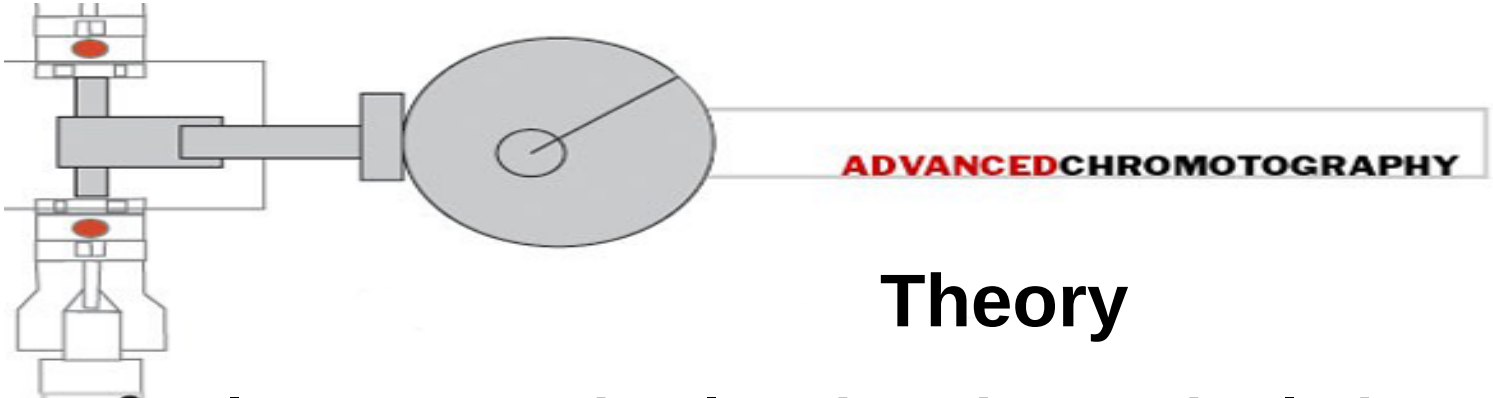


Theory

Electroosmotic Flow (EOF) - Manipulation of Electroosmotic flow

Ways to suppress or reduce electroosmotic flow include:

-coating (deactivating) the capillary walls with polymers (difficult to get uniform coatings)
-adding chemical reagents to the solution to reduce solute-capillary action.

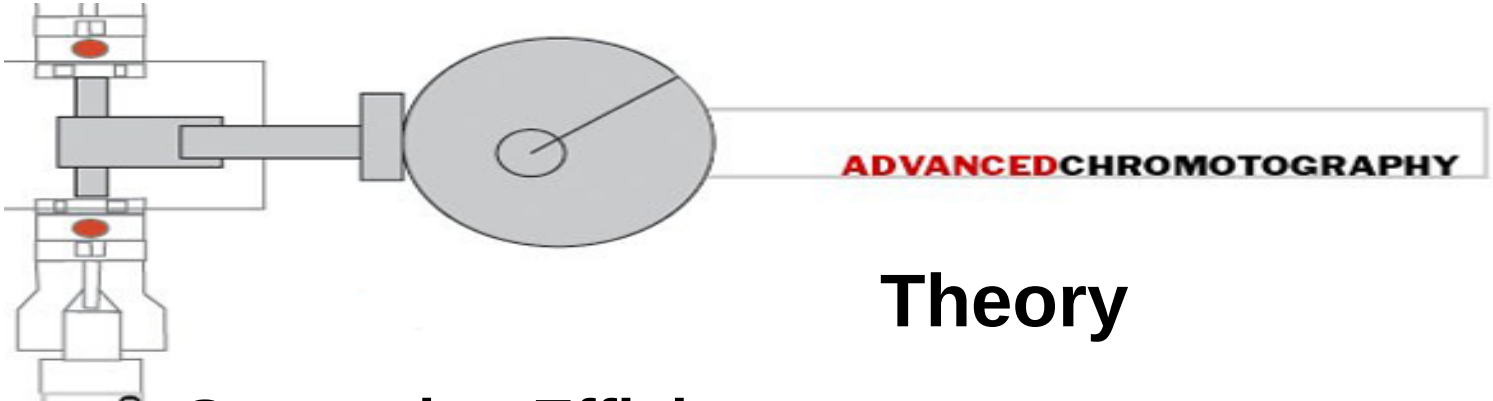


Theory

Electroosmotic Flow (EOF) - Manipulation of Electroosmotic flow

Overall – to cause changes in EOF: (mobility factor)

- **increase voltage - increase EOF**
- **increase electrolyte pH - increase EOF (for SiOH capillary walls)**
- **increase concentration of electrolyte - decrease EOF**
- **increase temperature - increase EOF**
- **add organic solvent - increase or decrease EOF - depends on η, ε, & zeta potential**
- **modify capillary wall - decrease or reverse EOF**
- **add surfactants - decrease or reverse EOF**



Theory

Separation Efficiency

EOF affects time solute resides in capillary

Efficiency & resolution are related to the direction & flow of the EOF

The EOF profile is “plug” like.

Theory

Separation Efficiency

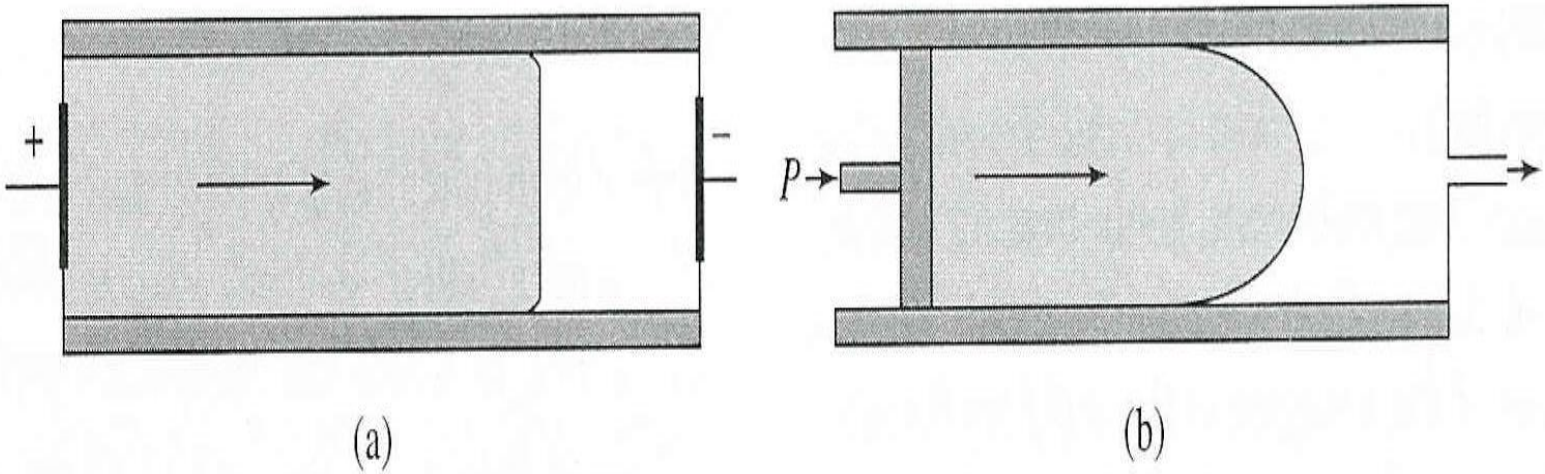
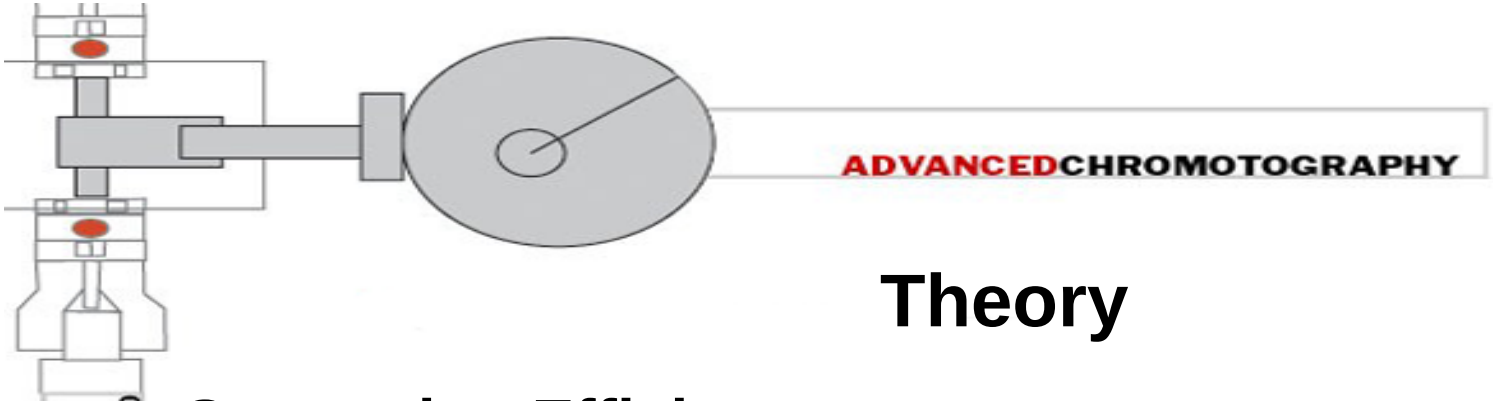


Figure 30-3 Flow profiles for liquids under (a) electroosmotic pressure and (b) hydrodynamic pressure.



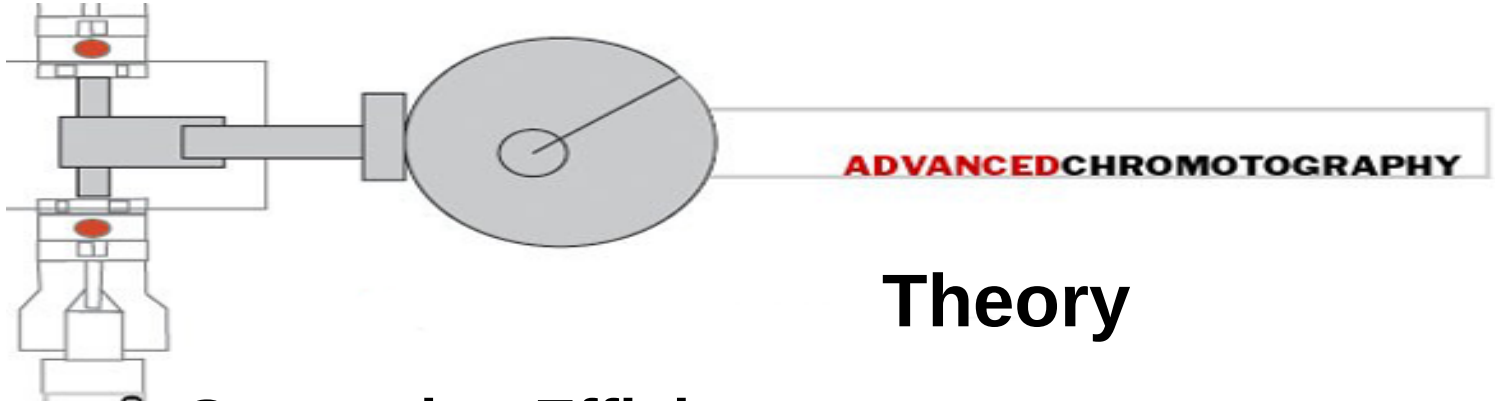
Theory

Separation Efficiency

Migration time of a solute to migrate from injection to detection is:

$$t = l/\upsilon = l/\mu E = Ll/\mu V$$

l - total length of capillary
L - length of capillary with charge applied ($l \approx L$)
μ - mobility
E - electric field (V/L)
V - applied voltage



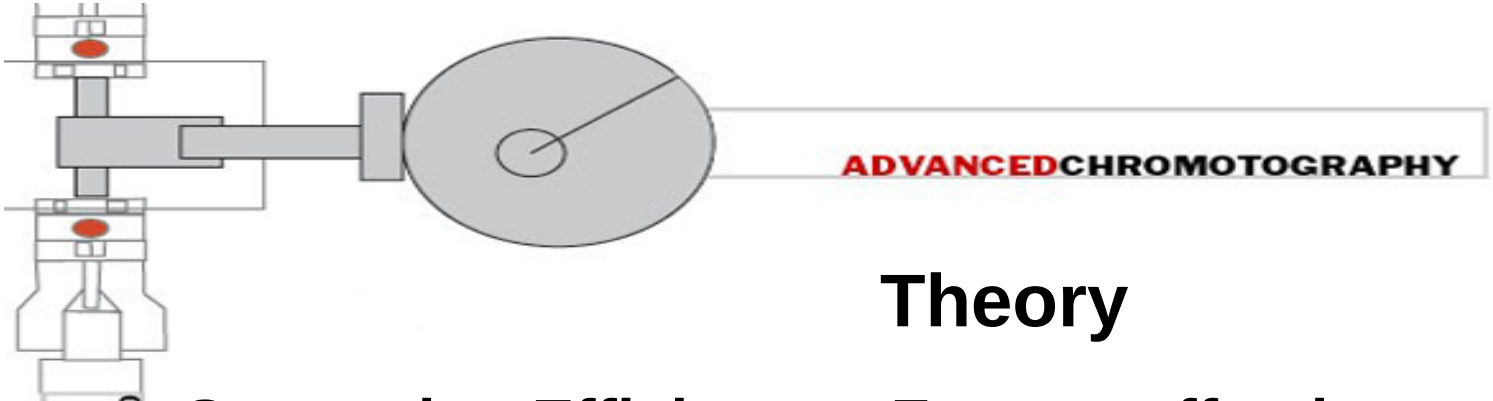
Theory

Separation Efficiency

Efficiency is expressed in the number of theoretical plates

$N = 16(t/w)^2$
w - peak width at base

$N = \mu V/2D$
D - solute diffusion coefficient (zone broadening)



