

Nonmechanical Pumping Using Selective Transport Membranes

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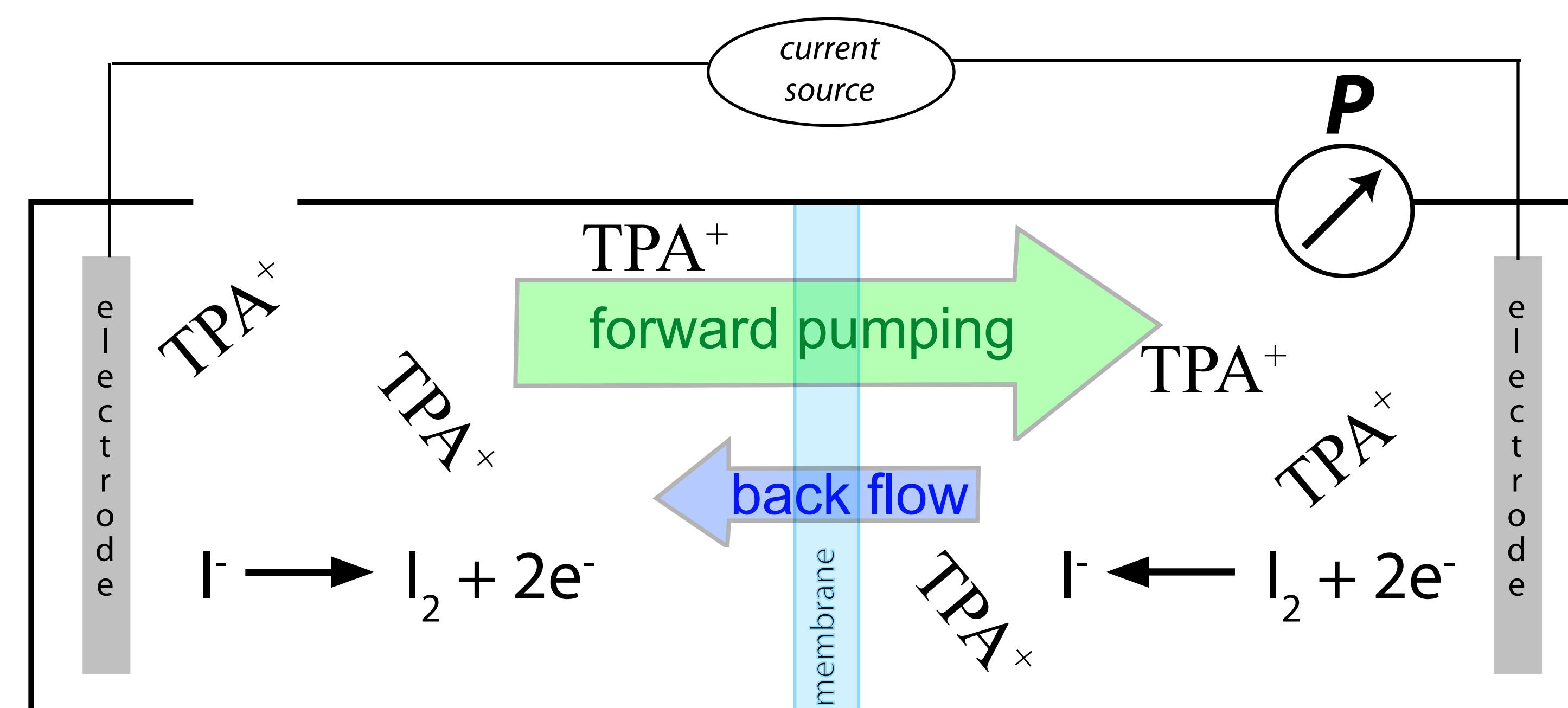
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Abstract

Nonmechanical pumping of liquids is of key interest for applications ranging from biomedical lab-on-a-chip systems to morphing mechanical structures. Here we present a pumping and pressurization system with no moving parts that uses only modest external power. To date, pressures up to 23 atm have been demonstrated using this epumping system! By creating a charge imbalance across a cation selective membrane, solvent is transported across the membrane along with the mobile cation, effectively pumping the liquid and creating pressure within the vessel.

