Large-Scale Electrophoretic Fractionation of Rare Earths

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Background

The lanthanides have been successfully fractionated by zone electrophoresis and by isotachophoresis in capillaries and microchips, which can batch process nanograms of sample in 10-15 minutes.

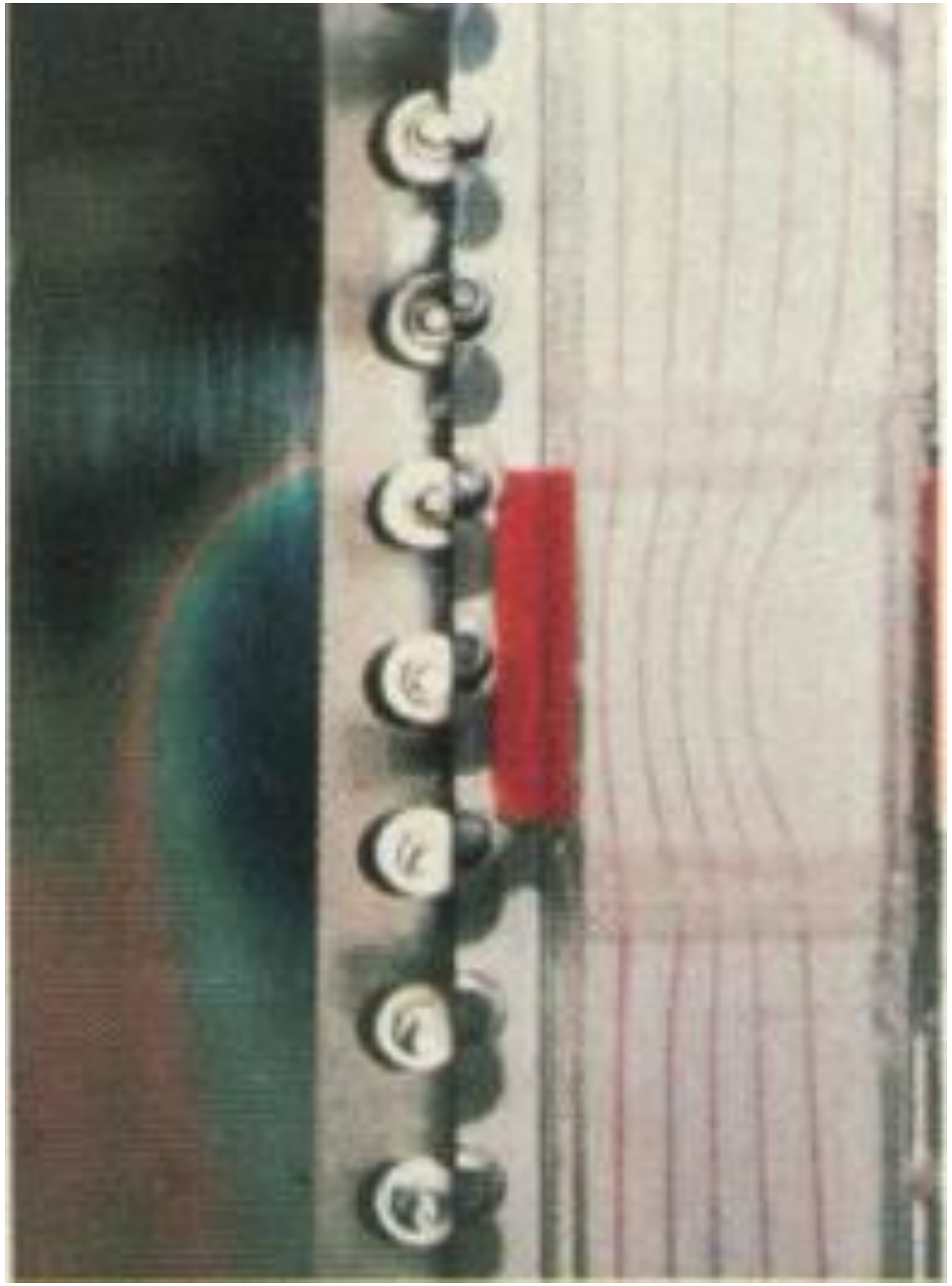
Free-Flow electrophoresis can continuously process ~10 micrograms of sample per minute, but lacks the resolving power needed to separate the rare earths because of small differences in their electrophoretic mobilities.

