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Making Shock Waves in Microfluidics: The Physics and Applications of Isotachophoresis

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Microfluidics lies at the interfaces between engineering, chemistry, and biology, and aims to develop chemical laboratories on a chip. An important technique is on-chip capillary electrophoresis which has been applied to a wide range of chemical and biochemical assay applications over the last decade. Perhaps the best way of improving the sensitivity of on-chip electrophoresis is to integrate an online sample preconcentration method. At Stanford, we are developing methods to concentrate ions into small volumes using a method called isotachophoresis (ITP). In ITP, sample ions are injected between the high mobility co-ions of a leading electrolyte (LE) and the low mobility co-ions of a trailing electrolyte (TE). Upon application of an electric field, the disparate ion mobilities of the LE and TE cause sample species to segregate and focus into a series of narrow self-sharpening zones which migrate at equal velocity (hence "isotacho"). ITP-type processes have been studied and used for more than 60 years, and yet there remain significant challenges in the robust modeling of these transport processes and the creation of widely applicable assays. We use ITP to create sample ion concentration "shock waves" in microchannels. These concentration waves can be integrated with on-chip electrophoresis for high sensitivity assays, and novel modes of operation. The talk will summarize the basic physics of ITP, experimental studies of ITP, models of ITP, and the development of novel ITP-assays with unprecedented sensitivity and new functionality. For example, using leading-to-sample ion concentration ratios of 10^{15} and local electric fields of $\sim$4 kV/cm, we can achieve order one micron wide ITP zones. We can achieve million fold preconcentration in 120 s and can detect 100 attomolar sample concentrations (to our knowledge the highest demonstrated sensitivity for an electrophoresis-related assay). We have also developed a method that uses ITP to separate, indirectly detect, and identify the electrophoretic mobilities of unlabeled (non-fluorescent) analytes using surrogate fluorescent molecules. Our goal is the development of novel on-chip ITP assays which expand the design space of microfluidic devices.