Summary

Liquid pumping using no moving parts has been successfully demonstrated. Electrochemical reactions are used to create a charge imbalance across an ionomer membrane. The mobile cation within the solution then migrates across the membrane to balance the charge, transporting solvent molecules with it. In this modified version of facilitated transport, the solvation shell of the ion appears to play a key role in the volume transport and the pressurization process. As demonstrated here, significant pressures and reversible operation can be achieved using this epump approach.



ePumping Conditions

Schematic: cell right side is closed, left side is open

Membrane: Nafion[®] 117, A = 0.55 cm²

Solvent: dimethylformamide (DMF)

Electrodes: Pt mesh

Redox Chemistry: $I_2 + 2e^- \longleftrightarrow 2I^-$

Migrating ion: tetrapropylammonium (TPA⁺)

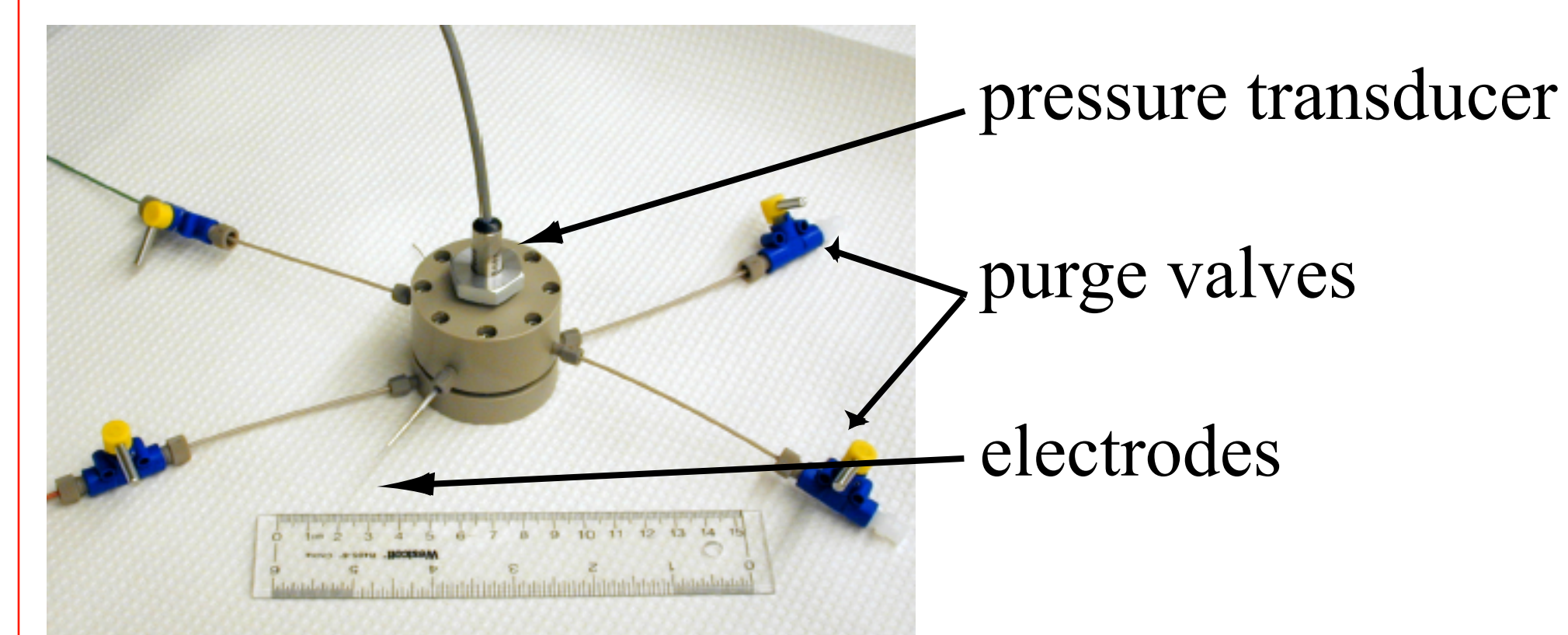
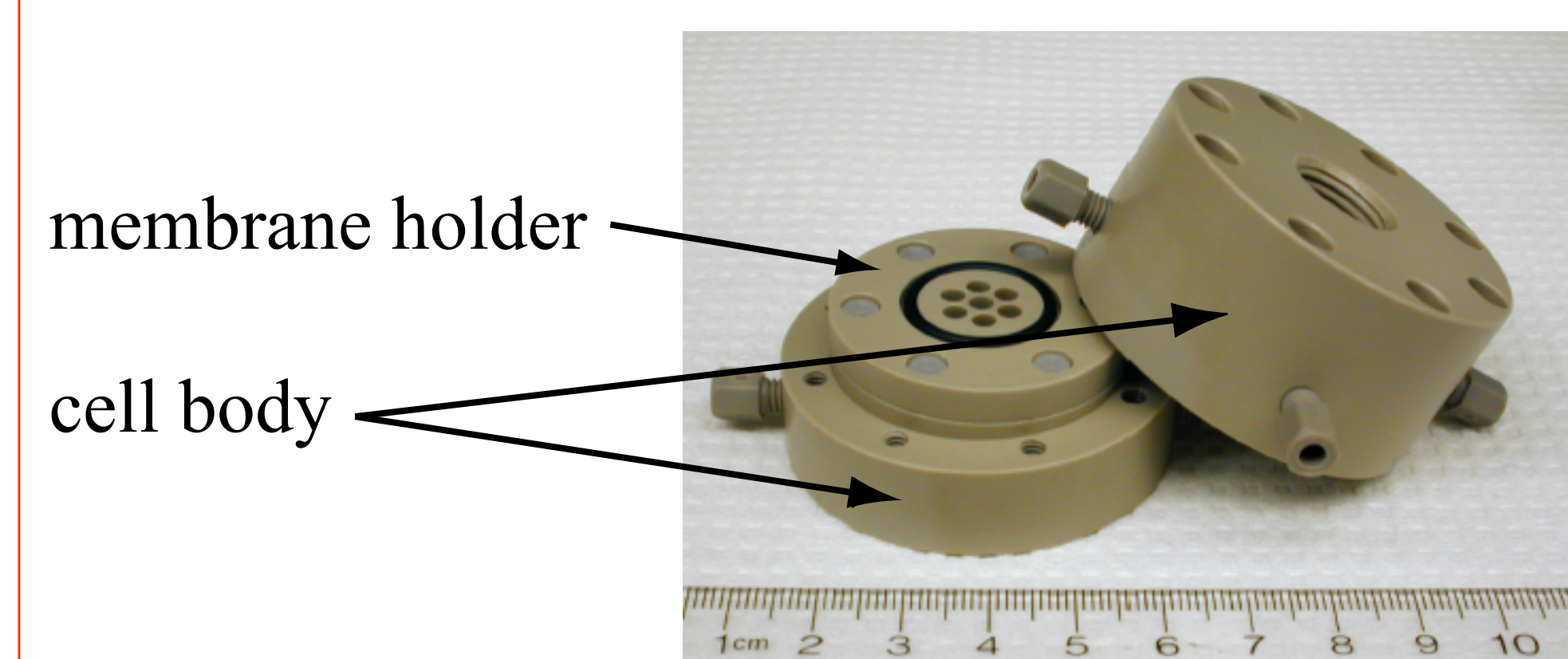
Cell volume: $V_{\text{anode}} = V_{\text{cathode}} = 1.25 \text{ mL}$