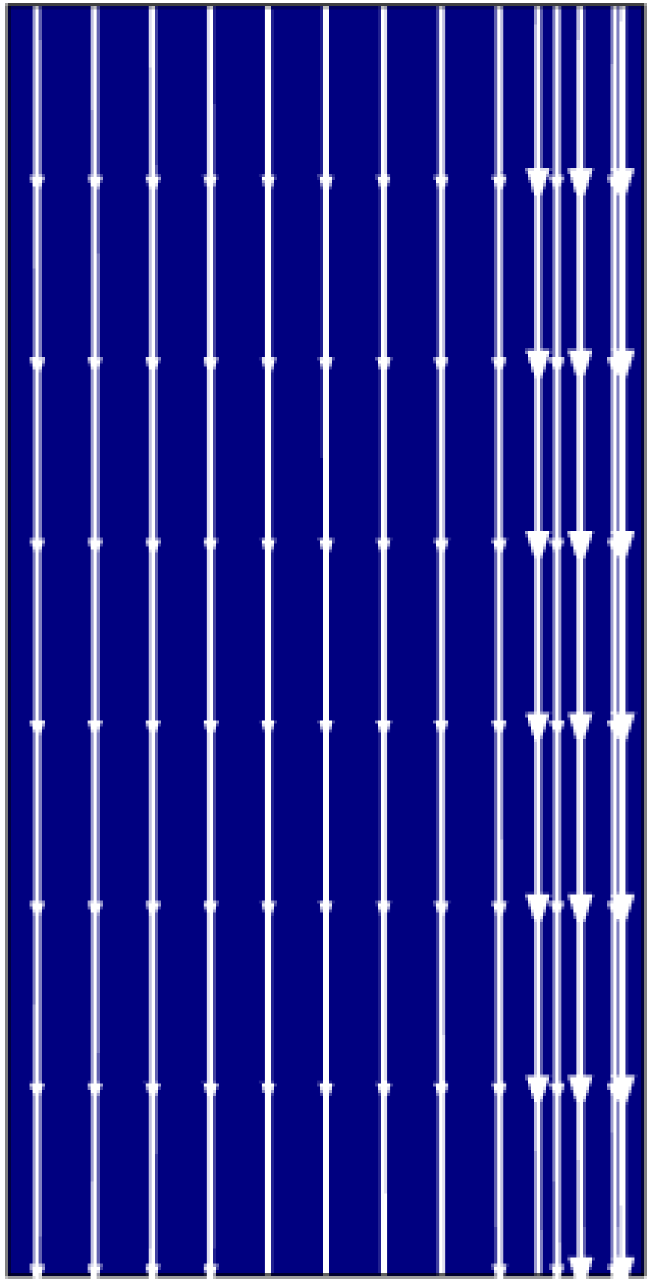
Vortex-stabilized electrophoresis has the resolving power to separate neighboring pairs of lanthanides at throughputs approaching 1 mg/min but cannot be scaled significantly beyond that.

Goal of this talk: To describe the 3 primary impediments that are hindering the development of industrial scale electrophoresis.

1. Unstable natural convection driven by Joule heating
2. Electrohydrodynamic instabilities that arise from conductivity gradients
3. Very small differences in electrophoretic mobilities of rare earths

