Polymeric Ion Pumps: Using an Oscillating Stimulus to Drive Solute Transport in Reactive Membranes

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Abstract

The development of membranes that separate molecules based on chemical factors, rather than physical factors, is one promising approach to meeting the demand for membranes that are more selective. In this paper, the design of multifunctional, pH-responsive membranes that selectively pump a target solute is detailed. The composite membranes consist of two components: a reactive matrix lined by iminodiacetic acid groups that bind divalent cations reversibly and a gate layer made from an amine-functionalized copolymer. These two chemistries exhibit concurrent changes in the cation binding affinity and gate permeability in response to the pH value of the surrounding solution such that when the membranes are exposed to an oscillating pH, the combination drives a facilitated transport mechanism that pumps ions. In mixed solute experiments, calcium permeated through the composite, reactive membrane four times faster than sucrose in the presence of an oscillating pH even though the solutes possess similar hydrodynamic sizes and permeated through the membrane at the same rate when the pH value was constant. The development of the polymeric ion pumps was guided by a model that provided several critical insights. First, the solute binding capacity and thickness of the membrane define the asymptotic limit for enhanced selectivity. Second, the maximum enhancement in selectivity is realized in the limit of infinitely rapid oscillations. The multifunctional membranes discussed here provide a platform for the development of processes that can fractionate molecules of similar size but varying chemistry.