Constant current measurements: 20 mA

Voltage: ~ 5 V

Cell material: PEEK (polyetheretherketone)

ePumping Cell

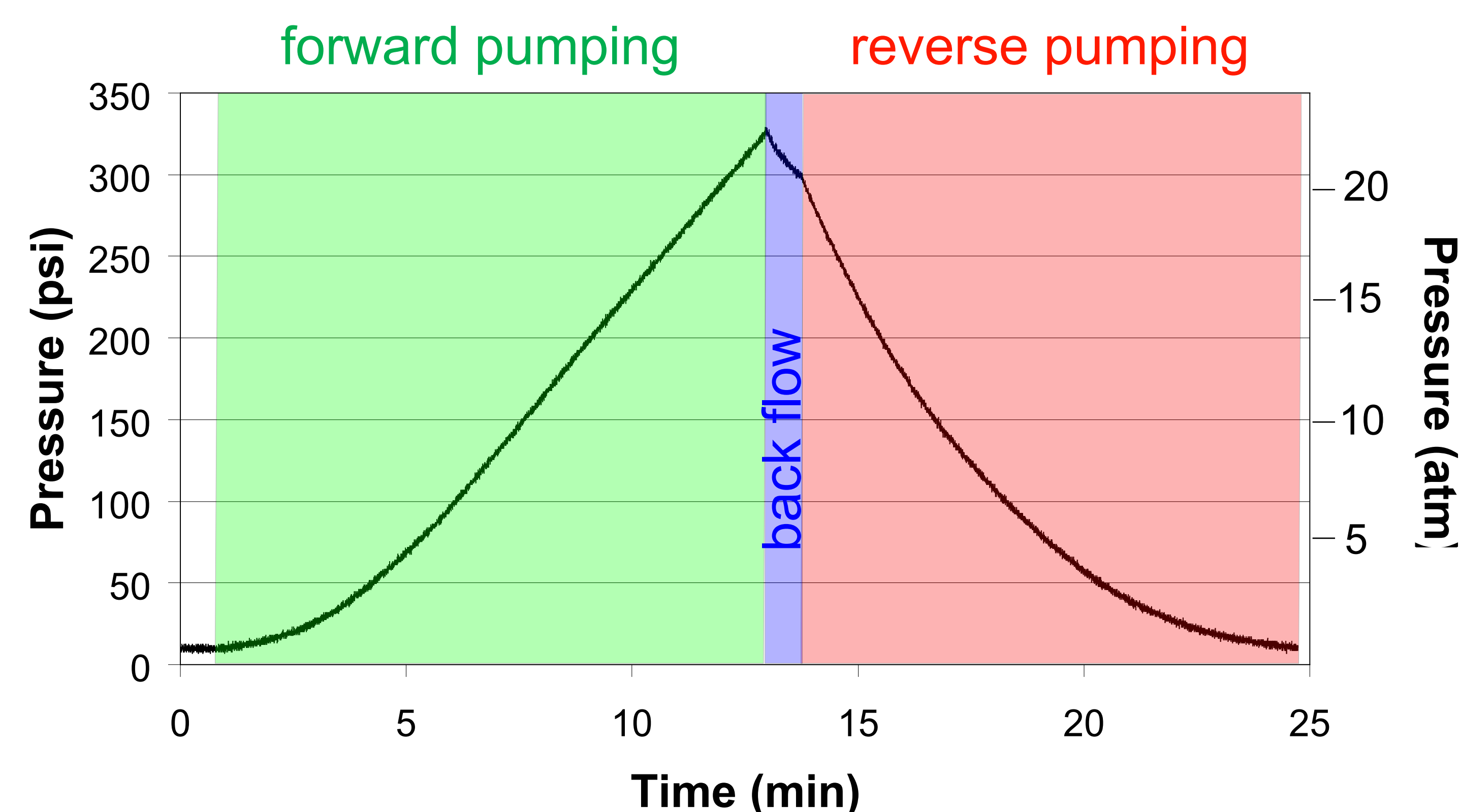


Acknowledgements

The authors wish to thank DARPA for financial support of this project and Dennis Curtin from DuPont Fluoroproducts for the membrane material.

High Pressure Performance of ePump

current = 20 mA; voltage ~ 5 V



High Pressure Performance at 23 atm

This nonmechanical pumping system has been successfully demonstrated up to 23 atm! An upper pressure limit has not yet been established. Based on data at 23 atm:

