ASGSR Meeting 2021

ASGSR Ken Souza Program 2020: Post-PDR Design Update

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University of Colorado, **Boulder**

Flight plan

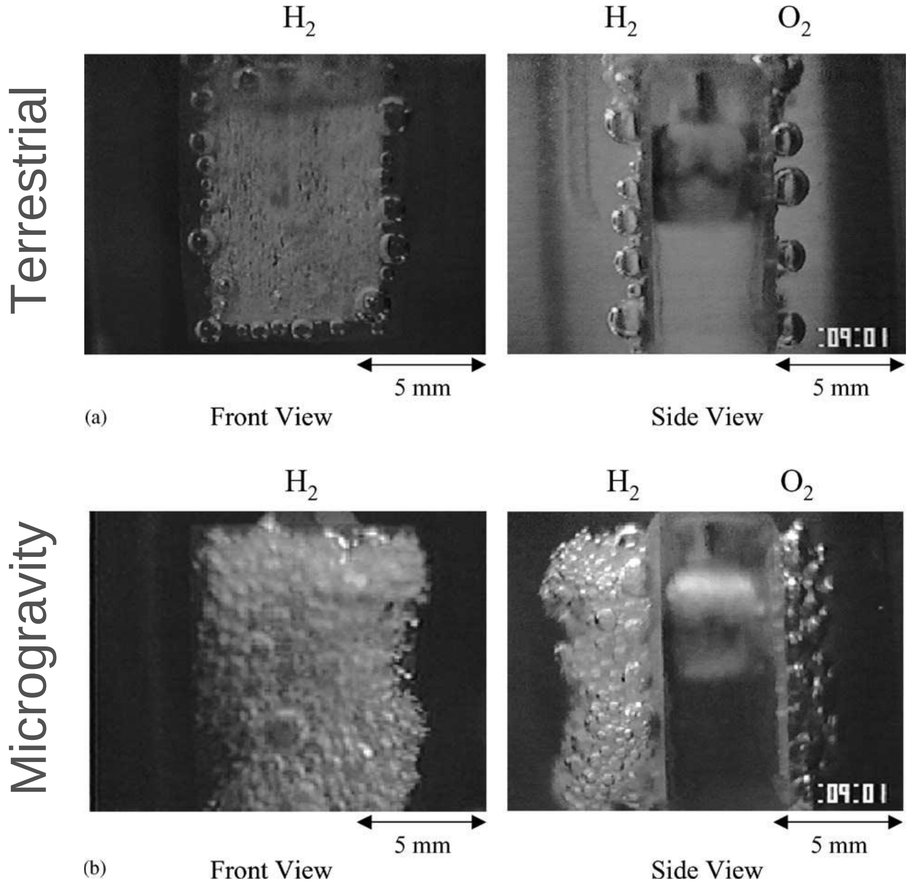
1. Introduction & Motivation
2. Blue Origin's New Shepard
3. Scientific Objectives & Payload Requirements
4. Experimental Setup
5. (Some) tests
6. Conclusions

Blue Origin

Introduction & Motivation

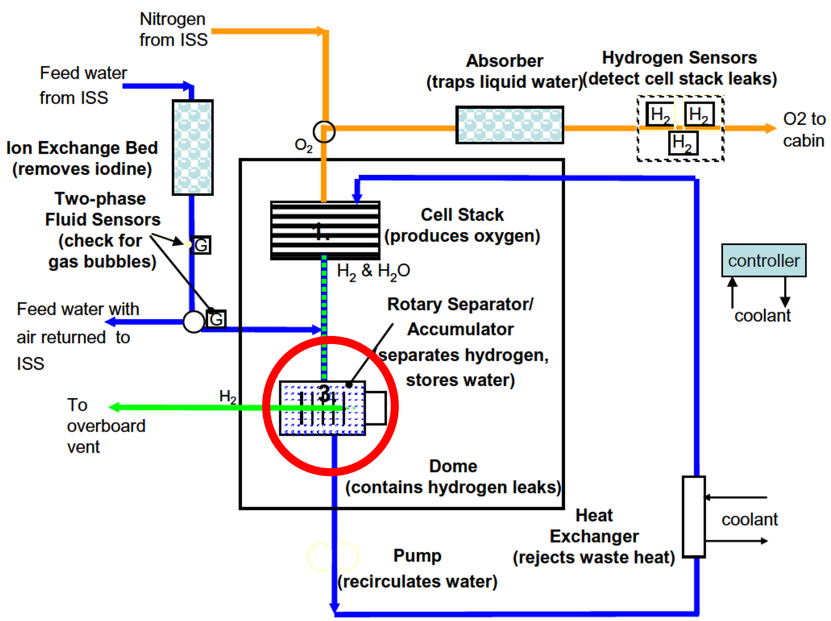
Mass transport issues in low-gravity electrolysis

Electrodes

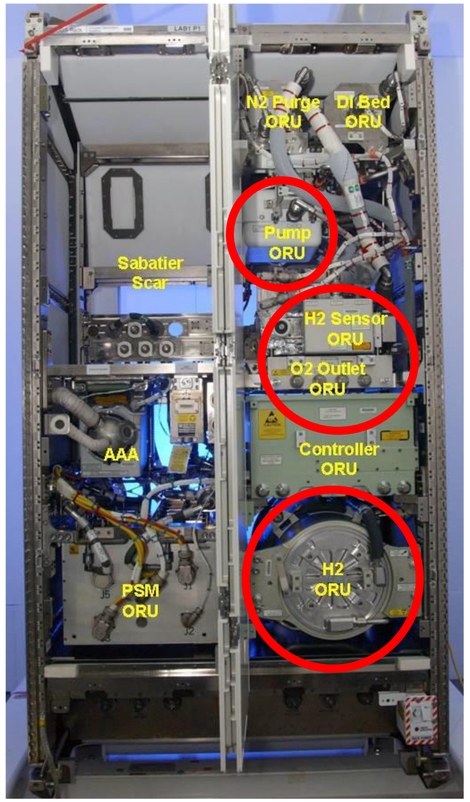


H. Matsushima et al., Water electrolysis under microgravity. Part 1. Experimental technique, Electrochimica Acta (48), 4119-4125, 2003