Theory

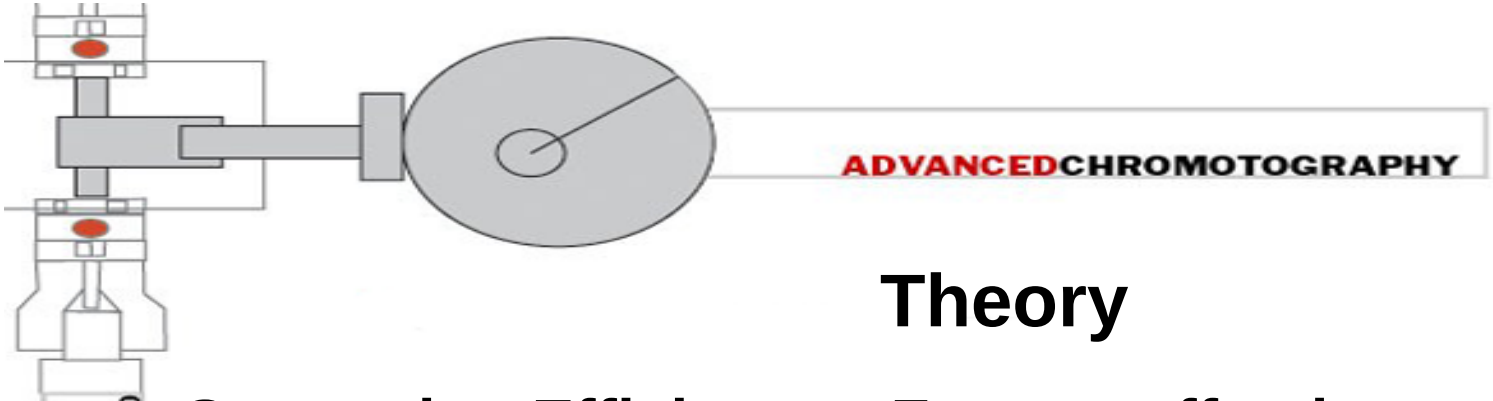
Separation Efficiency - Factors affecting separation efficiency

Injection length (volume-injection)

Volume of sample plug introduced into capillary may affect efficiency

At small injection lengths - zone length is determined by diffusion

At large injection length - diffusion is not important - zone length determined by injection length



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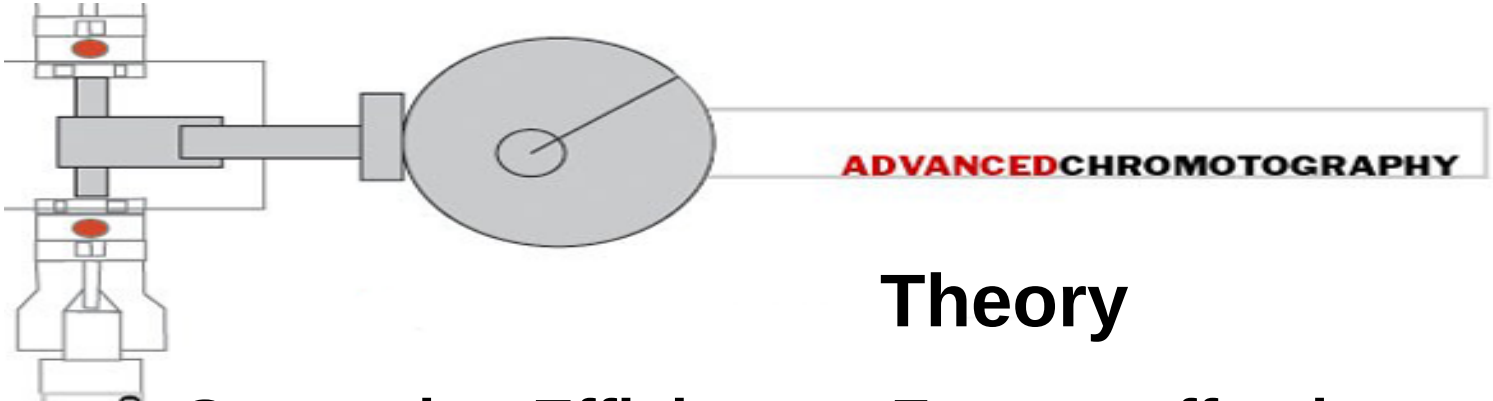
Theory

Separation Efficiency - Factors affecting separation efficiency

Diffusion

Eddy (A), longitudinal (B), resistance to mass transfer (C)

For CE - no A - no packed capillaries
- no C - no transfer between a stationary and liquid or liquid and gas phase
B - only source of zone broadening



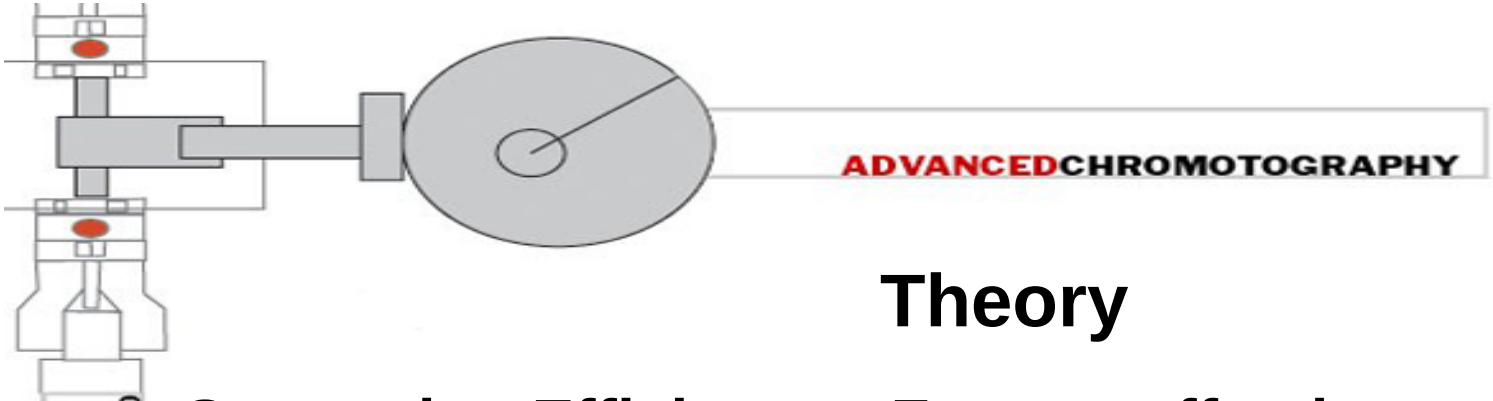
Theory

Separation Efficiency - Factors affecting separation efficiency

Joule Heating

If high voltages are applied to minimize diffusion excessive band broadening may occur because of joule heating of the liquid inside the capillary.

Joule heating - heat generated by collisions between solute and electrolyte ions as a result of the conduction of electric currents.



CHEM5390

Theory

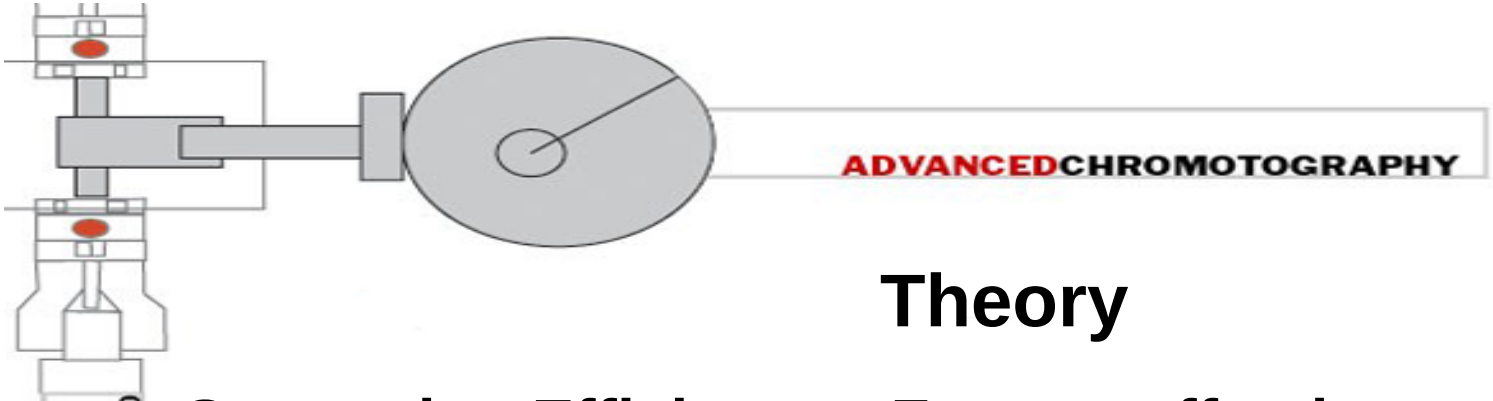
Separation Efficiency - Factors affecting separation efficiency

Joule Heating

Since capillary is cooler at the outside than inside, the viscosity of the electrolyte can be lower in the center.

Viscosity decreases ~2.7% per degree Celsius, and the migration velocity of the analytes will be higher.

Smaller diameter capillary give more efficient separations.



Theory

Separation Efficiency - Factors affecting separation efficiency

Joule Heating

How to determine the best voltage for a set of conditions?

Ohm's law plot - plot voltage versus current

A deviation from linearity shows that the temperature removal capacity of the system has been exceeded.

Theory

Separation Efficiency - Factors affecting separation efficiency

Joule Heating

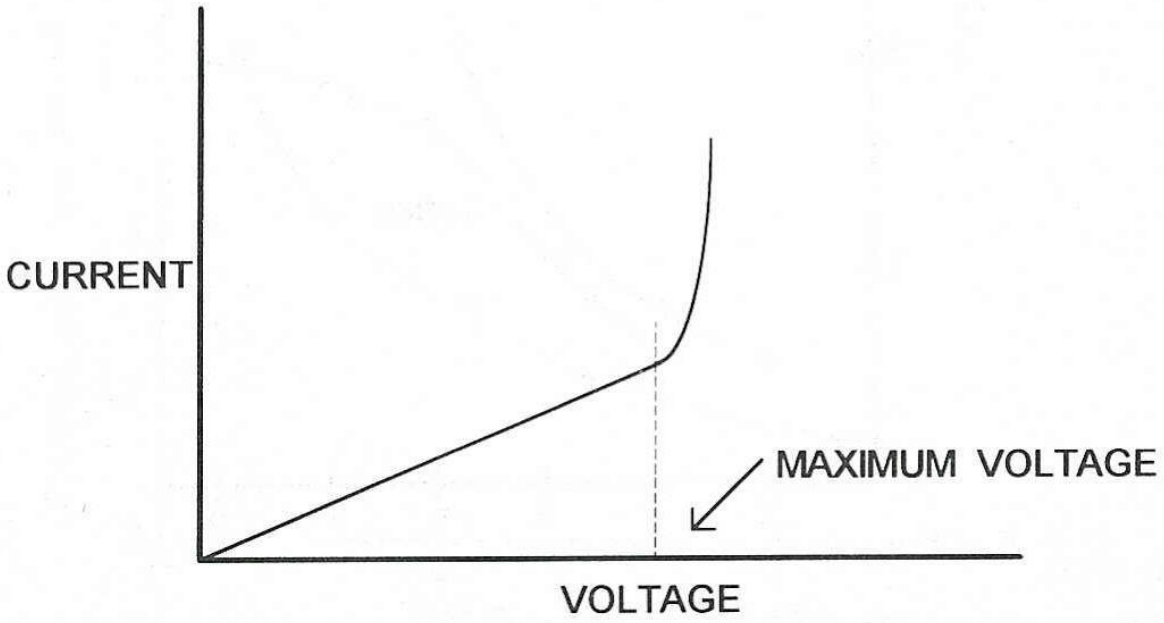
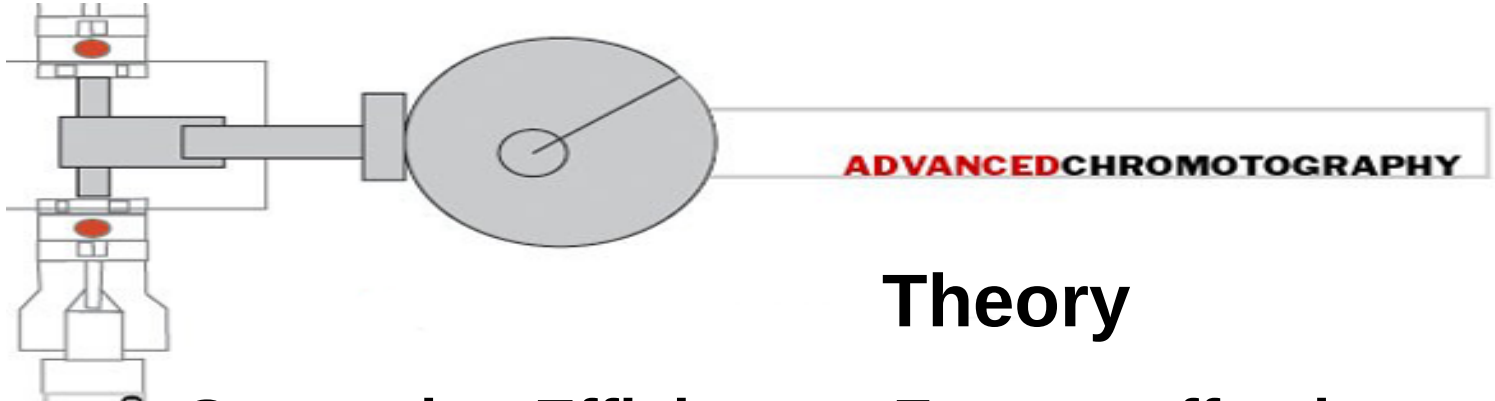


Fig. 2.6. Ohm's law plot. The voltage indicated by the dashed line is the maximum voltage that should be used.



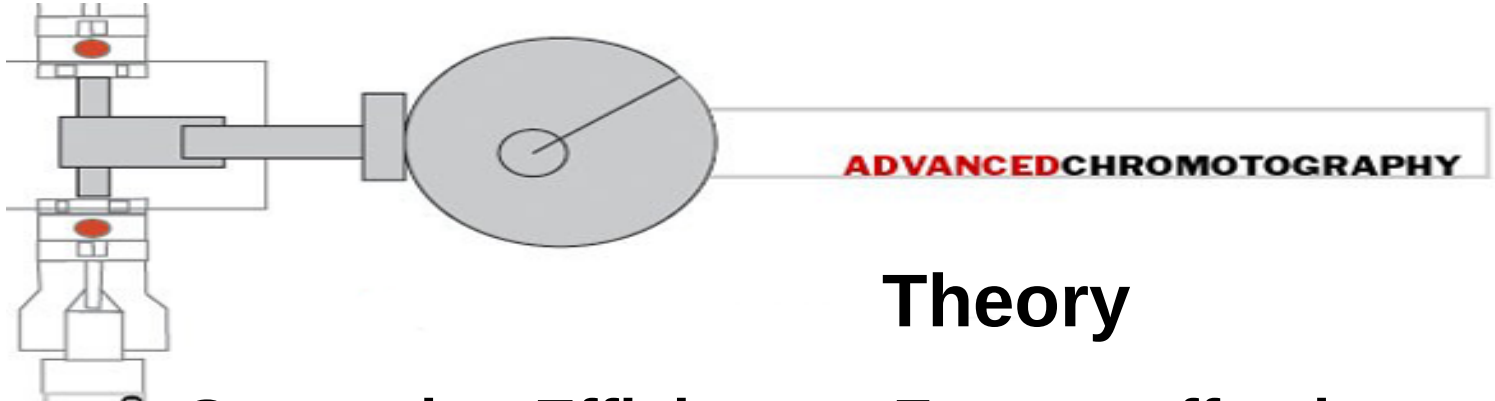
Theory

Separation Efficiency - Factors affecting separation efficiency

Solute - Wall interactions

Interaction between solute and the capillary walls leads to band broadening, peak tailing, and irreproducibility.