Unstable Natural Convection





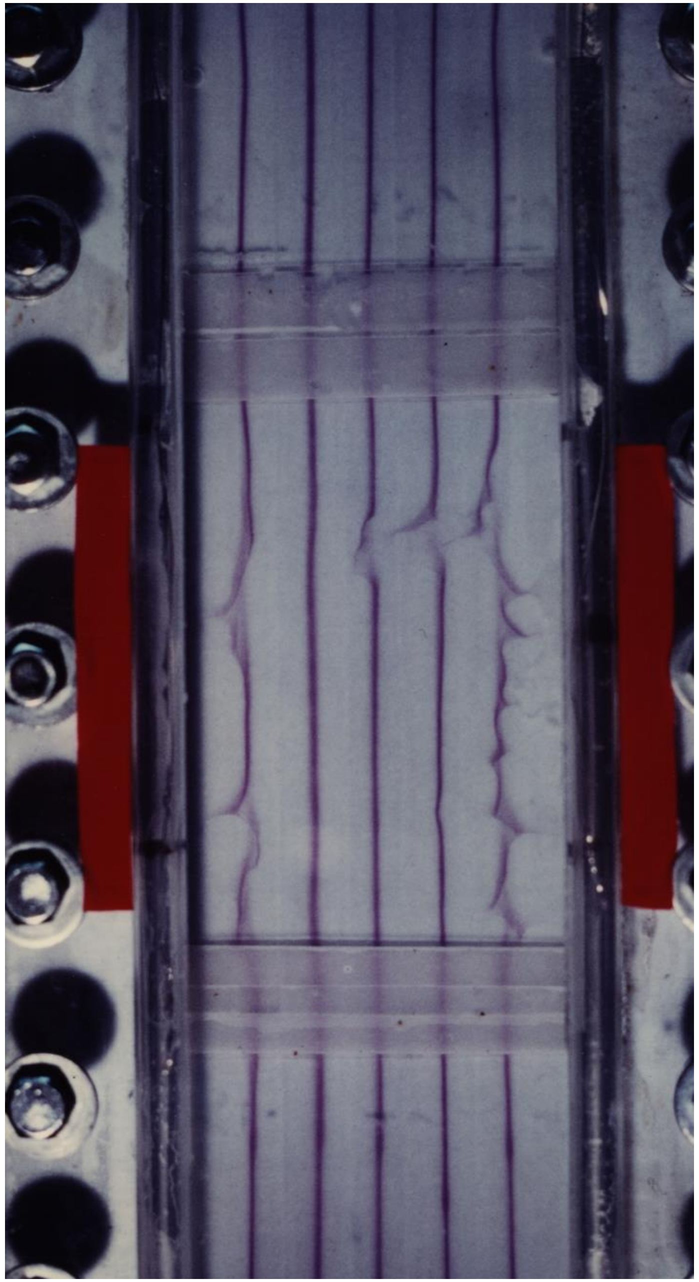
COMSOL Multiphysics® simulation of the flow instability in a continuous flow electrophoresis apparatus. This instability, which manifests as an asymmetric vortex attached to one side of the chamber, can be greatly reduced by using upward flow and insulating the heat-transfer surfaces on the front and/or back surfaces.