ISS Oxygen Generation Assembly



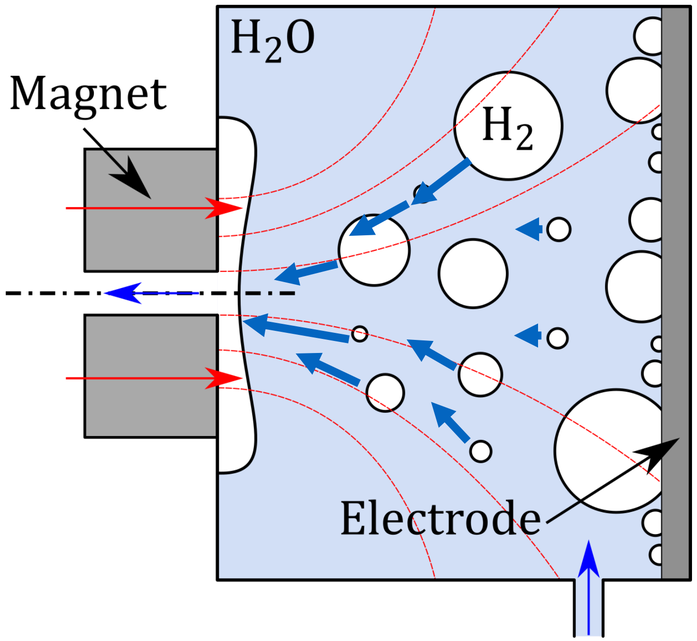
R.J. Erickson et al., International Space Station United States Orbital Segment Oxygen Generation System On-orbit Operational Experience, AE Int. J. Aerosp. 1(1):15-24, 2009



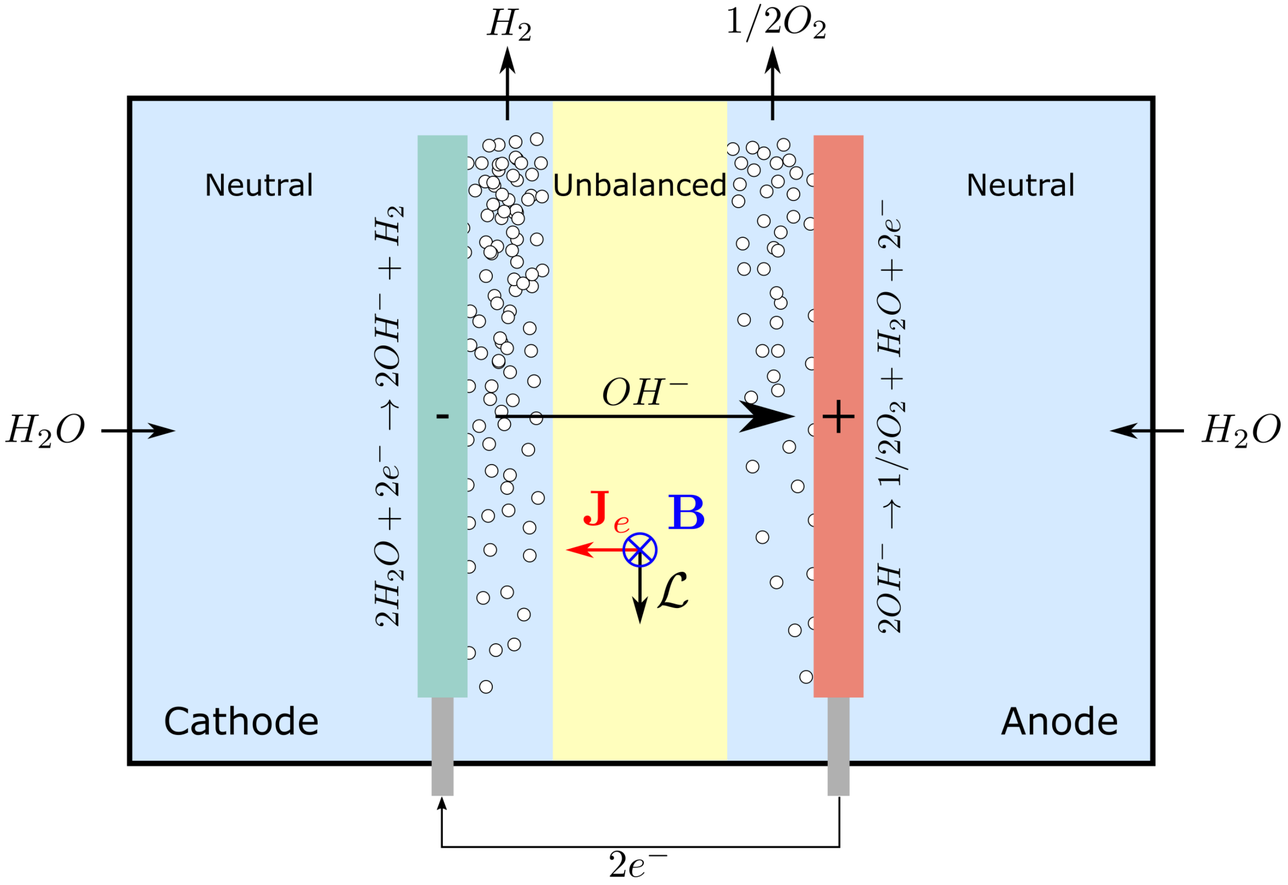
https://youtu.be/KIJsVqc0ywM

Magnetically enhanced electrolysis

Diamagnetic approach



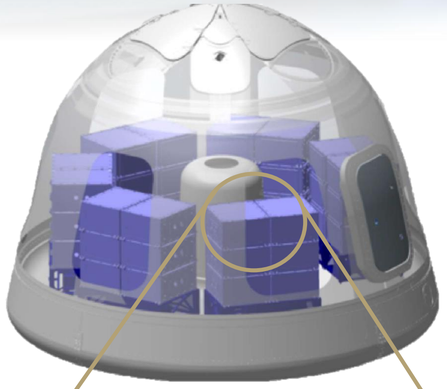
Lorentz-force approach

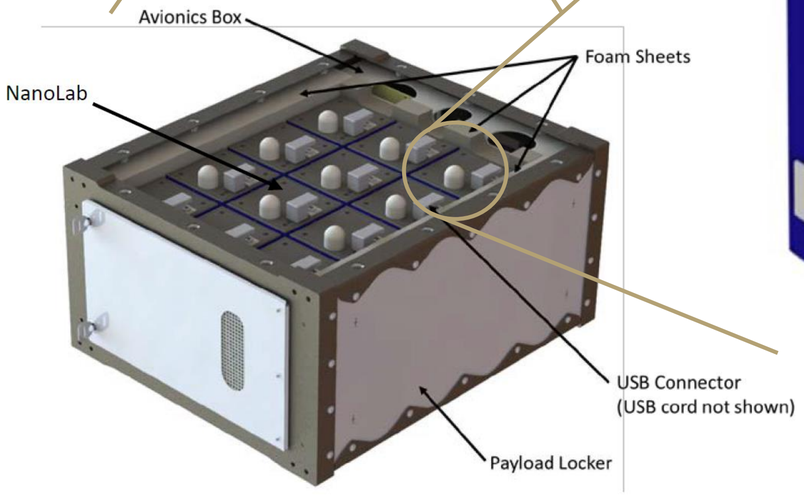


Romero-Calvo Á, Cano-Gómez G, Schaub H., "Diamagnetically Enhanced Electrolysis and Phase Separation in Low Gravity", Journal of Spacecraft and Rockets, 2021, *in press*