Primary causes of adsorption:
-hydrophobic interactions
-ionic interactions between cations solutes (i.e. proteins) and SiO- groups.



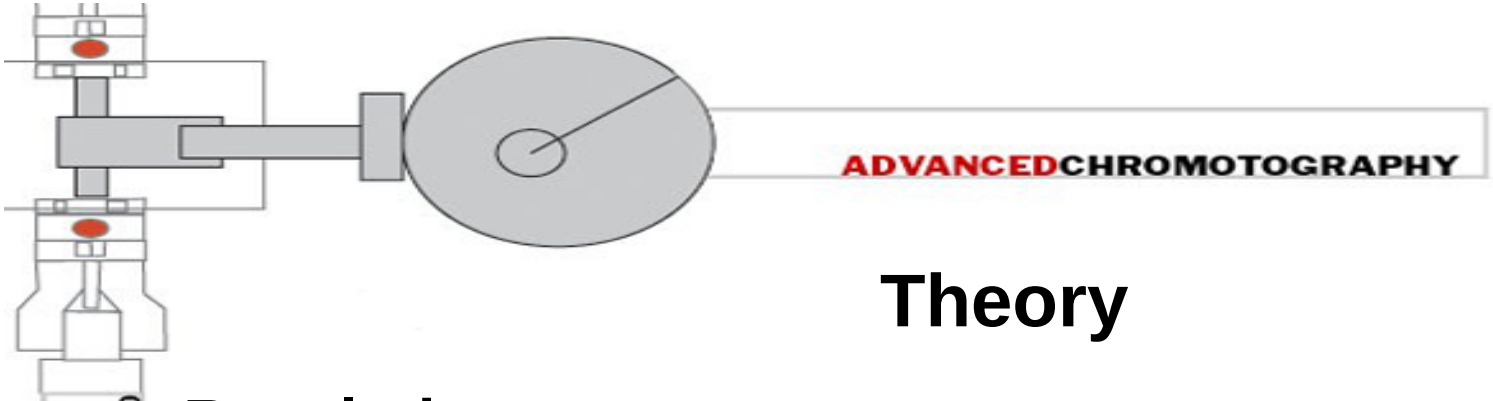
Theory

Separation Efficiency - Factors affecting separation efficiency

Solute - Wall interactions

Reduce interactions by:

- **coating capillary wall (drawback: uneven coating)**
- **increase ionic strength (competition adsorption sites) (drawback: increase ionic strength need decreasing voltage to avoid joule heating)**
- **use extreme pH's (pH 1.5 - silanol groups are not ionized).**



Theory

Resolution

Function of selectivity, column efficiency, and migration time.

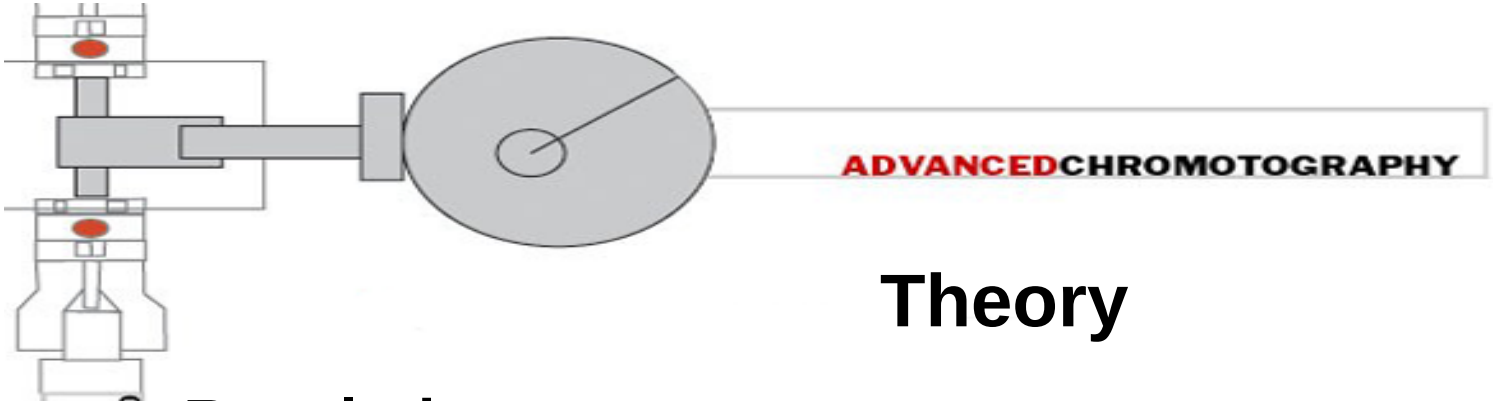
These are influenced by: applied voltage, pH, ionic strength, capillary wall.

pH major factor to manipulate resolution

Resolution, Rs

$$Rs = 2(t_2 - t_1)/w_1 + w_2$$

t - migration time
w - baseline width



Theory

Resolution

Define resolution in terms of efficiency:

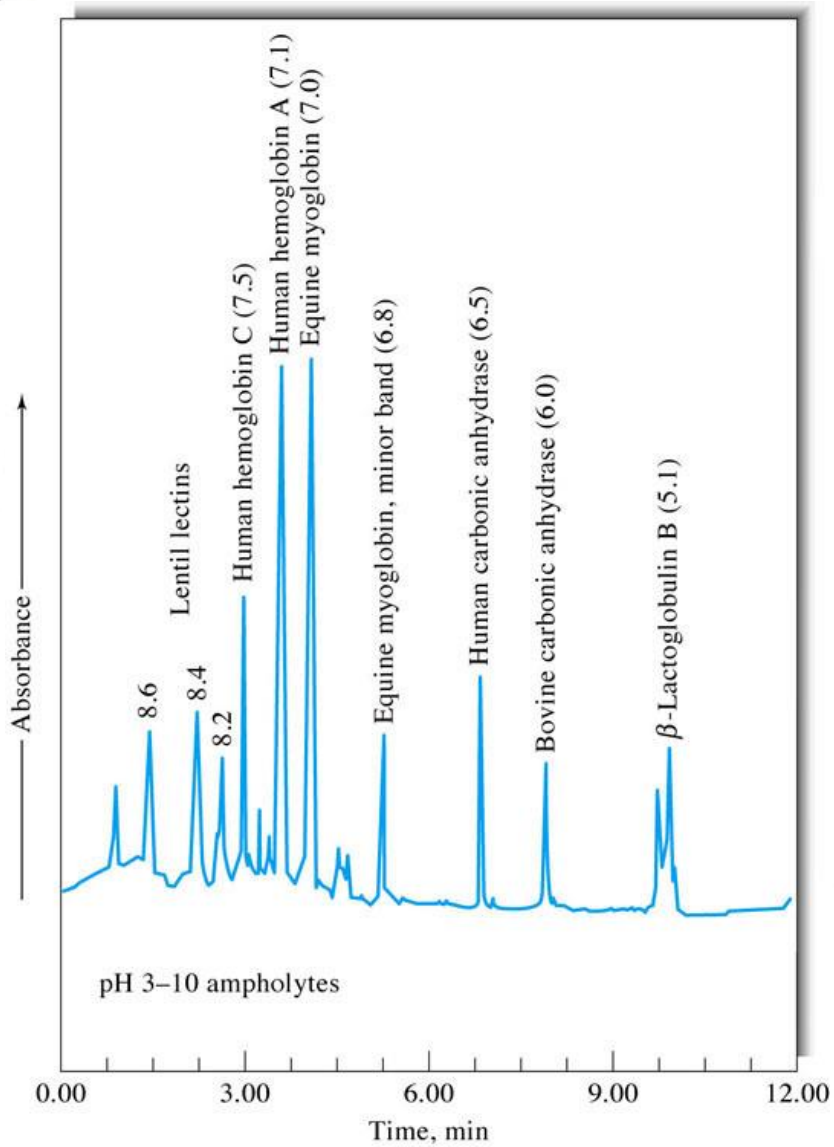
$$Rs = l(\mu_2 - \mu_1) N^{1/2} / 4(\mu + \mu_{eo})$$

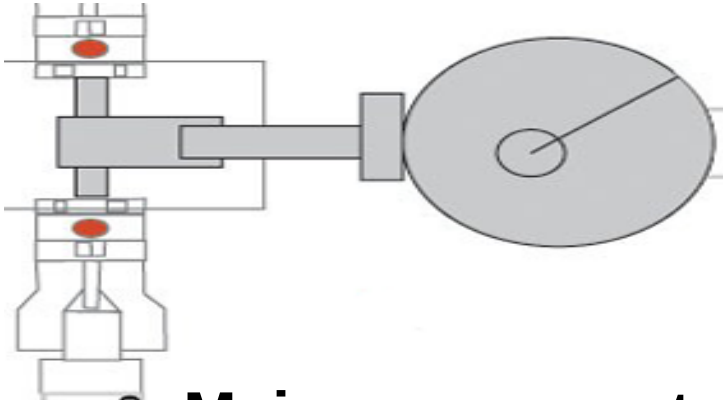
$$Rs = 0.177 (\mu_2 - \mu_1) [V/D(\mu + \mu_{eo}]^{1/2}$$

Increasing V is not efficient way to affect resolution
Voltage must be quadrupoled to double resolution.

Typically operating voltages for CE are between 10 – 30 kV
(because of joule heating - not a large range)

Resolution





Instrumentation

Main components:

- high-voltage supply
- source and destination vials
- capillary
- detector

Instrumentation

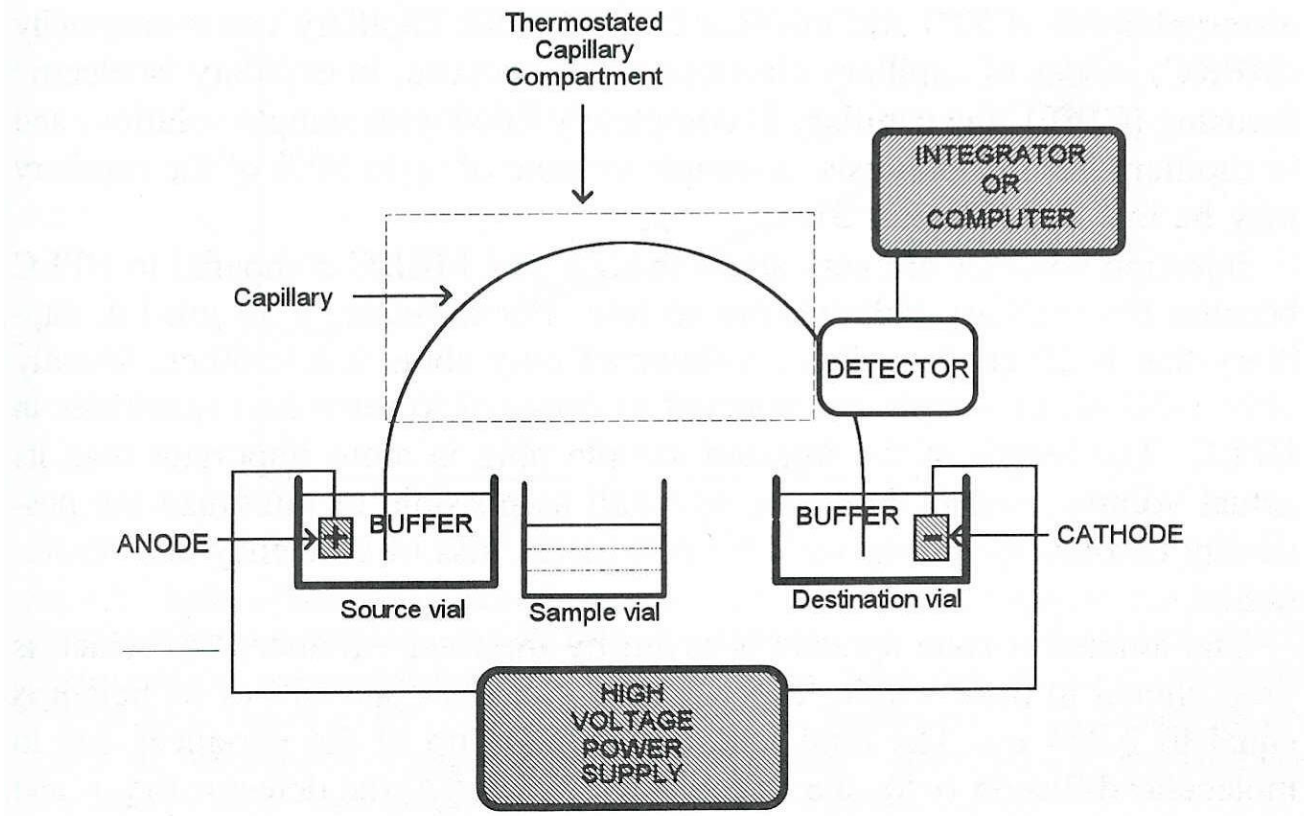
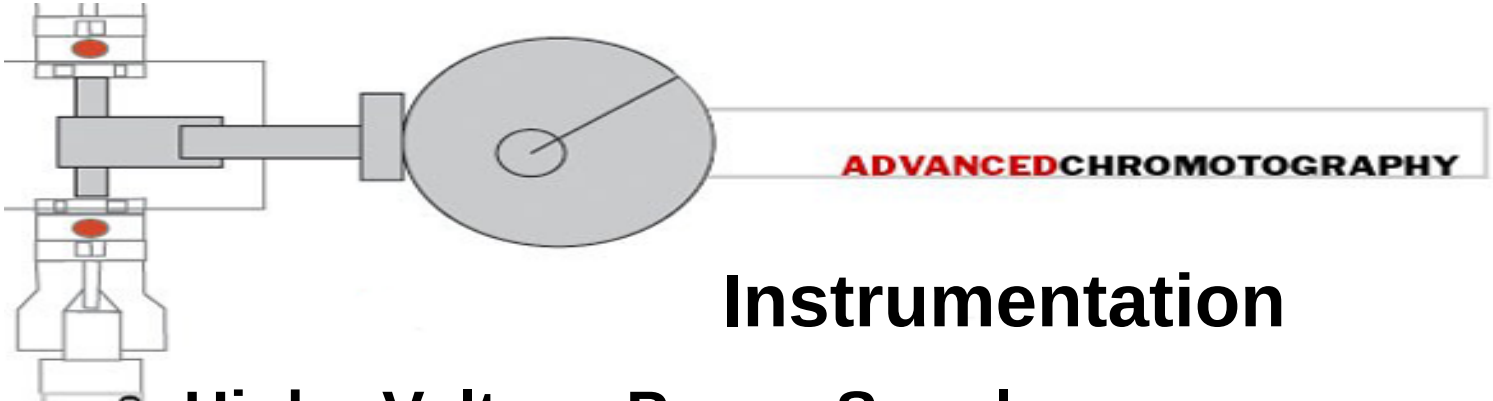


Fig. 4.1. Drawing of the main components of a capillary electrophoresis system. The capillary inlet is in the source vial and the outlet in the destination vial. For an injection, the capillary inlet and anode are placed in the sample vial.