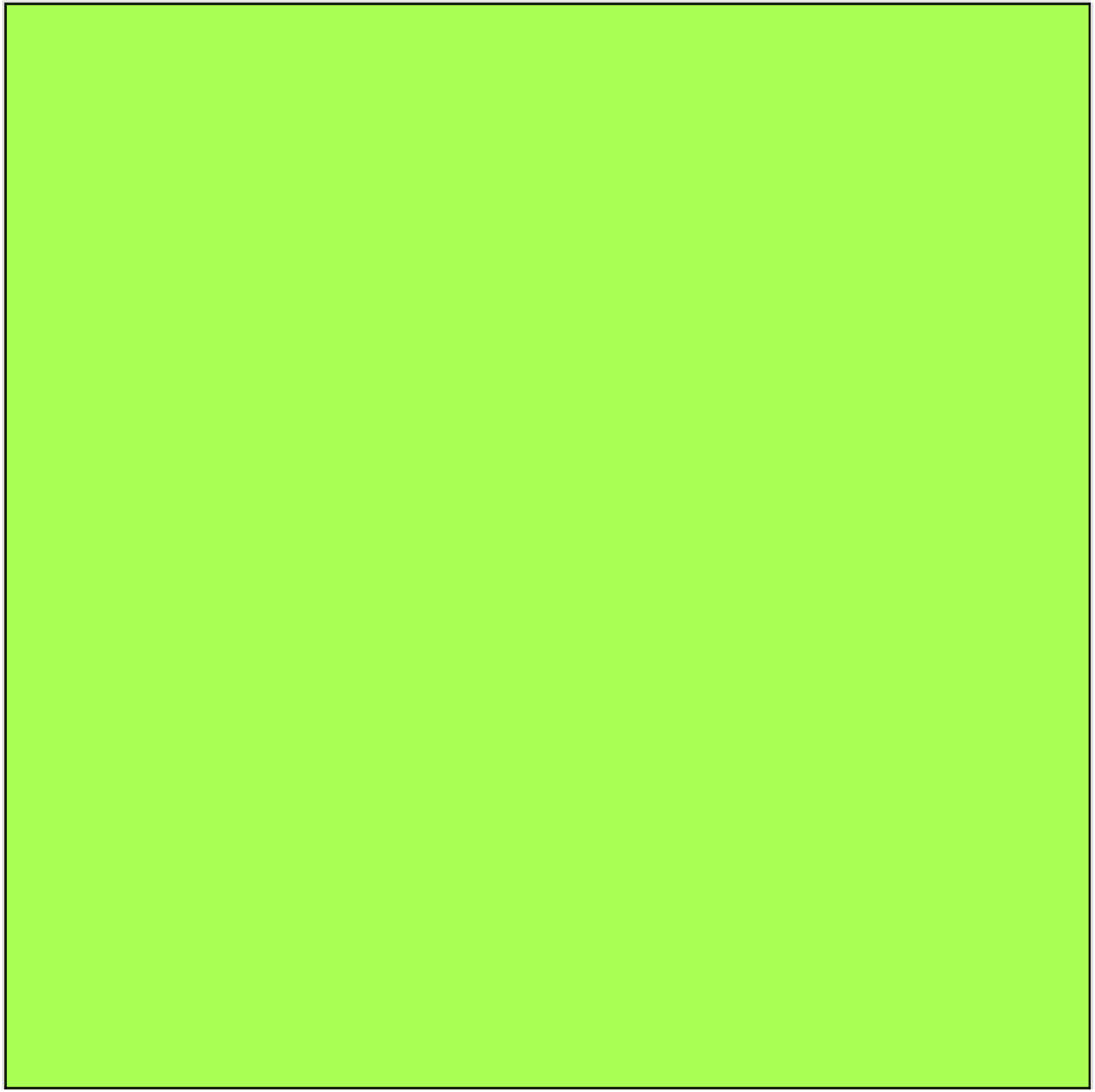
Left: The temperature profile in the chamber is shown on a liquid crystal thermometer attached to the back of the apparatus. A hot-spot is visible under the vortex that forms in the flow.

Center: Streamlines showing vortex formation in the electrode section of a thin-film electrophoresis apparatus with downward flow.

Right: COMSOL Multiphysics® shows that, near the critical Rayleigh number for this system, the instability emerges quickly after a long lag time. COMSOL also shows that reversing the flow and insulating the heat transfer surfaces greatly extends the stable operating range of this device.