Blue Origin's New Shepard

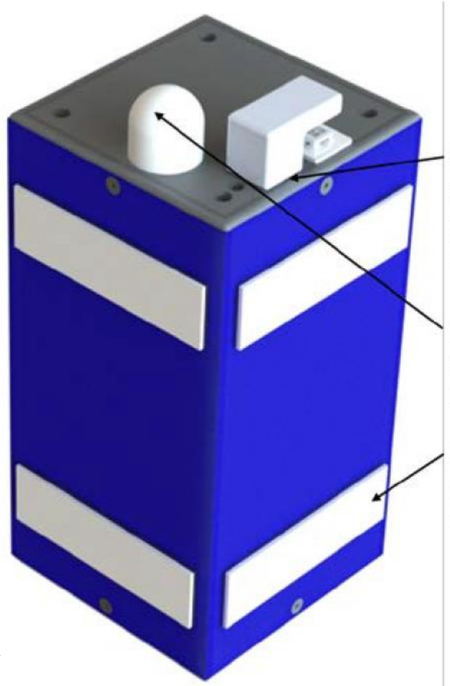
Blue Origin's New Shepard





NanoRacks Feather Frame

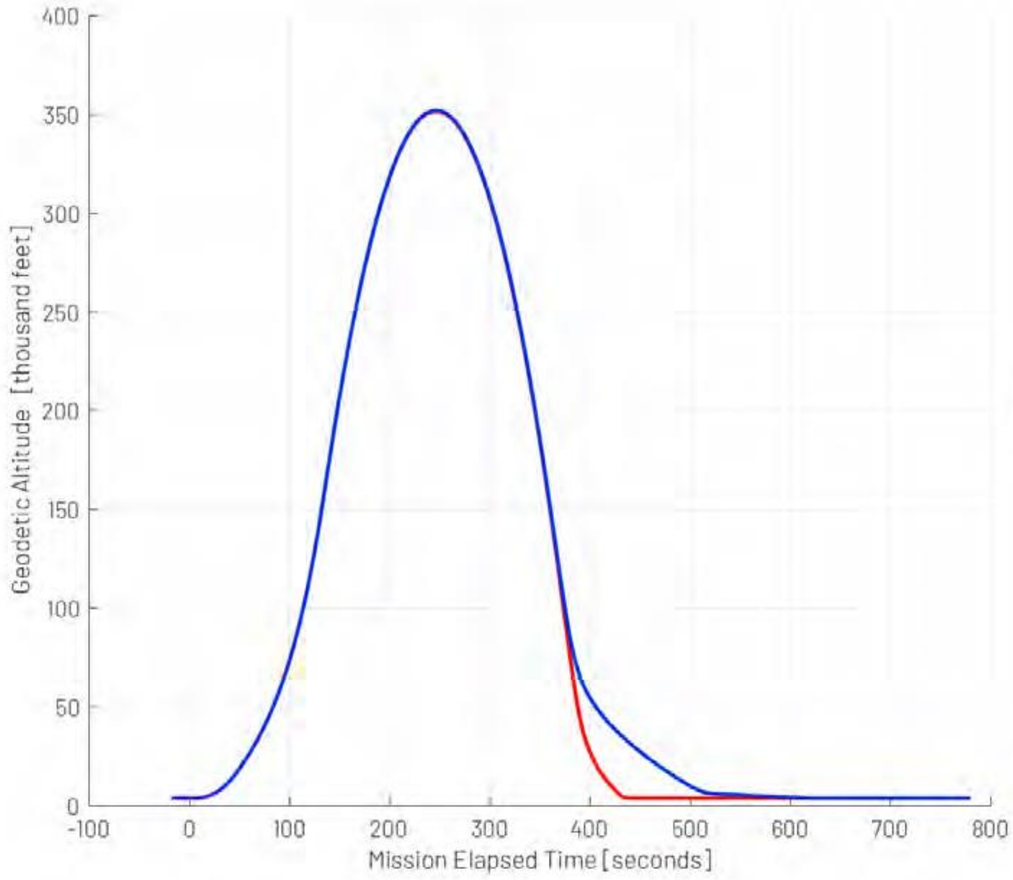
2U, 0.5 kg payload

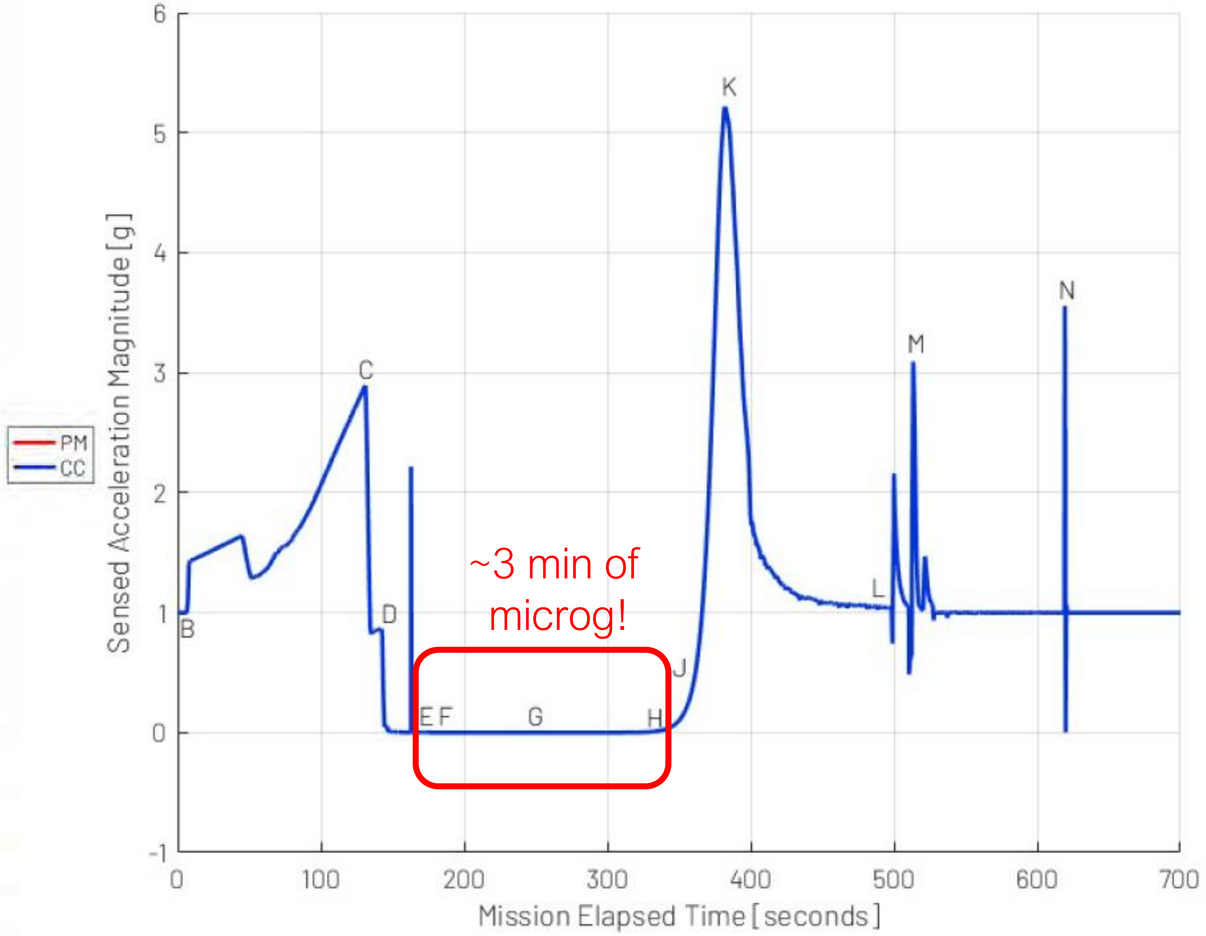


New Shepard Payload User's Guide, Sept 2019

Mission profile

New Shepard Payload User's Guide, Sept 2019





Scientific Objectives
&
Payload Requirements

Technology demonstrator: ASGSR Ken Souza 2020