Instrumentation

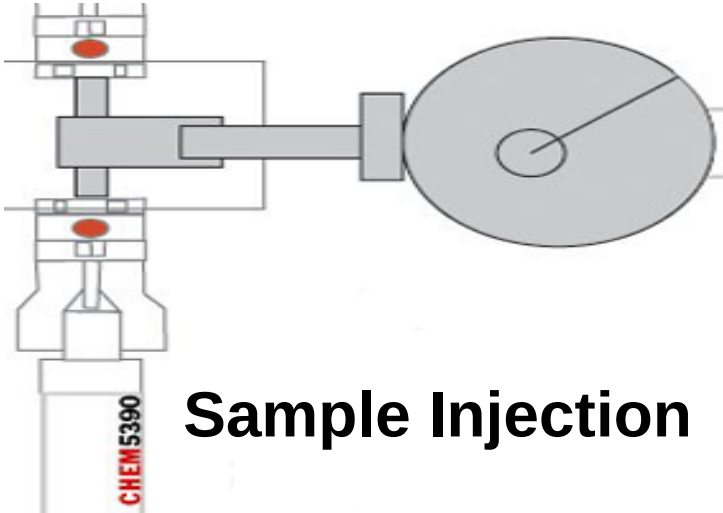
High - Voltage Power Supply

Provides electric field to establish EOF of bulk solution and electromigration of the charged analytes.

Most power supplies provide ~-30 kV to +30 kV with current levels of ~200-300 µA.

Since detector end must be anodic or cathodic - needs to be possible to switch polarity.

For CE - stable voltage regulation is important to maintain migration time reproducibility.



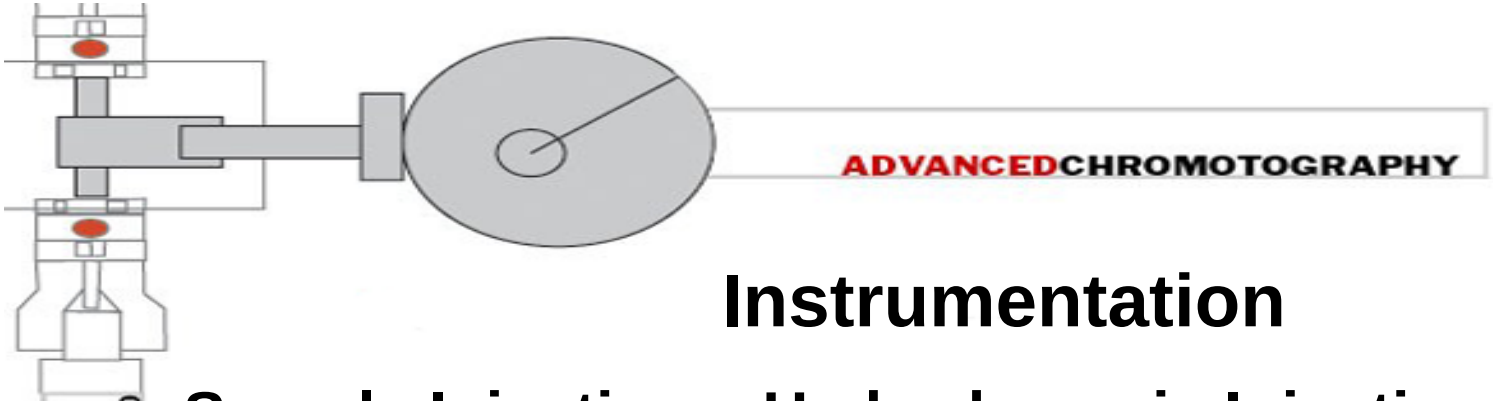
Instrumentation

Sample Injection

Unlike GC or HPLC, the sample is loaded into the capillary while there is no flow of buffer through the capillary.

There are several injection methods:

- hydrodynamic or hydrostatic
- electrokinetic or electromigration



Instrumentation

Sample Injection – Hydrodynamic Injection

Use either pressure or gravity.

Pressure injection by simply applying pressure to the vial.

Pressure injections can also be made by applying a vacuum to the destination valve.

Gravity injection done be simply raising the sample vial above the destination vial.

Instrumentation

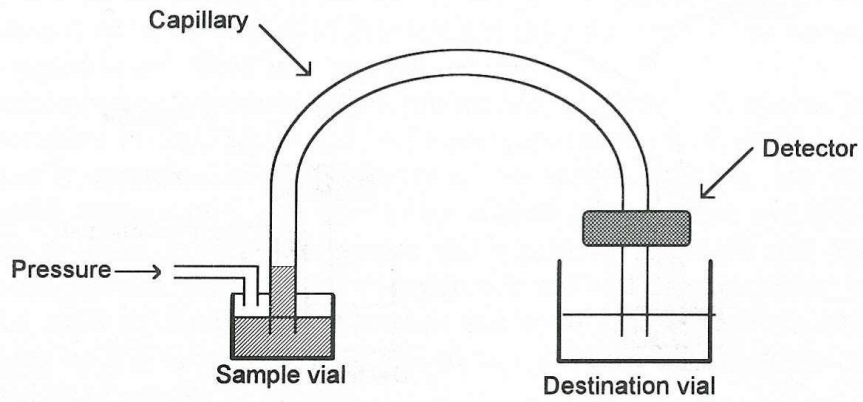


Fig. 4.3. Hydrodynamic injection by pressure. The sample vial is pressurized, forcing the sample solution into the capillary. The volume of sample injected depends on the magnitude and duration of pressure applied, sample solution viscosity, and capillary dimensions. After injection, the capillary is placed back into the source vial and an electric field applied.

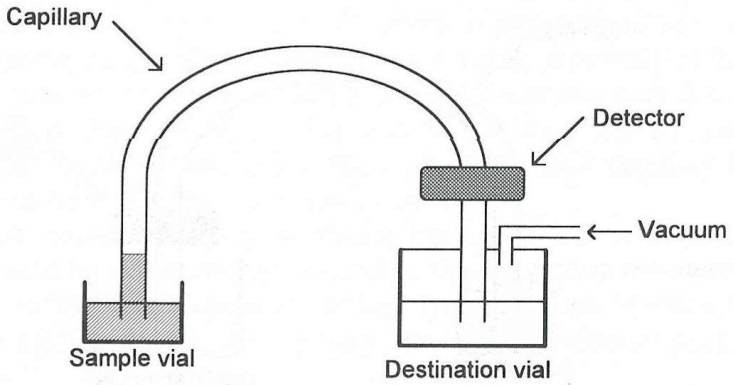


Fig. 4.4. Hydrodynamic injection by vacuum. A vacuum is applied to the destination vial, pulling the sample solution into the capillary. The volume of sample injected depends on the magnitude and duration of vacuum applied, sample solution viscosity, and capillary dimensions. After injection, the capillary is placed back into the source vial and an electric field applied.

Instrumentation

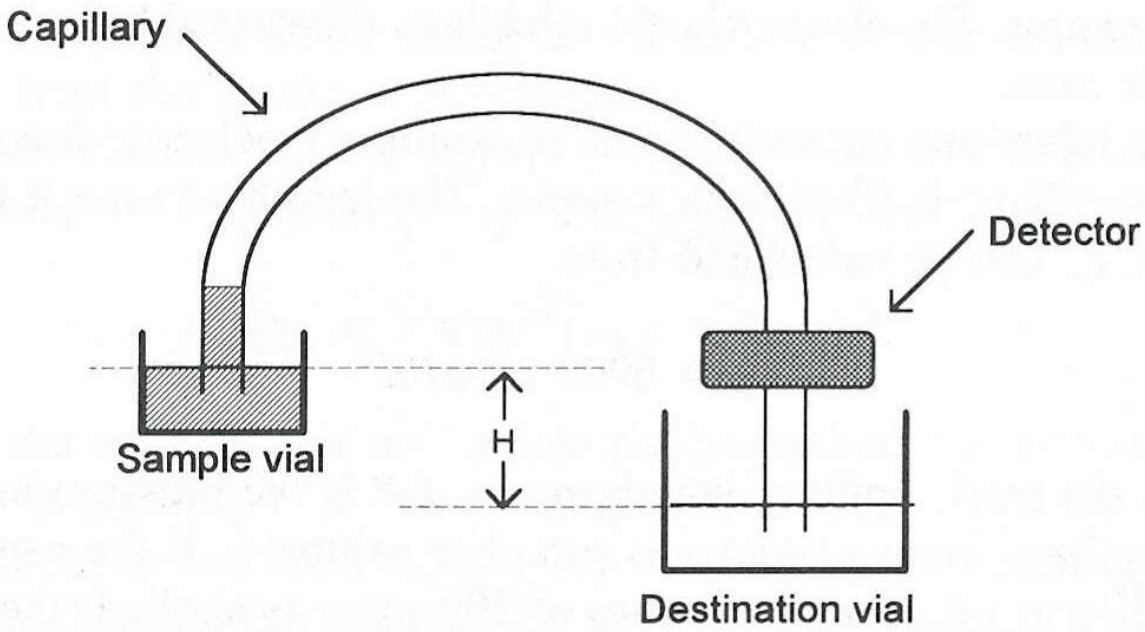
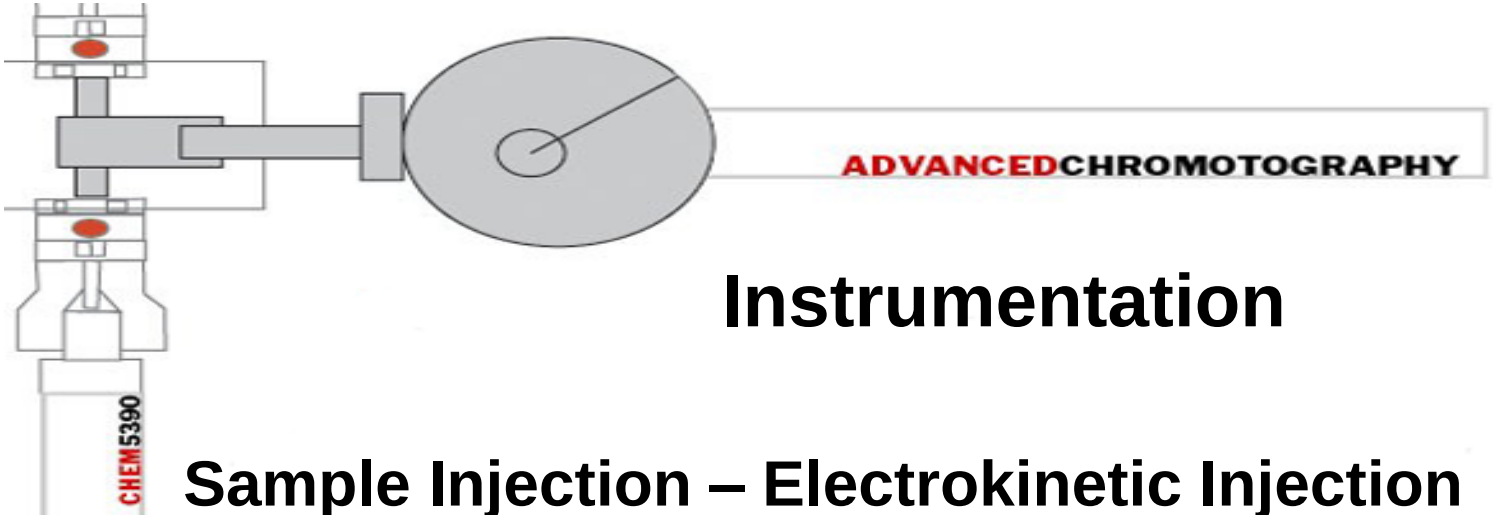


Fig. 4.5. Hydrodynamic injection by gravity (also called siphoning). The capillary is placed into the sample vial, and the vial and capillary are raised a distance, *H*, above the destination vial, causing the sample solution to siphon into the capillary. The volume of sample injected depends on *H*, the length of time the vial is raised, capillary dimensions, and the sample solution viscosity. After injection, the capillary is placed back into the source vial and an electric field applied.



Instrumentation

Sample Injection – Electrokinetic Injection

The capillary and the anode are placed into a sample vial and a voltage is applied for a given period of time.

After the sample is introduced, the anode and capillary are placed back into the source vial, an electric field is applied and electrophoresis continues.