Electrohydrodynamic (EHD) Instability



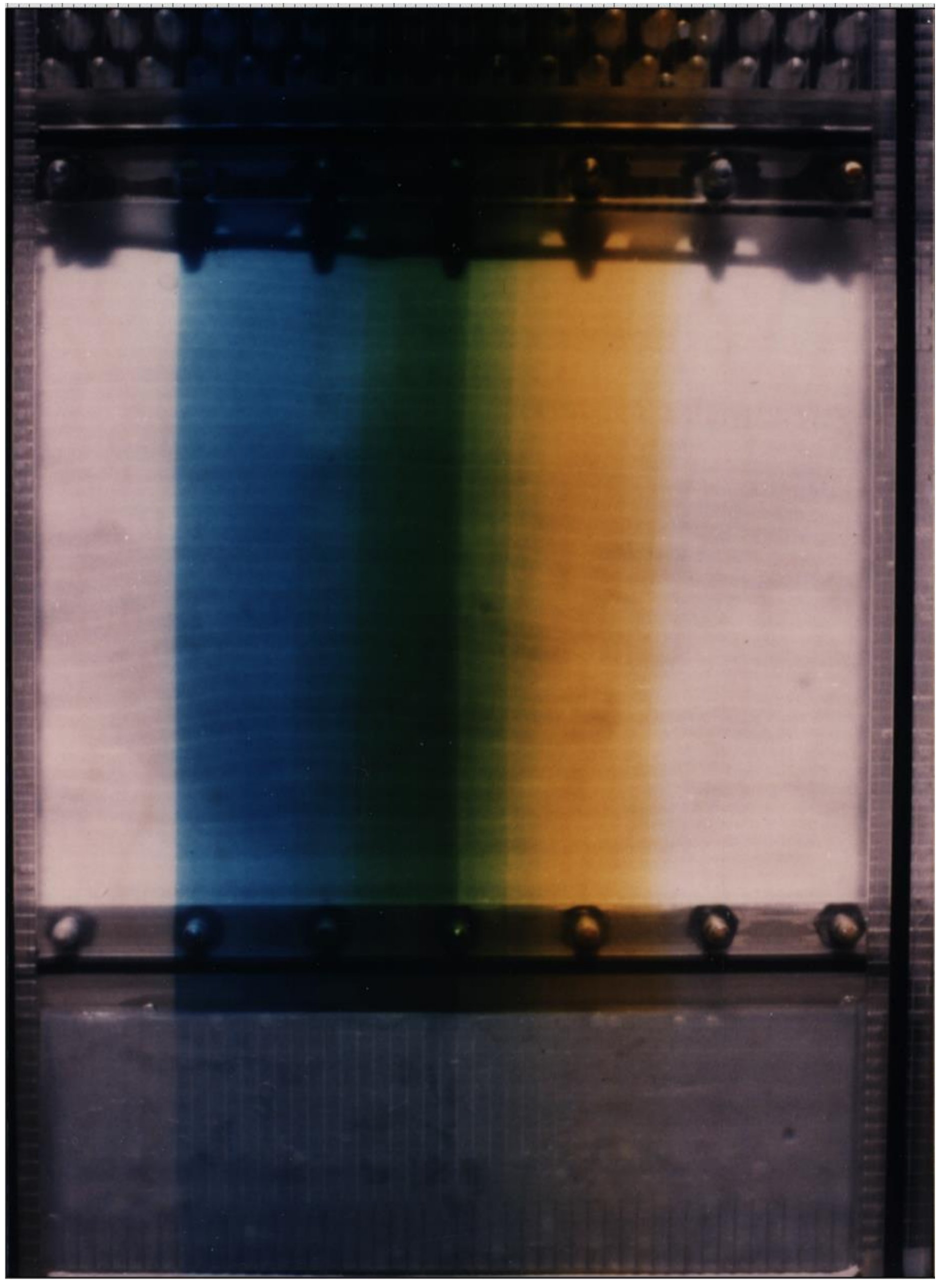


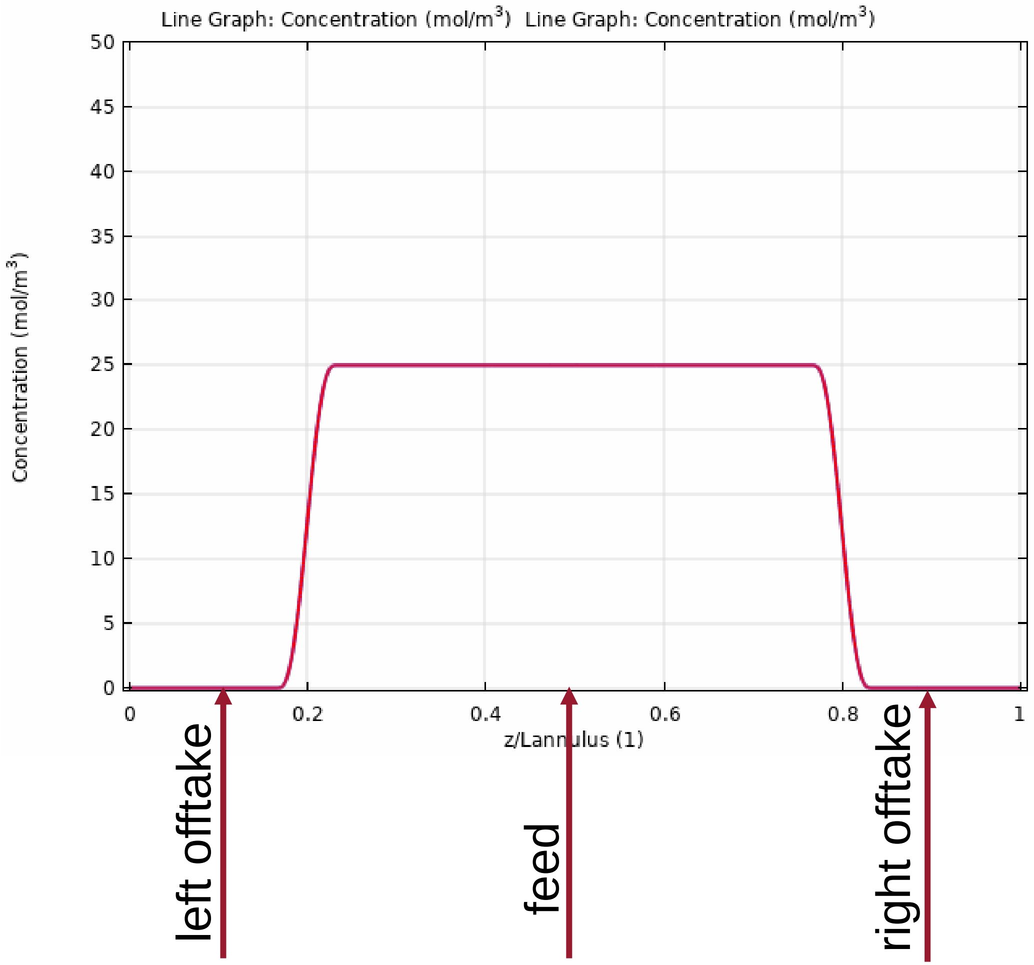
COMSOL Multiphysics® simulation (right) of the evolution of an EHD instability in a thin, stationary film. This instability arises when current is passed through a steep conductivity gradient as illustrated on the left.

Left: High conductivity dye streamlines are passed through low-conductivity buffer in a thin-film electrophoresis device. The cusp-shaped instability arises when sufficient current is passed left-to-right through the streamlines.

This instability is mitigated by reducing conductivity gradients that might occur during electrophoretic processing.

Recycle Continuous Flow Electrophoresis (CFE)





COMSOL Multiphysics® simulation of the evolution of a separation of two species with 0.25% difference in their electrophoretic mobilities in a 12-inch wide recycle CFE. Feed is continuously injected into the bottom center port and products are taken out of the chamber at the left and right offtake ports. Recycling allows the hold-up time to be increased until the two species are separated.

Conclusions

- Unstable natural convection can be greatly reduced by using upflow with insulating chamber surfaces,
- EHD instabilities can be mitigated by minimizing conductivity gradients,
- Bicomponent targets with small mobility differences can be separated by using recycle to increase holdup times.

Questions?


50-Channel Peristaltic Pump
Separation Chamber
Recycle Lines

Additional Reading

- Unstable natural convection: Ivory, C. F., W. A. Gobie, J. B. Beckwith, R. Hergenrother and M. Malec, “Electromagnetic Stabilization of Weakly Conducting Fluids,” Science, 238(4823) 58 (1987).

- EHD instability: Baygents, J. C. and F. Baldessari, ‘‘Electrohydrodynamic Instability in a Thin Fluid Layer with an Electrical Conductivity Gradient,’’ Phys. Fluids, 10 301 (1998).

- Large-Scale Electrophoresis: “Electrically Driven Separations Processes. Analytical and Preparative Methods,” Ivory, C. F., in Downstream Processing in Biotechnology, J. Asenjo, ed., Marcel Dekker, Inc., New York 1990.