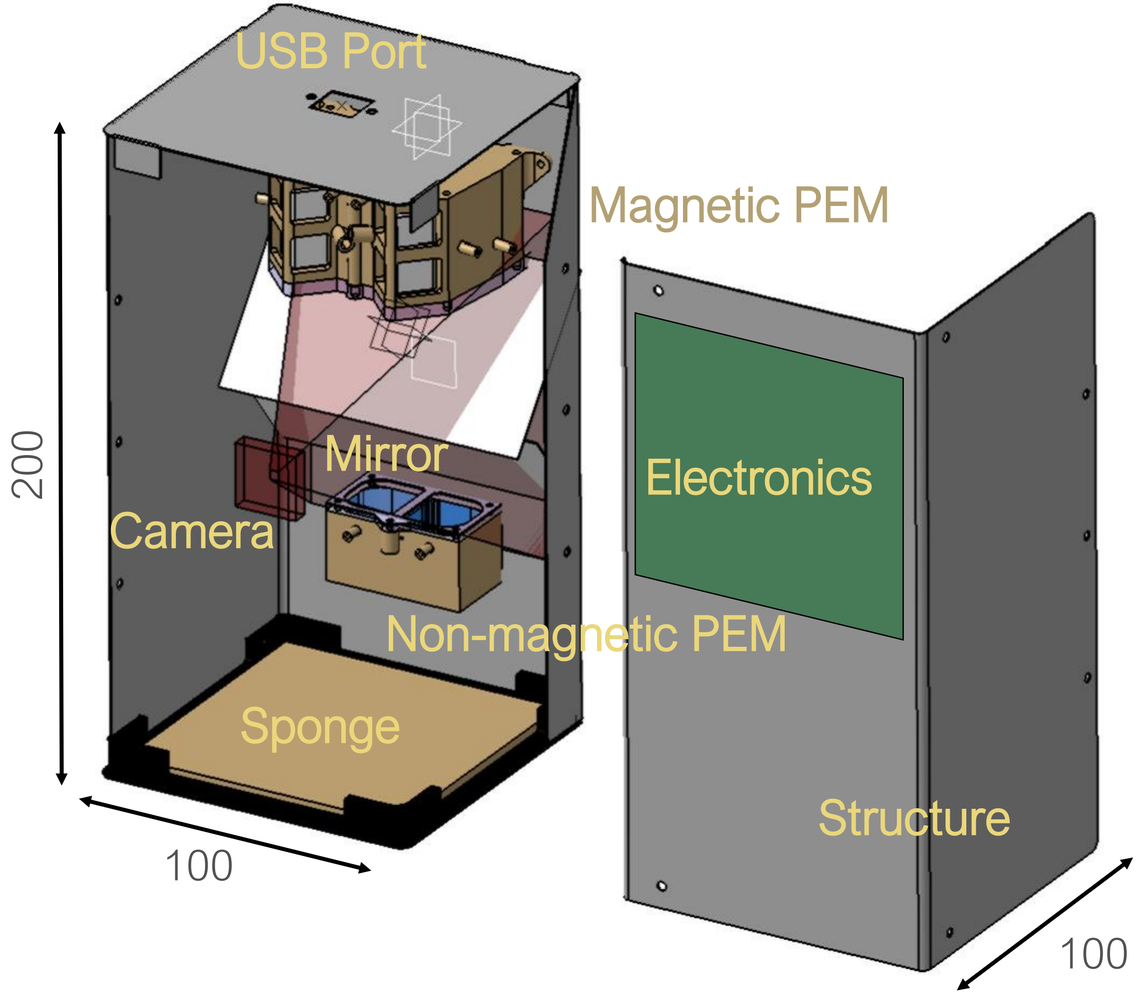
Objectives:

1. Assess the capability of N52 neodymium magnets to **induce liquid/gas phase separation** in low-gravity and to **passively detach** H_2 or O_2 bubbles from the electrode of an electrolytic cell.

2. Study the impact of magnetic buoyancy on the **performance** of an electrolytic cell in microgravity (**voltage** & **current**).