Instrumentation

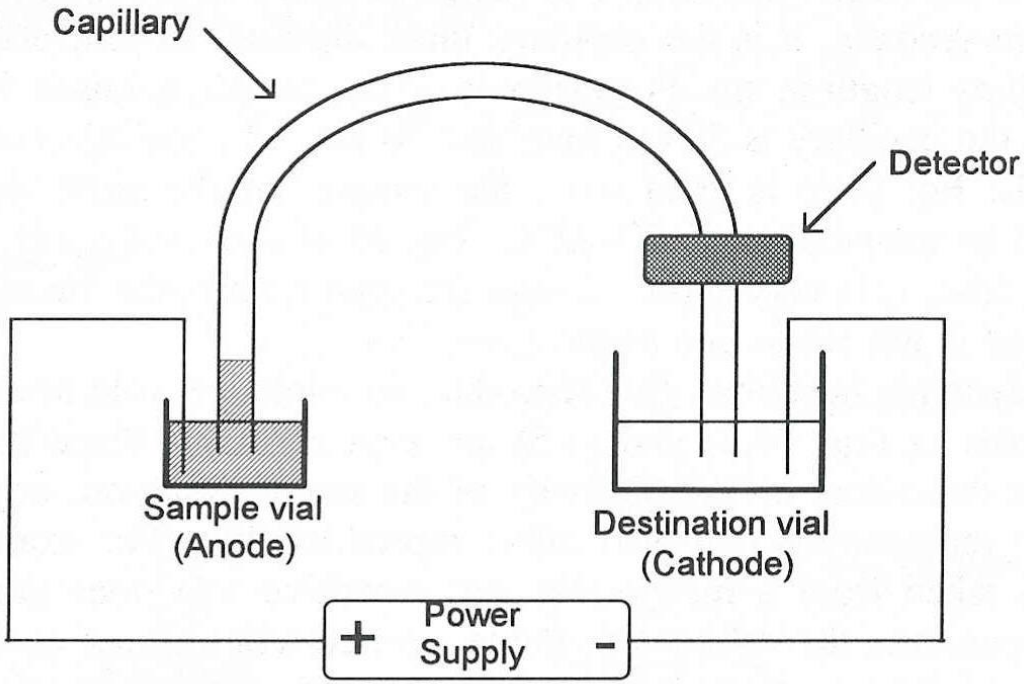
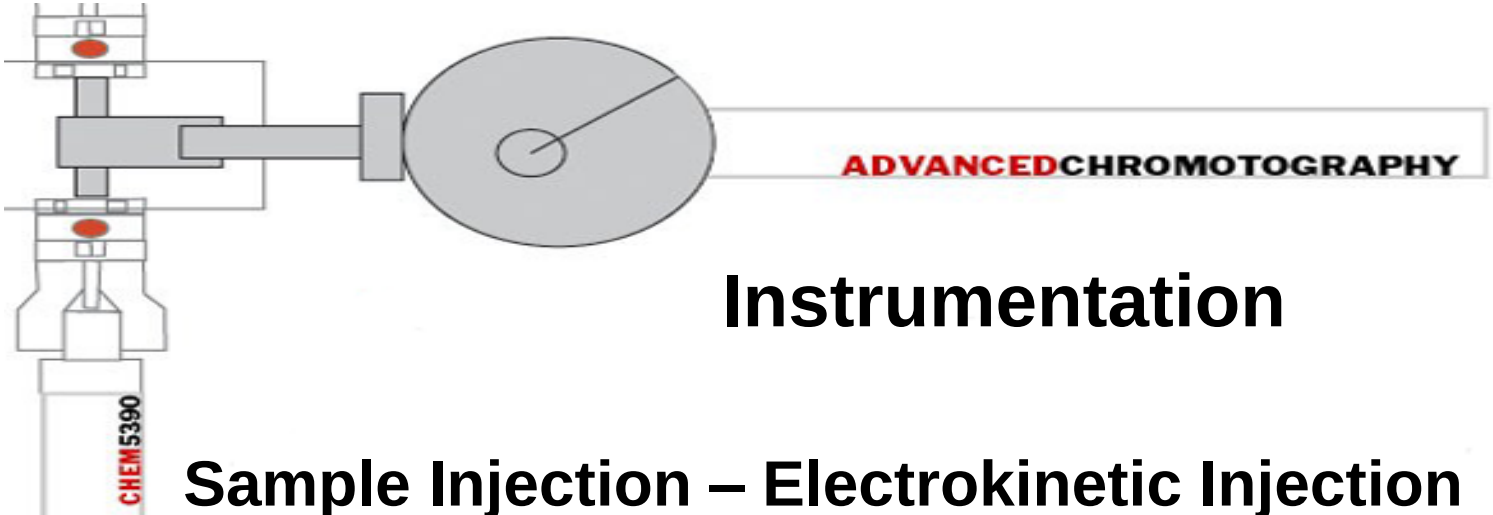


Fig. 4.6. Electrokinetic injection. The capillary and the anode (in this example) are placed in the sample vial. A voltage is applied which causes the sample ions to migrate into the capillary due to electroosmosis and electrophoretic mobility. The amount of sample injected depends on the electrophoretic mobility of the solutes, electroosmotic flow rate, applied voltage, capillary dimensions, and solute concentrations. After sample injection, the capillary and anode are placed back into the source vial and a voltage is applied.



Instrumentation

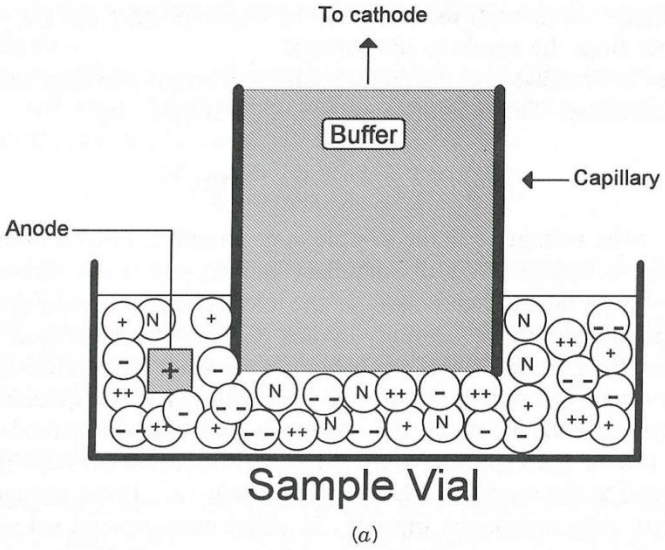
Sample Injection – Electrokinetic Injection

There is a sampling bias with this type of injection.

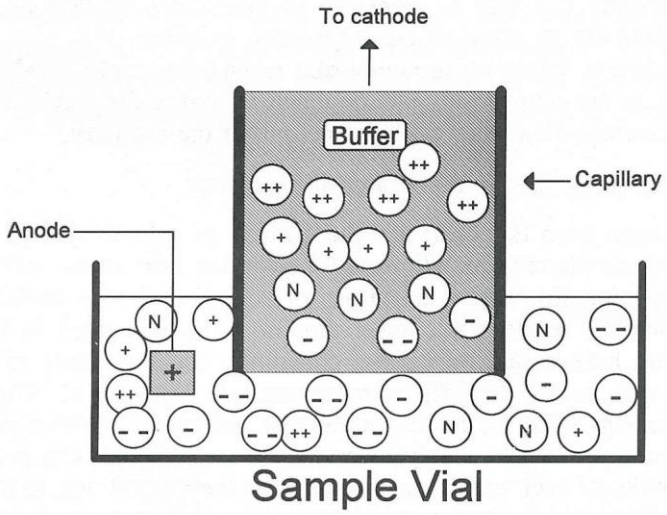
Larger quantities of solutes with high mobilities are injected than solutes with lower mobilities.

i.e. doubly charged cations have higher mobilities than singly charged cations or neutrals or anions.

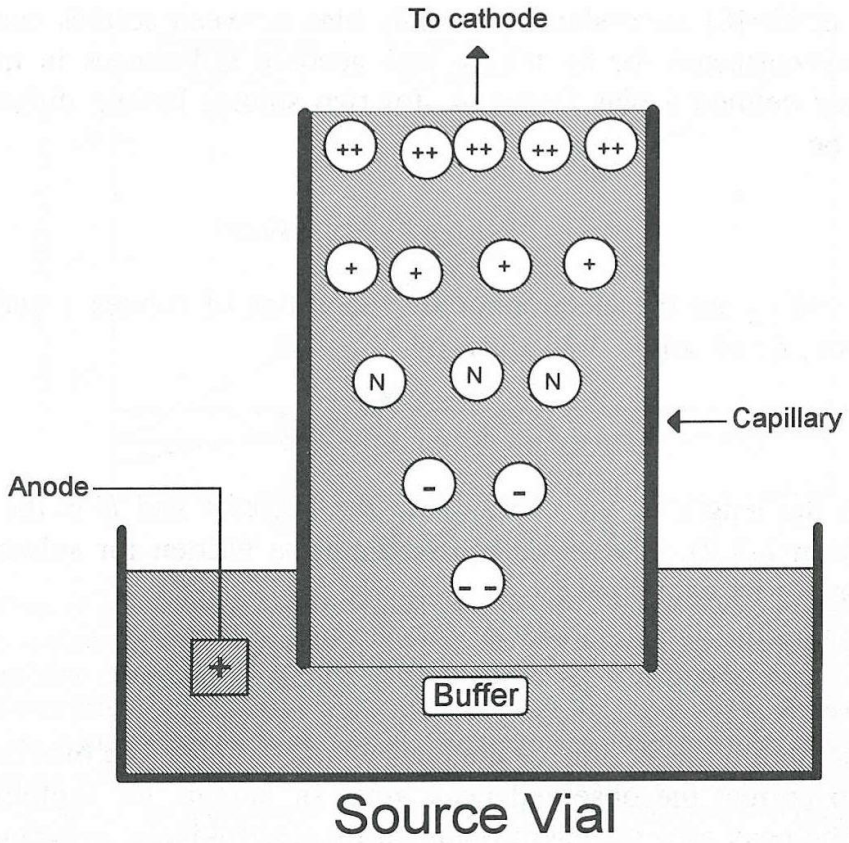
Instrumentation



(a)



(b)



(c)

Instrumentation

Sample Injection

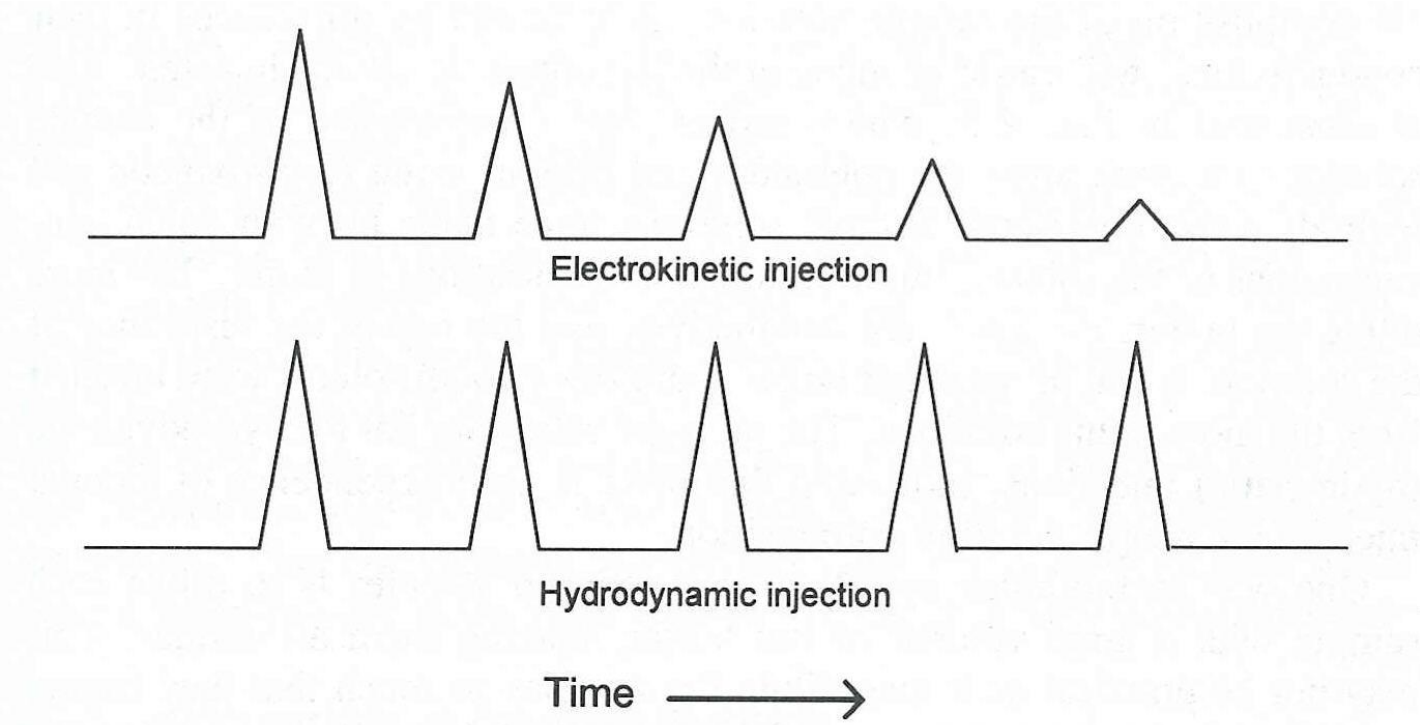


Fig. 4.8. Drawing of electropherograms showing sampling bias with electrokinetic injection as opposed to hydrodynamic injection. For this illustration, it is assumed that the solutes were initially present in equal concentrations and they all have the same detector response.

Instrumentation

Capillary tubes

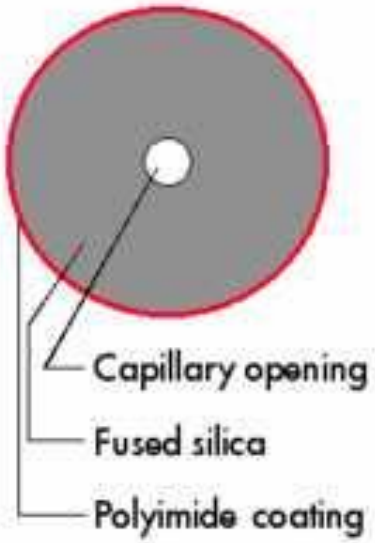
Capillary tube

ID typically 25-75 μm.

Length varies based on application but is normally in the 20-50 cm range.

The small bore and thickness of the silica are important. When a current is applied, this leads to Joule heating.

Using a small ID and having a thick wall reduces this problem.



Instrumentation

Detection

TABLE 30-1 Detection Modes Developed for Capillary Electrophoresis[a]

Detection Principle	Representative Detection Limit[b] (moles detected)
Spectrometry	
Absorption[c]	10^{-15}–10^{-13}
Fluorescence	
Precolumn derivatization	10^{-17}–10^{-20}
On-column derivatization	8×10^{-16}
Postcolumn derivatization	2×10^{-17}
Indirect fluorescence	5×10^{-17}
Thermal lens[c]	4×10^{-17}
Raman[c]	2×10^{-15}
Mass spectrometry	1×10^{-17}
Electrochemical	
Conductivity[c]	1×10^{-16}
Potentiometry	Not reported
Amperometry	7×10^{-19}
Radiometry[c]	1×10^{-19}

[a]From A. G. Ewing, R. A. Wallingford, and T. M. Olefirowicz, *Anal. Chem.*, **1989,** *61,* 298A. With permission.
[b]Detection limits quoted have been determined with a wide variety of injection volumes that range from 18 pl to 10 nL.
[c]Mass detection limit converted from concentration detection limit using a 1-nL injection volume.