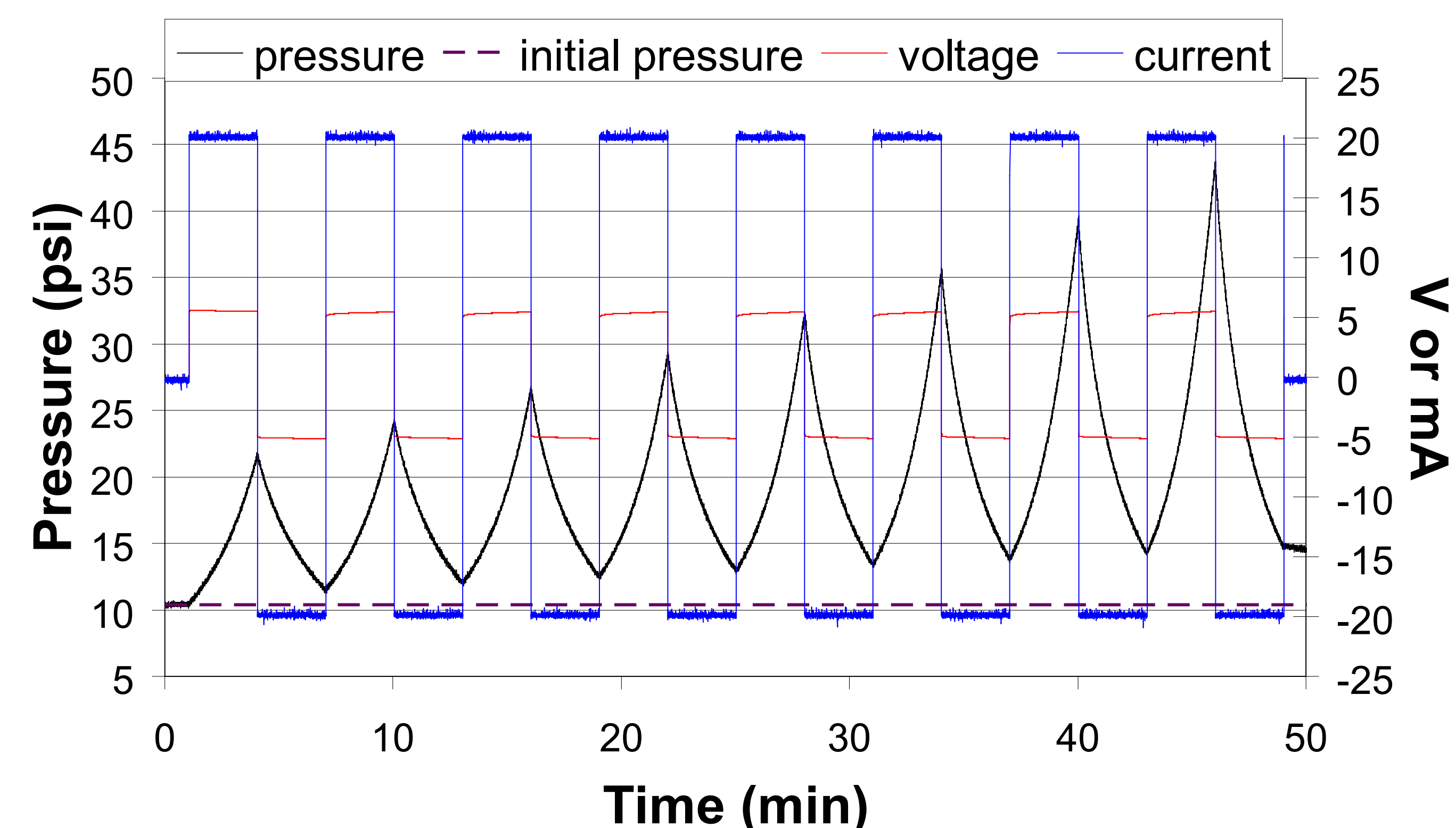
the measured overall forward flow is
2.2 atm/min or 2.0 atm/C

the measured back flow at $i = 0$ is
2.3 atm/min

resulting in a calculated forward flow of
4.5 atm/min

That is, under these experimental conditions, the forward flow is approximately twice the back flow.

Pressure Cycling Performance



Pressure Cycling Performance

In addition to unidirectional pumping, reversible pressure cycling behavior has been successfully demonstrated. By using a square-wave current input and varying the current above and below $i = 0$, bidirectional pumping is possible. As shown to the left, an asymmetric pressure response is observed in forward vs. reverse pumping. This effect is also seen in the forward and reverse pumping rates measured at atmospheric pressure (+6.8 $\mu\text{L}/\text{min}$ and -5.6 $\mu\text{L}/\text{min}$, respectively). This asymmetry may be advantageous for certain pressurization applications. Preliminary indications are that deformation of the membrane is contributing to this unusual effect and investigations are presently underway.