3. Analyze the **dynamics of bubbles in low-gravity** in the presence of inhomogeneous magnetic fields.

Units in mm



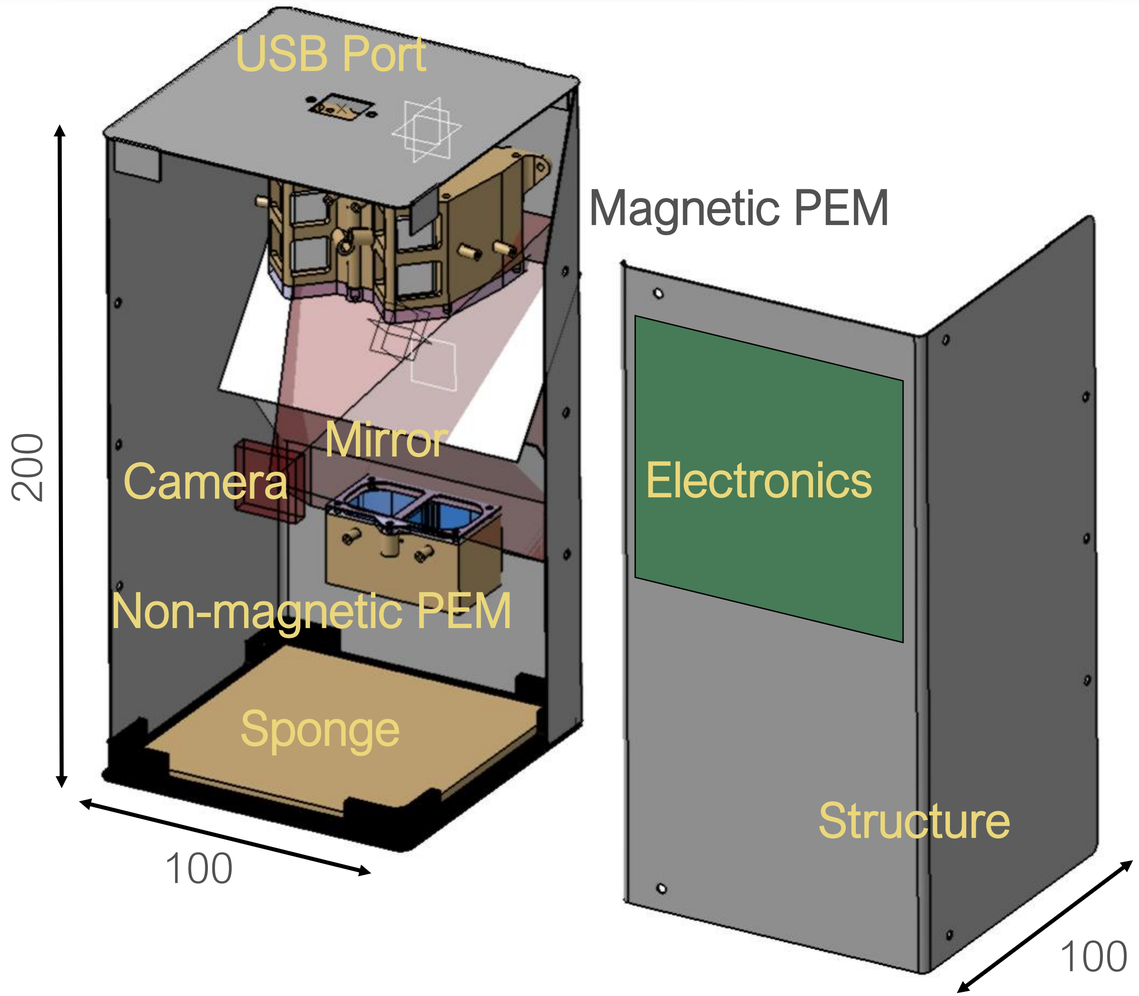
Payload Requirements

- May contain **up to 150 ml of approved non-hazardous liquids** –OR– Blue Origin Mini Payload approved batteries without fluids with **2 containment layers**
- Contains **no significant hazards** (**chemical**, biological, stored energy, or **RF transmitters**).
- Hardware dimensions shall not exceed **10x10x20 cm**
- Total mass shall not to exceed **0.5 kg**.
- Blue Origin provides **5V and 0.9 A of power** and **mission data via USB** connector from **~5m before launch** to ~5m after landing
- Standard operations:
  - Payload shipment to be received no later than **L-2 weeks**; integration by Blue Origin into the vehicle on **L-4 days**
  - Removal from vehicle estimated at L+8 hours
  - In the event of a launch scrub, payload will remain on the vehicle
  - No support services at Launch Site
  - Blue Origin to return Mini/Nanolab via ground shipment back to the research team

Experiment setup

Overview

Units in mm



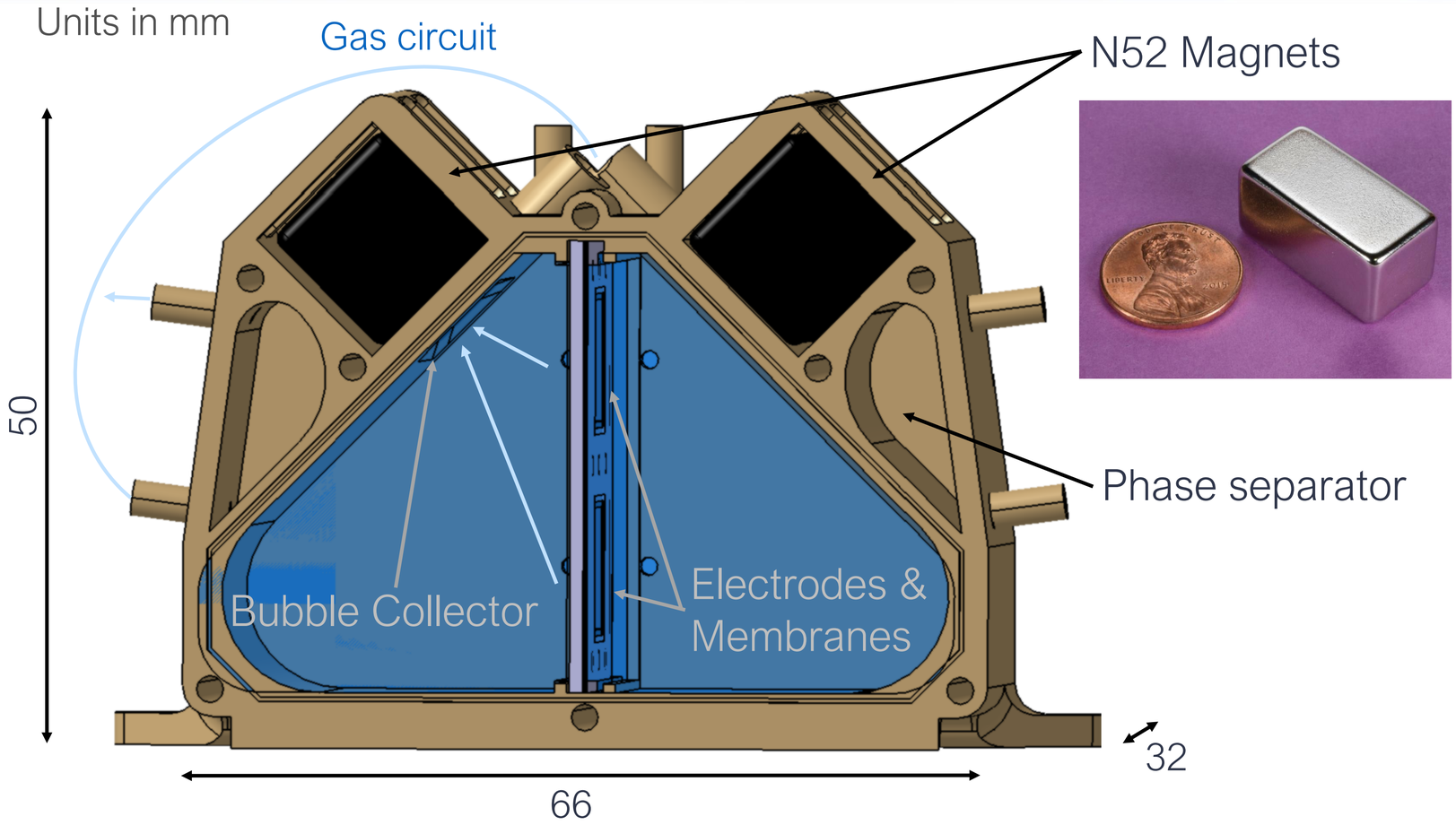
Experiment:

- 3 electrolytic cells in 2 cell assemblies
- Top cell is **magnetic**
- Bottom cell is **non-magnetic**
- Non-hazardous K_2SO_4 electrolyte

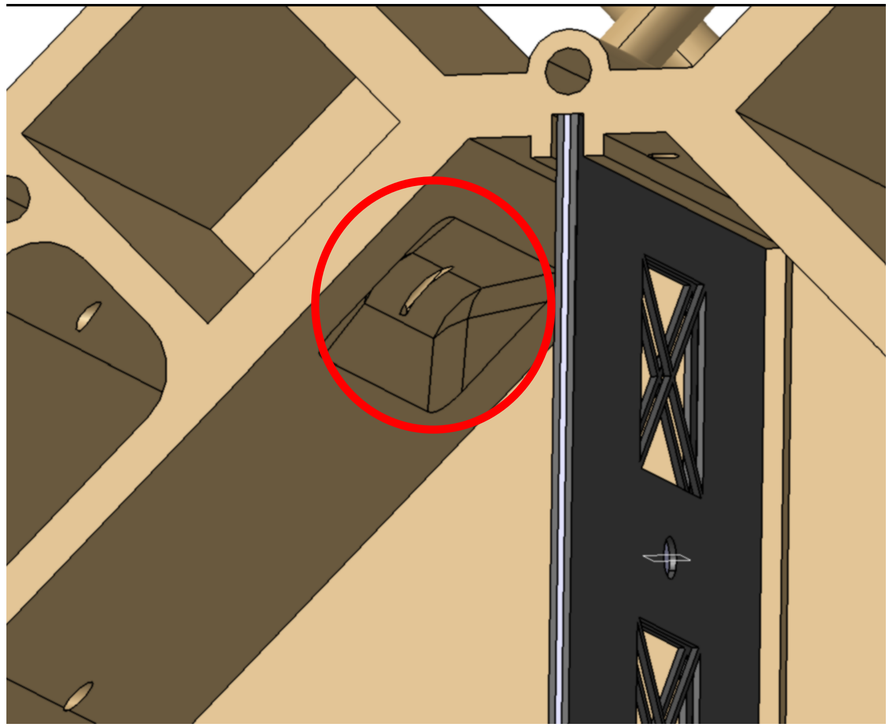
Measured variables:

- General visualization of bubbles
- Current (constant) and voltage through each cell
- Characteristic I-V curves of each cell