Instrumentation

Detection

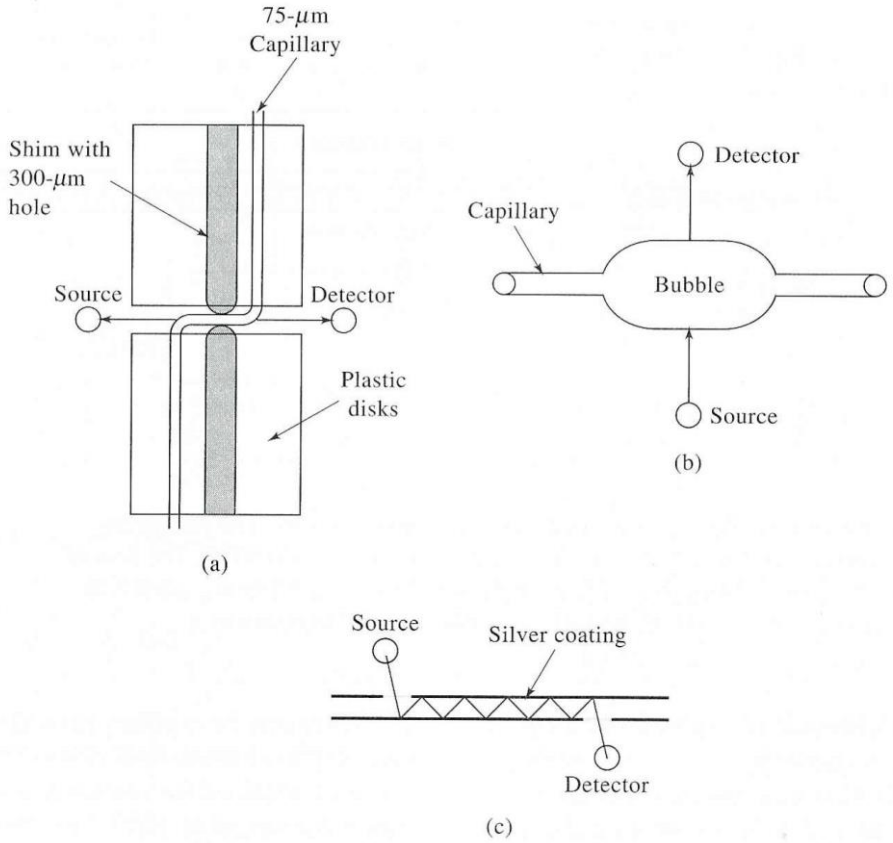


Figure 30-5 Three types of cells for improving the sensitivity of detection by absorbance measurements: (a) the 3-mm z cell, (b) the 150-μm bubble cell, (c) the multireflection cell.

Instrumentation

Detection

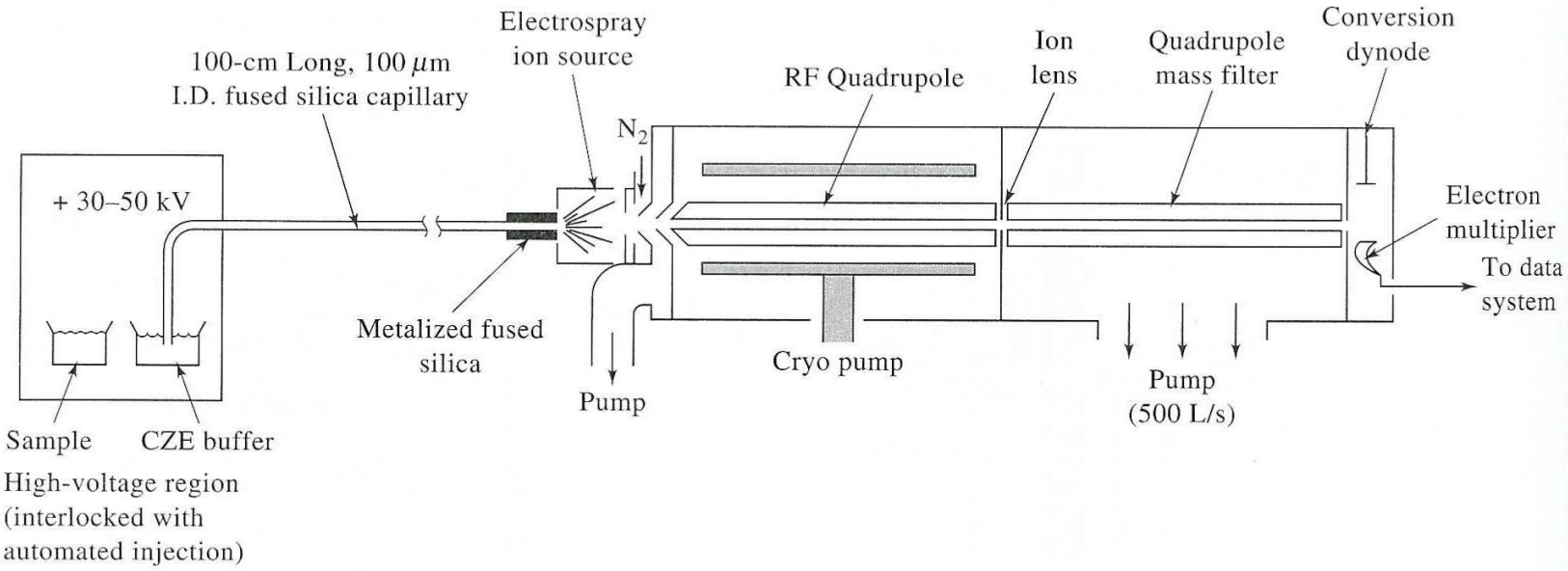
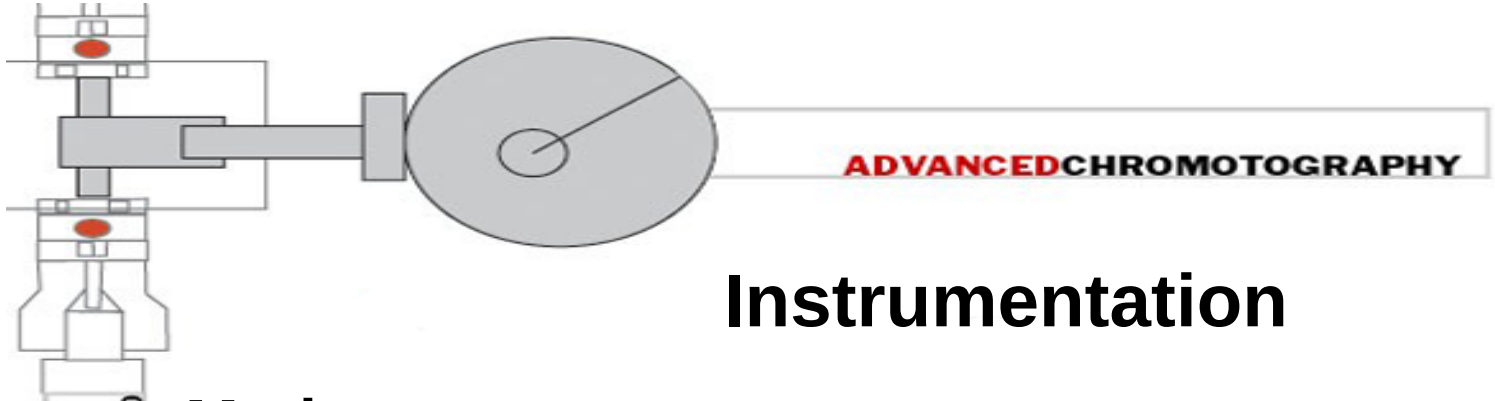


Figure 30-7 An instrument for capillary electrophoresis/mass spectrometry. The voltage between the buffer solution on the left and the metalized silica capillary is 30 to 50 kV. The flow of nitrogen is 3 to 5 kV. The flow of nitrogen at ≈70°C for desolvation is 3 to 6 L/min. *(From R. D. Smith, J. A. Olivares, N. T. Nguyen, and H. R. Udseth,* Anal. Chem., ***1988,*** 60, *437. With permission.)*



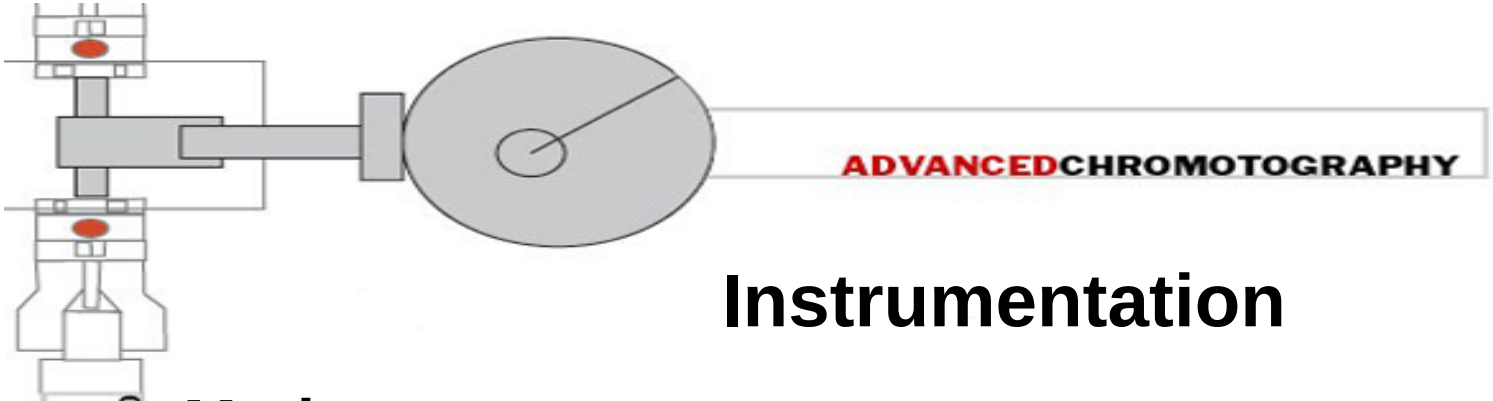
Instrumentation

Modes

Most common modes of capillary electrophoresis:

- Capillary zone electrophoresis (CZE)
- Micellar electrokinetic capillary chromatography (MEKC)(MECC)
- Capillary isoelectric focusing (CIEF)
- Capillary isotachophoresis (CITP)

CZE and MEKC are zonal techniques
CIEF is a focusing technique
CITP is a moving boundary or displacement technique

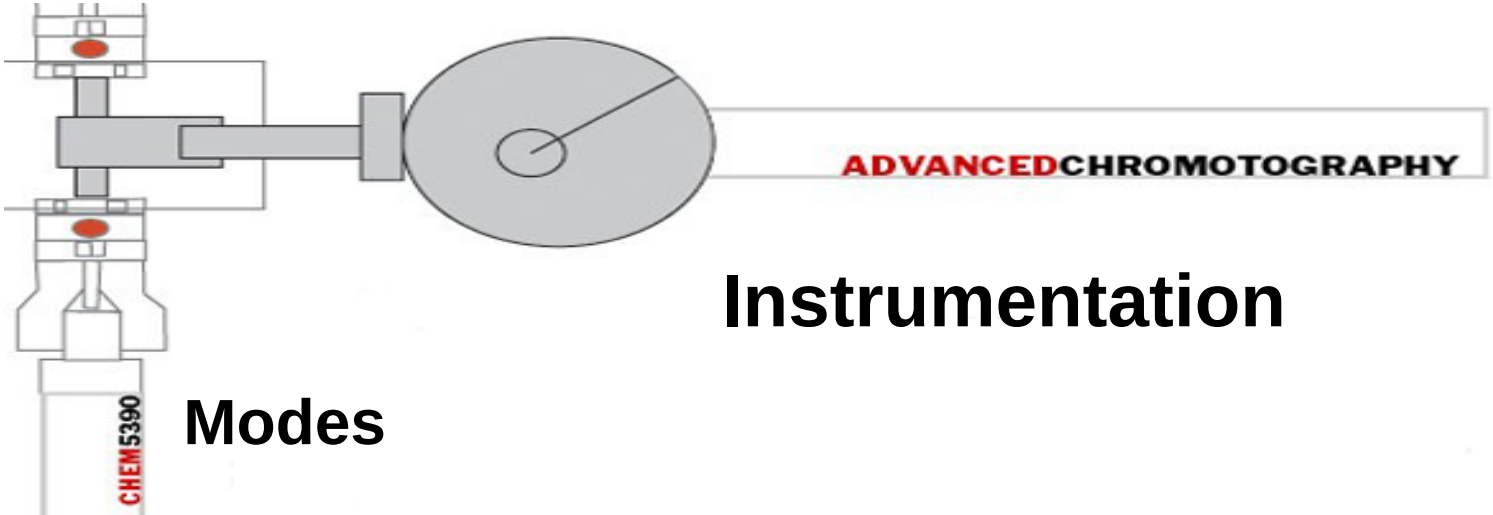


Instrumentation

Modes

Most common modes of capillary electrophoresis:

- Micellar electrokinetic capillary chromatography (MEKC)(MECC)
  - -Micelles added to buffer (from surfactants)
  - -Allows separation of neutrals based on partitioning of analytes between micelle interiors (hydrophobic environment) and bulk mobile phase
  - -Anionic micelles will travel slower than EOF and neutrals will elute between micelle flow and EOF flow



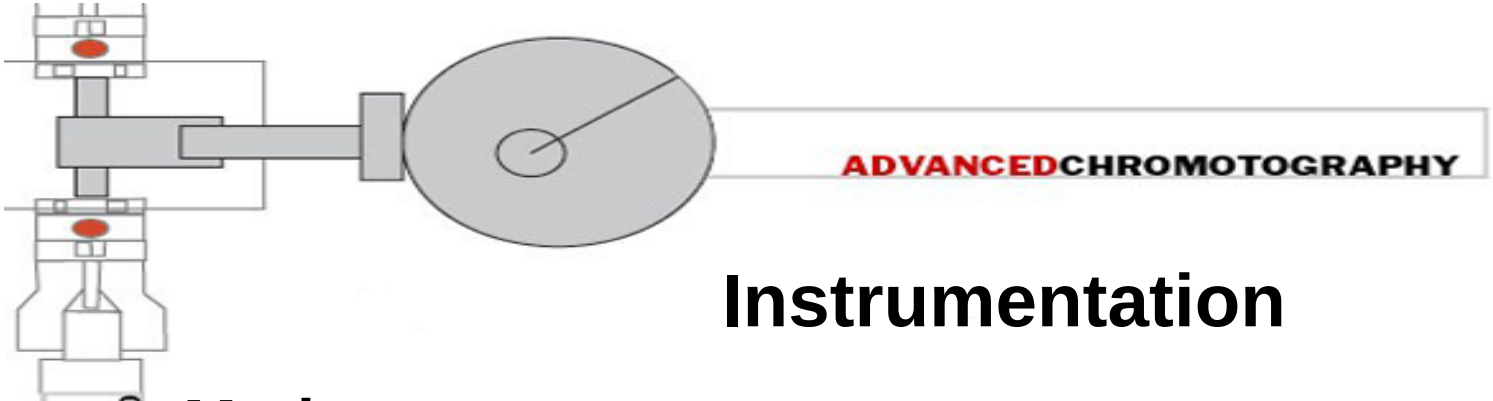
Instrumentation

Modes

Most common modes of capillary electrophoresis:

- Micellar electrokinetic capillary chromatography

MEKC is a hybrid technique that merges electrophoresis and chromatography.
It involves adding surfactant micelles to the electrolyte.
Neutral analytes partition between the aqueous phase and the micelle core, while charged analytes migrate according to their charge-to-mass ratio.
MEKC's versatility allows for the separation of both neutral and charged compounds. However, micelle stability can affect reproducibility.