Magnetic assembly

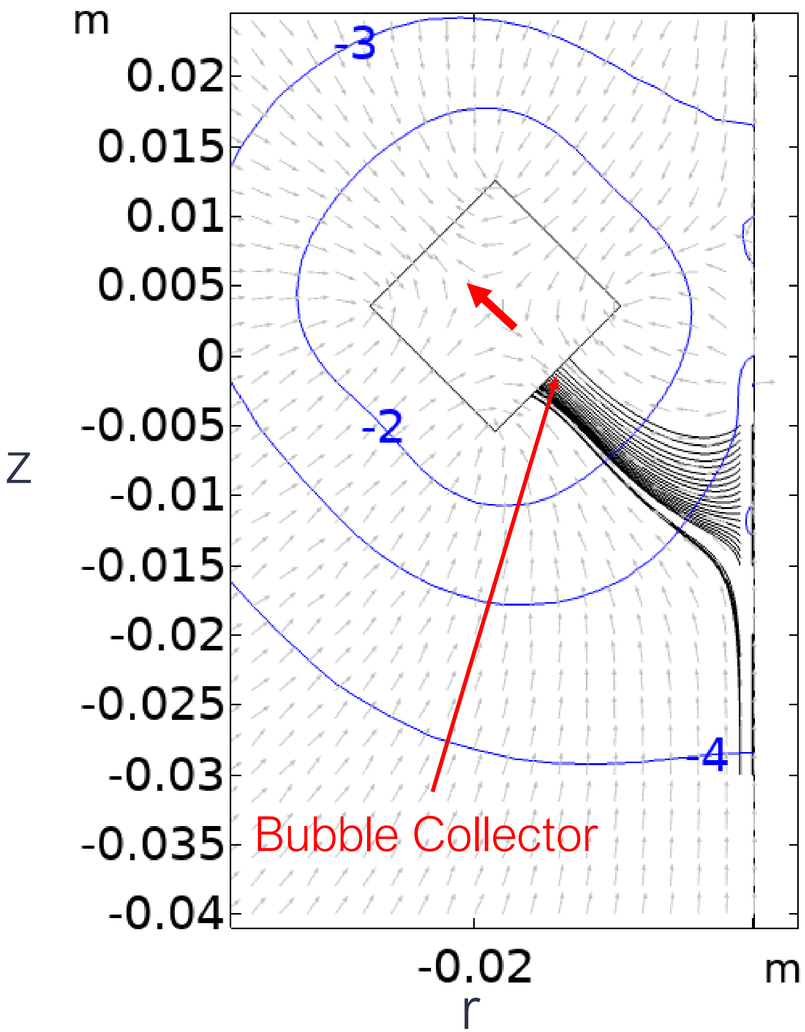


Bubble Collector



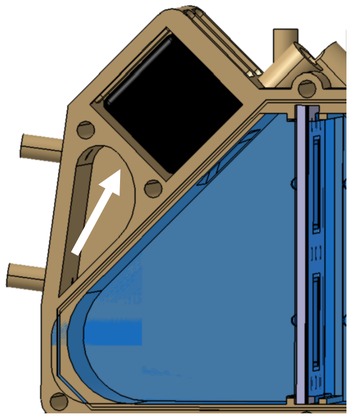
Rationale behind magnetic design

Bubble terminal velocity contours $[\log_{10}(v_m)]$

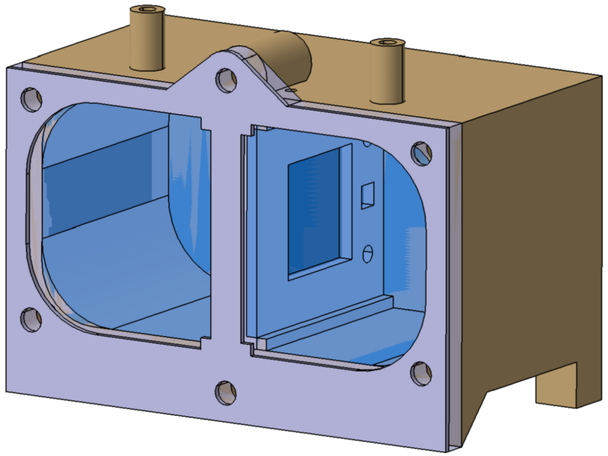


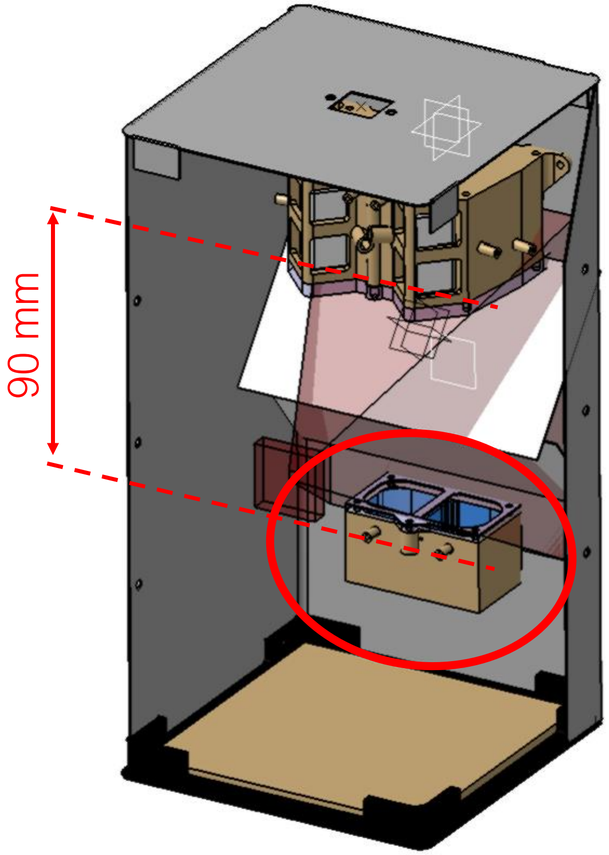
Goal: Maximize magnetic force with minimum mass & EMI

- Terminal velocities between 0.1 and 1 mm/s and **maximum gas flow rate** between 0.6 and 6 $\mathrm{cm}^3/\mathrm{min}$ at the surface of the electrodes (max production ~2 $\mathrm{cm}^3/\mathrm{min}$)
- Mass of 61.4 g (12% total weight)
- 2 modes of operation: normal traction (upper cell) and shear force (lower cell)
- **Phase separators**: magnetic buoyancy reinforces conduit geometry