Instrumentation

Modes

Most common modes of capillary electrophoresis:

•Capillary isoelectric focusing (CIEF)

This technique exploits differences in the isoelectric points (pI) of analytes to achieve separation.
The capillary is filled with an ampholyte buffer, creating a pH gradient. Analytes migrate to their respective pI, where they become electrically neutral and halt.
This technique is excellent for proteins and peptides with distinct pIs. But, CIEF is time-consuming due to the need for pI calibration, and complex samples can challenge resolution.

Instrumentation

Modes

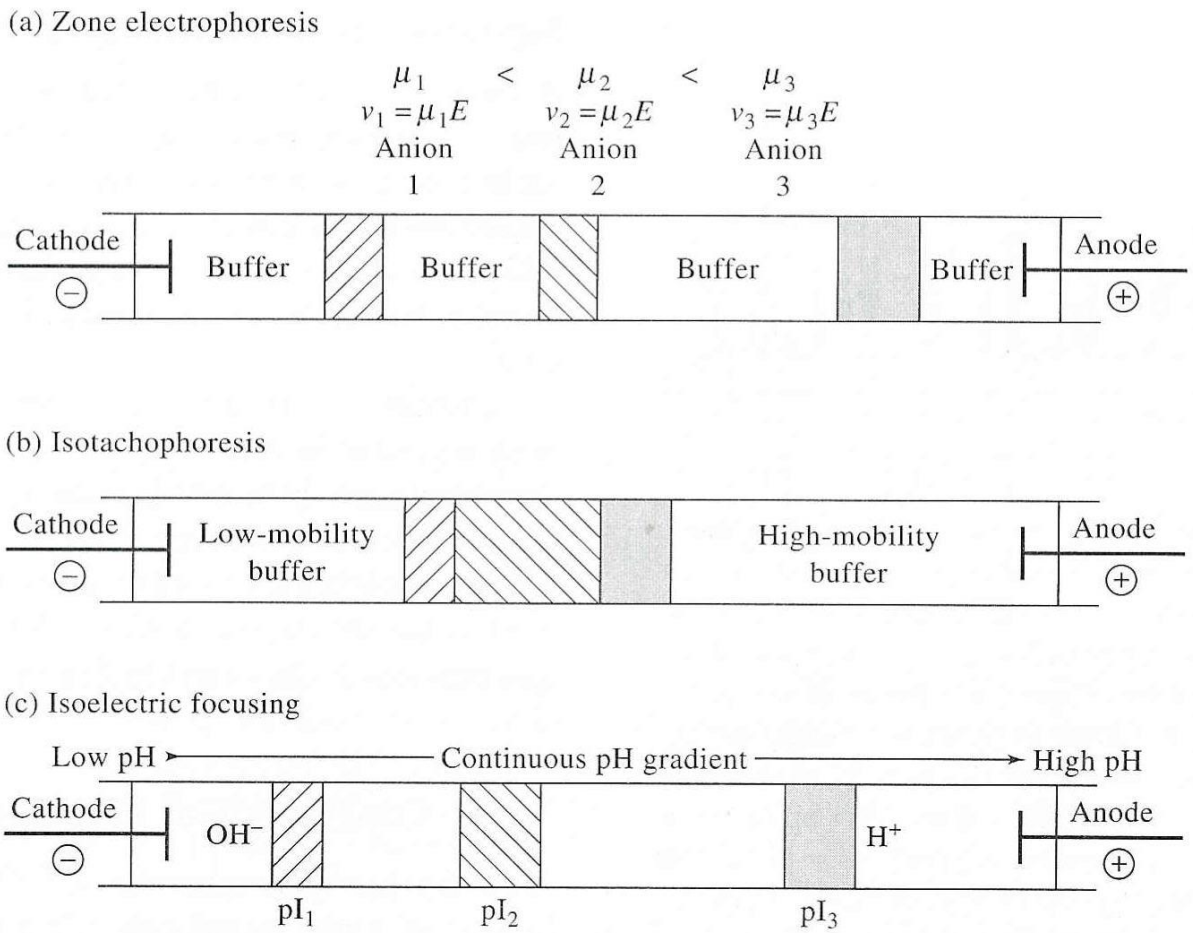
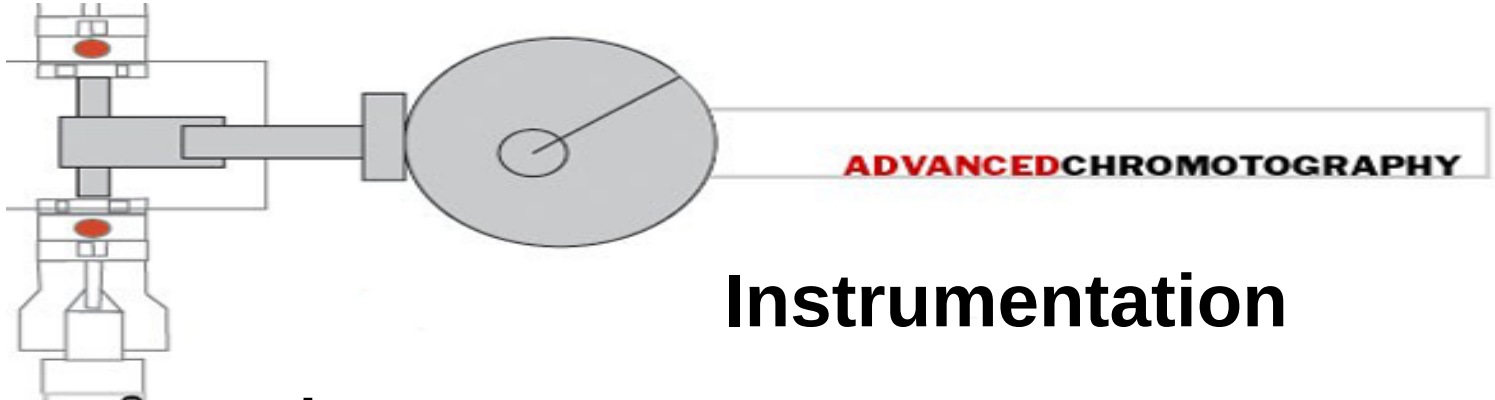


Figure 30-9 Three modes of separation by electrophoresis.



Instrumentation

Modes

Most common modes of capillary electrophoresis:

- Capillary isotachophoresis (CITP)

In CITP, the separation of analytes is based on their ionic mobilities in a stepwise manner.
A leading electrolyte with lower mobility and a trailing electrolyte with higher mobility sandwich the analytes, driving them toward the detector.
CITP excels in separating complex mixtures, ensuring that each analyte occupies a distinct migration zone. However, concentration effects can lead to distortion of peak shapes.

Instrumentation

Modes

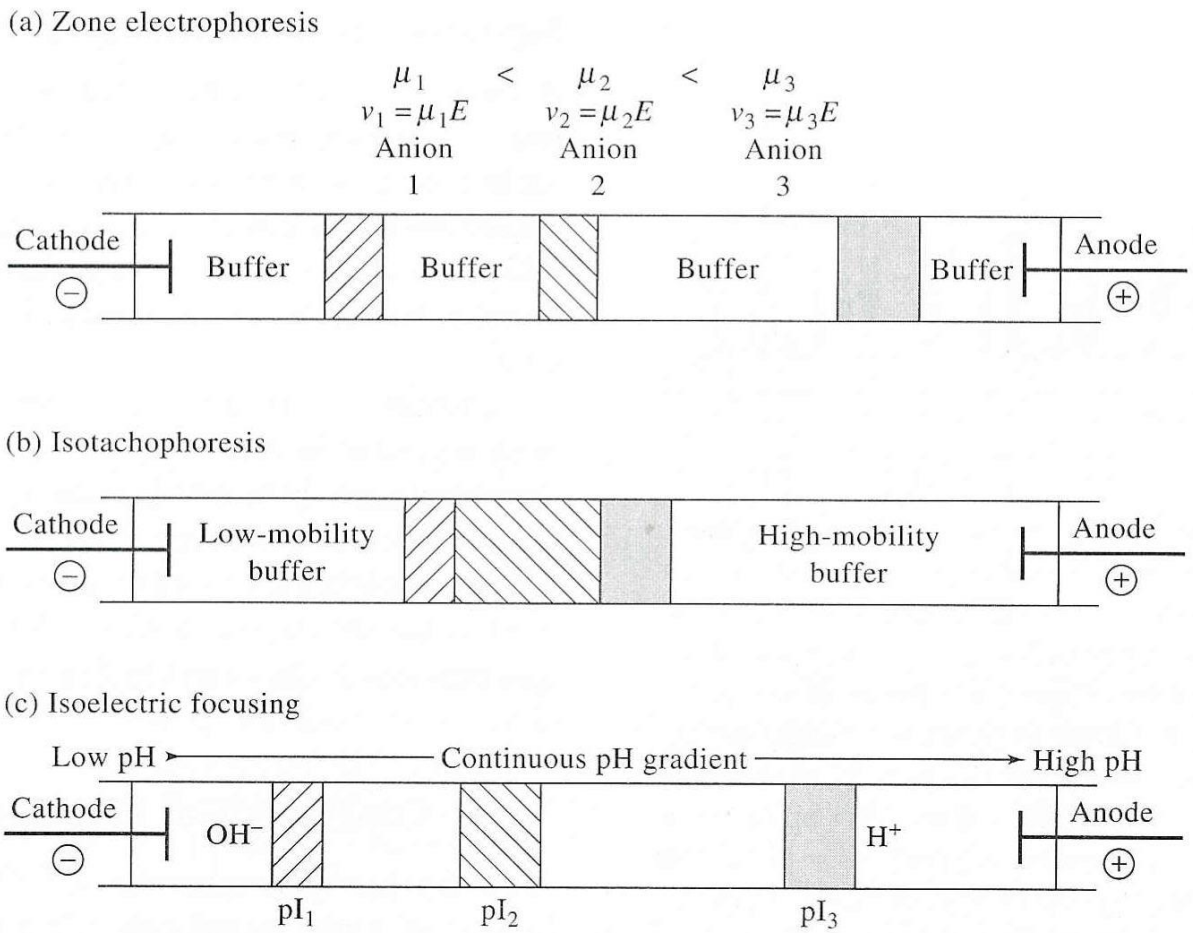
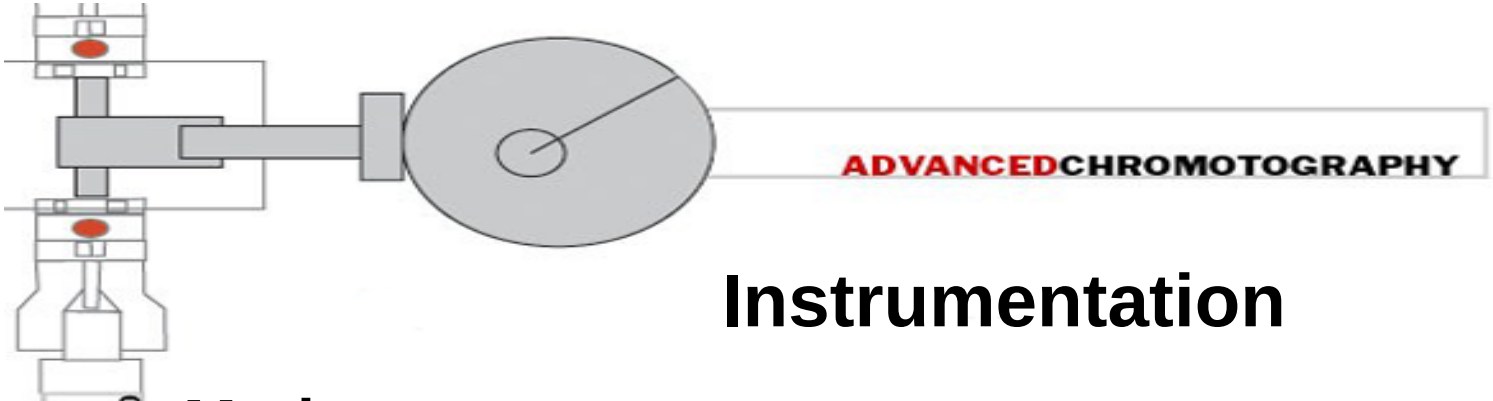


Figure 30-9 Three modes of separation by electrophoresis.



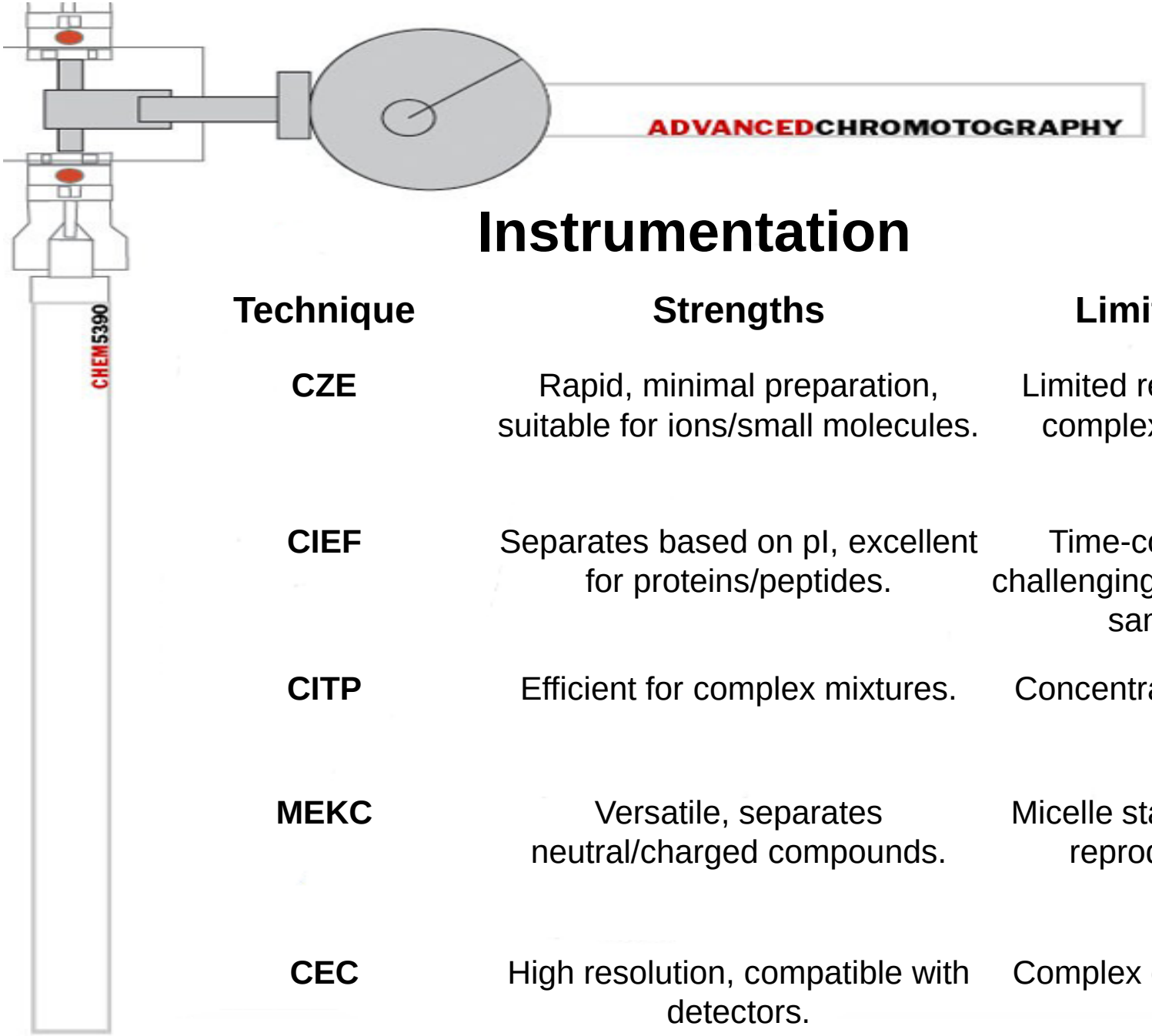
Instrumentation

Modes

Most common modes of capillary electrophoresis:

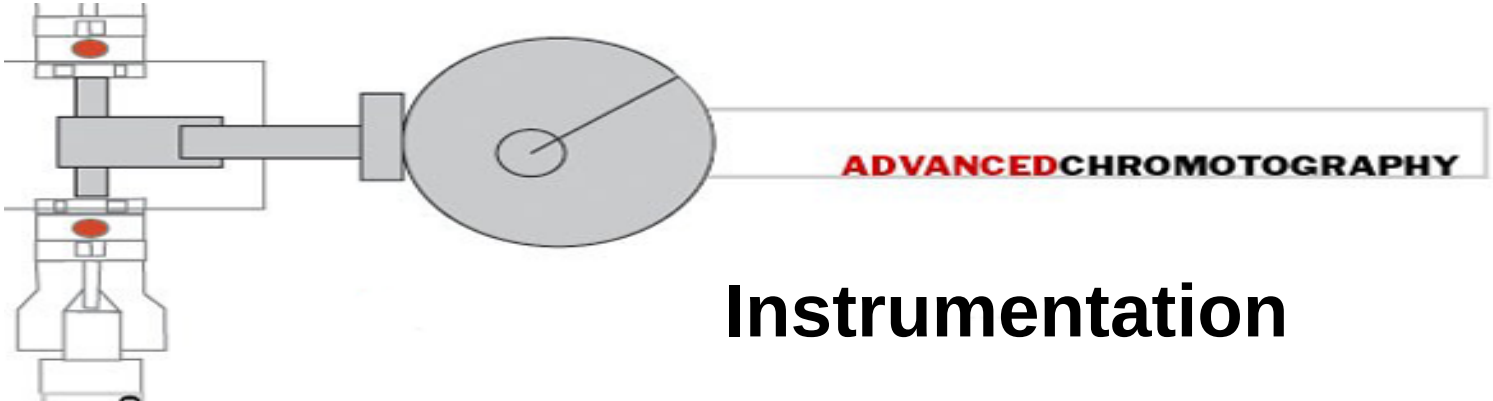
- Capillary electrochromaotography (CEC) (recent technique)

CEC combines chromatography and electrophoresis principles. A stationary phase coats the inner capillary wall, interacting with analytes similarly to traditional chromatography. This interaction, combined with electrophoretic mobility, offers high-resolution separations.
CEC is compatible with various detection methods and is capable of separating complex samples. However, the optimization of stationary phases and mobile phases can be intricate.



Instrumentation

Technique	Strengths	Limitations
CZE	Rapid, minimal preparation, suitable for ions/small molecules.	Limited resolution for complex mixtures.
CIEF	Separates based on pI, excellent for proteins/peptides.	Time-consuming, challenging with complex samples.
CITP	Efficient for complex mixtures.	Concentration effects.
MEKC	Versatile, separates neutral/charged compounds.	Micelle stability affects reproducibility.
CEC	High resolution, compatible with detectors.	Complex optimization.



Instrumentation

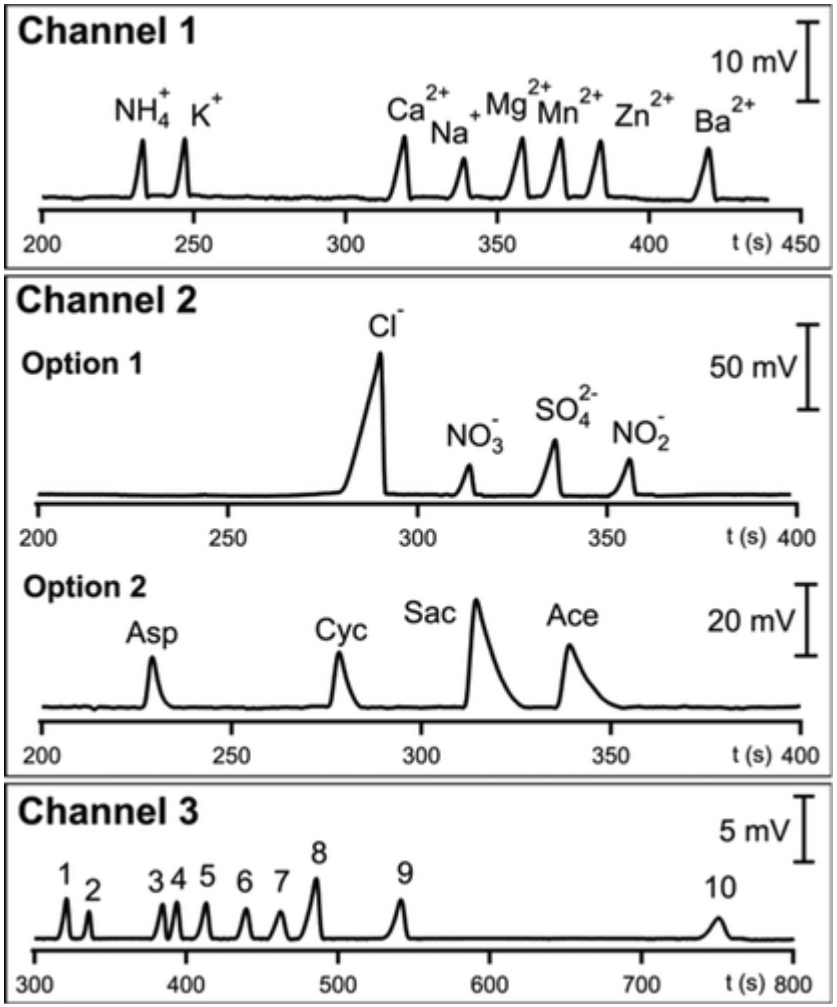
Applications

Food analysis:

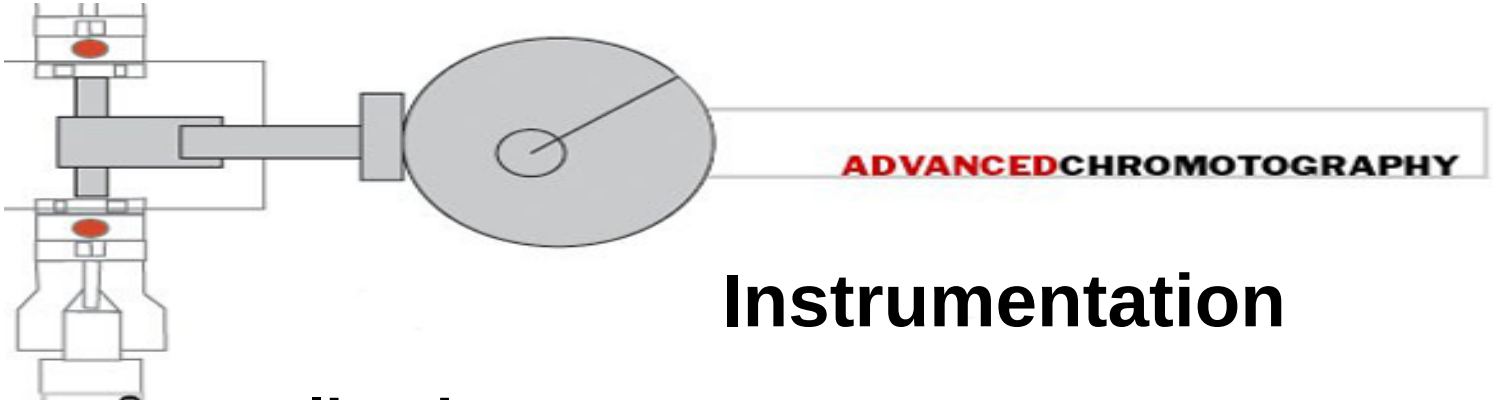
CE contributes to food safety and quality control.

Detection of allergens, additives and contaminants, quantification of vitamins, amino acids and fatty acids, ensuring nutritional label accuracy.

CE also helps to detect food product adulterations.



CE electropherograms for the concurrent separations of inorganic cations, inorganic anions or artificial sweeteners, and organic anions. Channel 1, inorganic cations. Channel 2, option 1, inorganic anions; option 2, artificial sweeteners, aspartame (Asp), cyclamate (Cyc), saccharine (Sac), and acesulfame-K (Ace). Channel 3, organic anions (1) oxalate, (2) formate, (3) tartrate, (4) malate, (5) succinate, (6) citrate, (7) pyruvate, (8) acetate, (9) lactate, and (10) ascorbate.

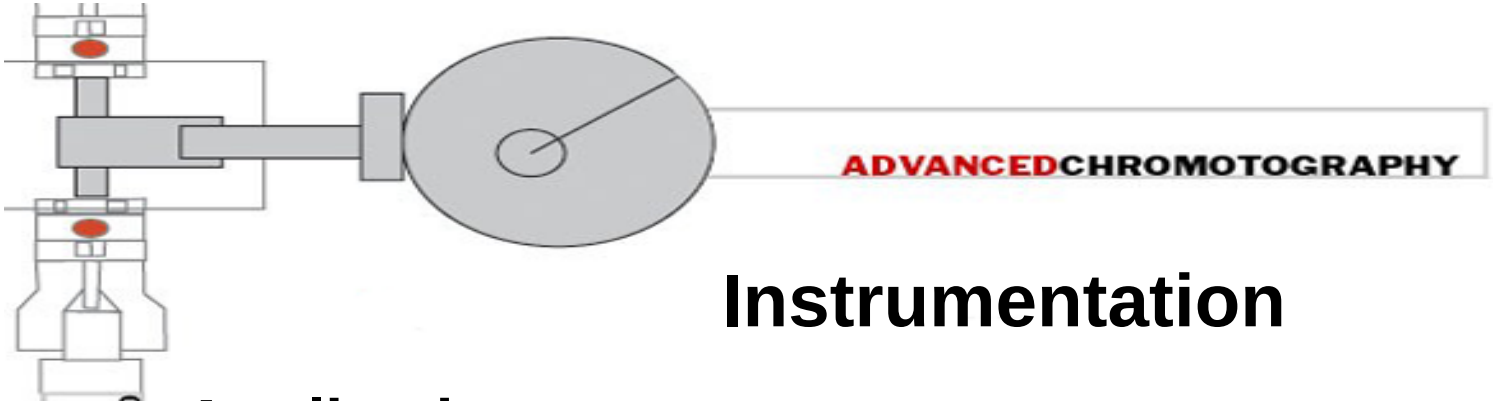


Instrumentation

Applications

Environmental monitoring:

CE used in environmental testing of pollutants, heavy metals and organic compounds in water and soil samples.
Detection of pesticide residues and pharmaceutical pollutants.
CE also assists in monitoring water quality, allowing the quantification of relevant anions like nitrates and sulfates



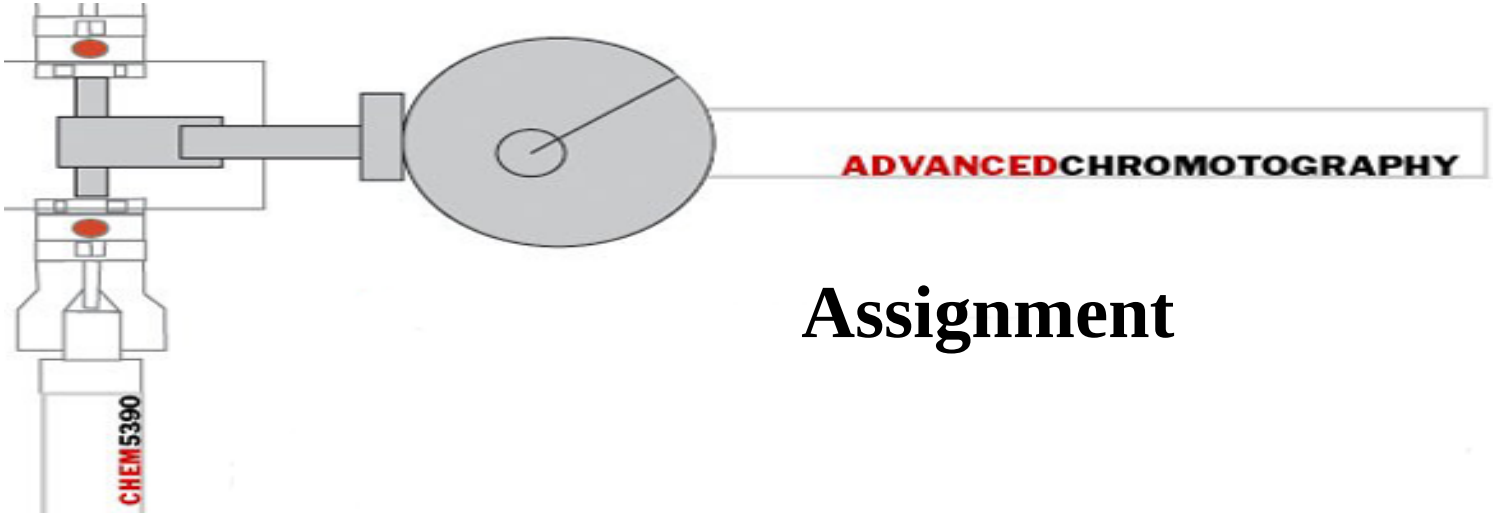
Instrumentation

Applications

Forensic science:

CE facilitates forensic DNA analysis, vital in criminal investigations and paternity testing.

The technique's sensitivity enables the analysis of minute samples, often crucial in solving cold cases.



Assignment

- Research Paper Due Today