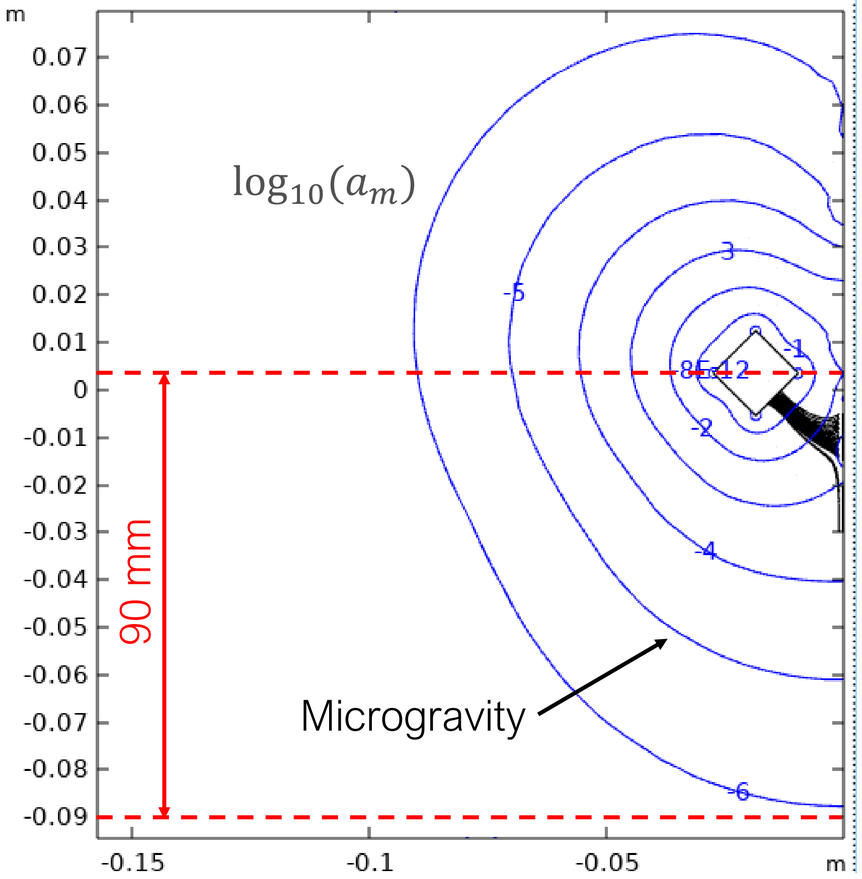


Non-magnetic assembly

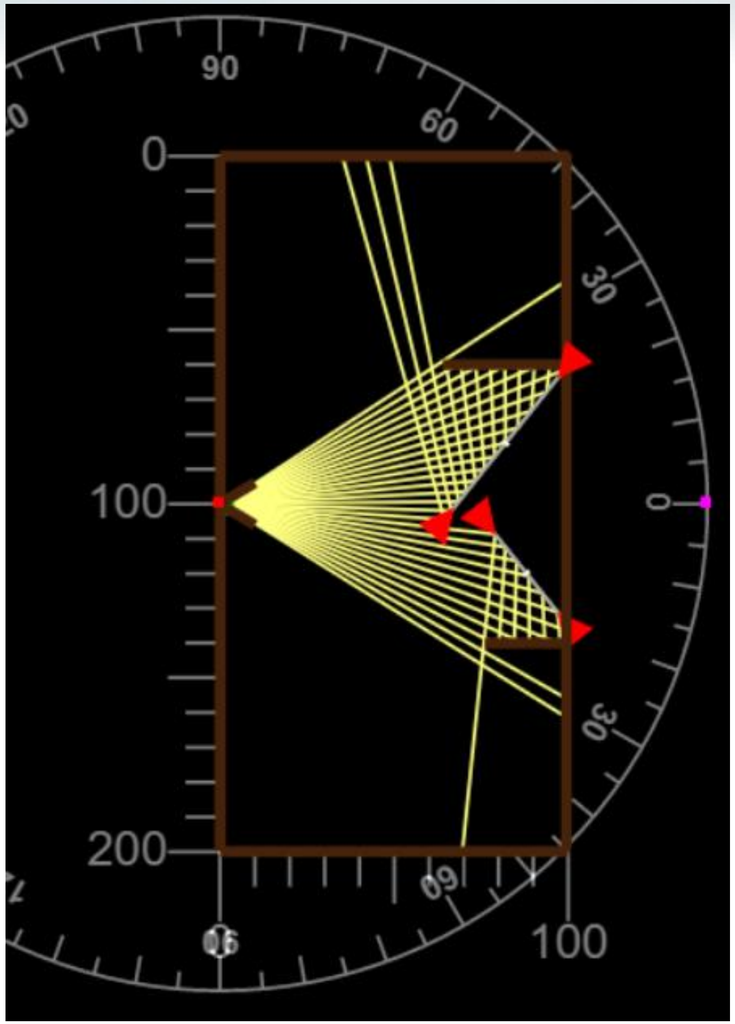




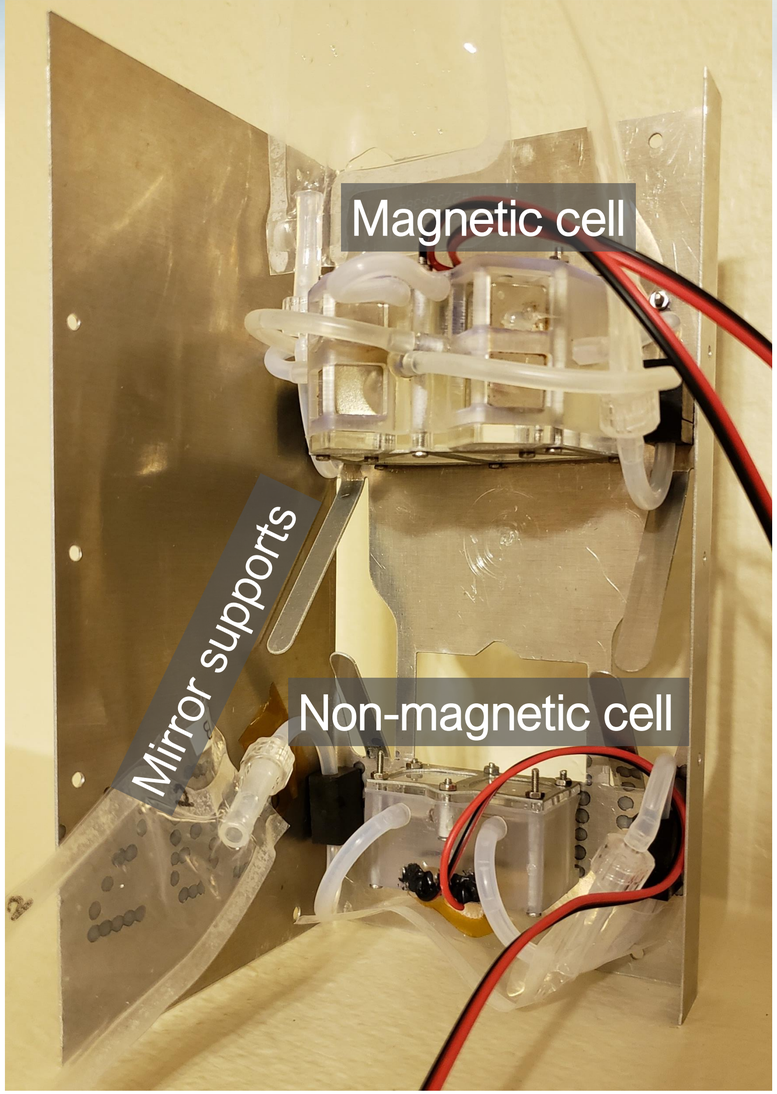
Magnetic acceleration contours (log)



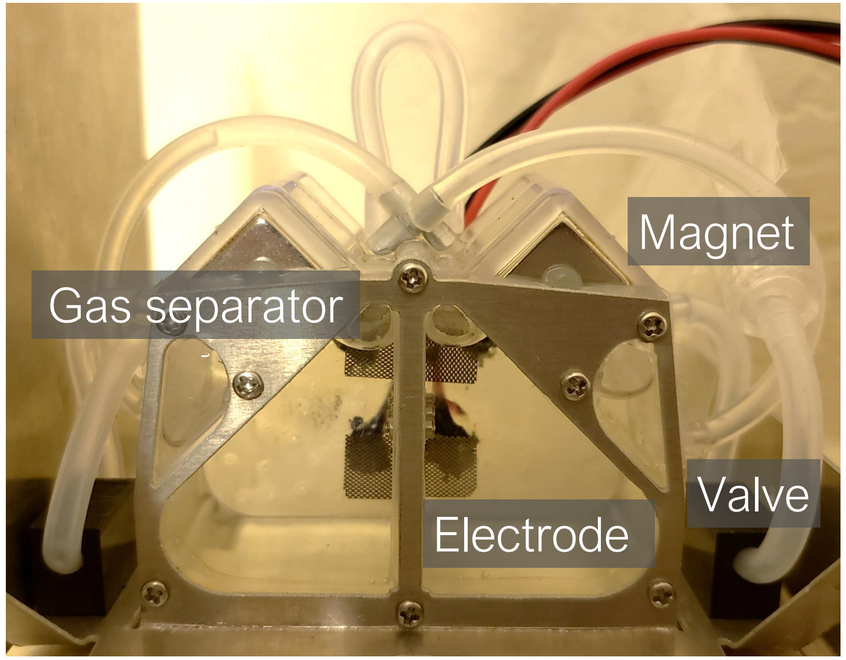
Visualization system



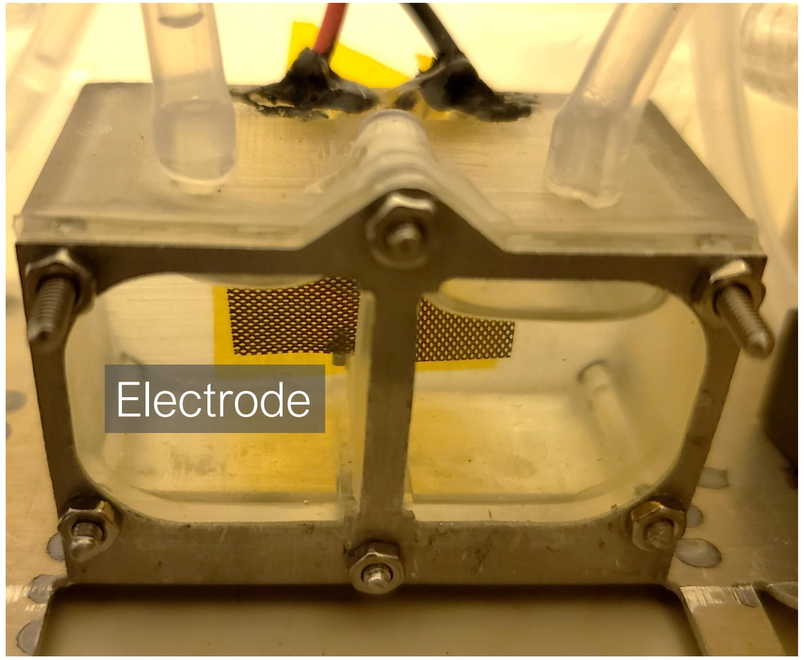
Cell implementation



Magnetic cell

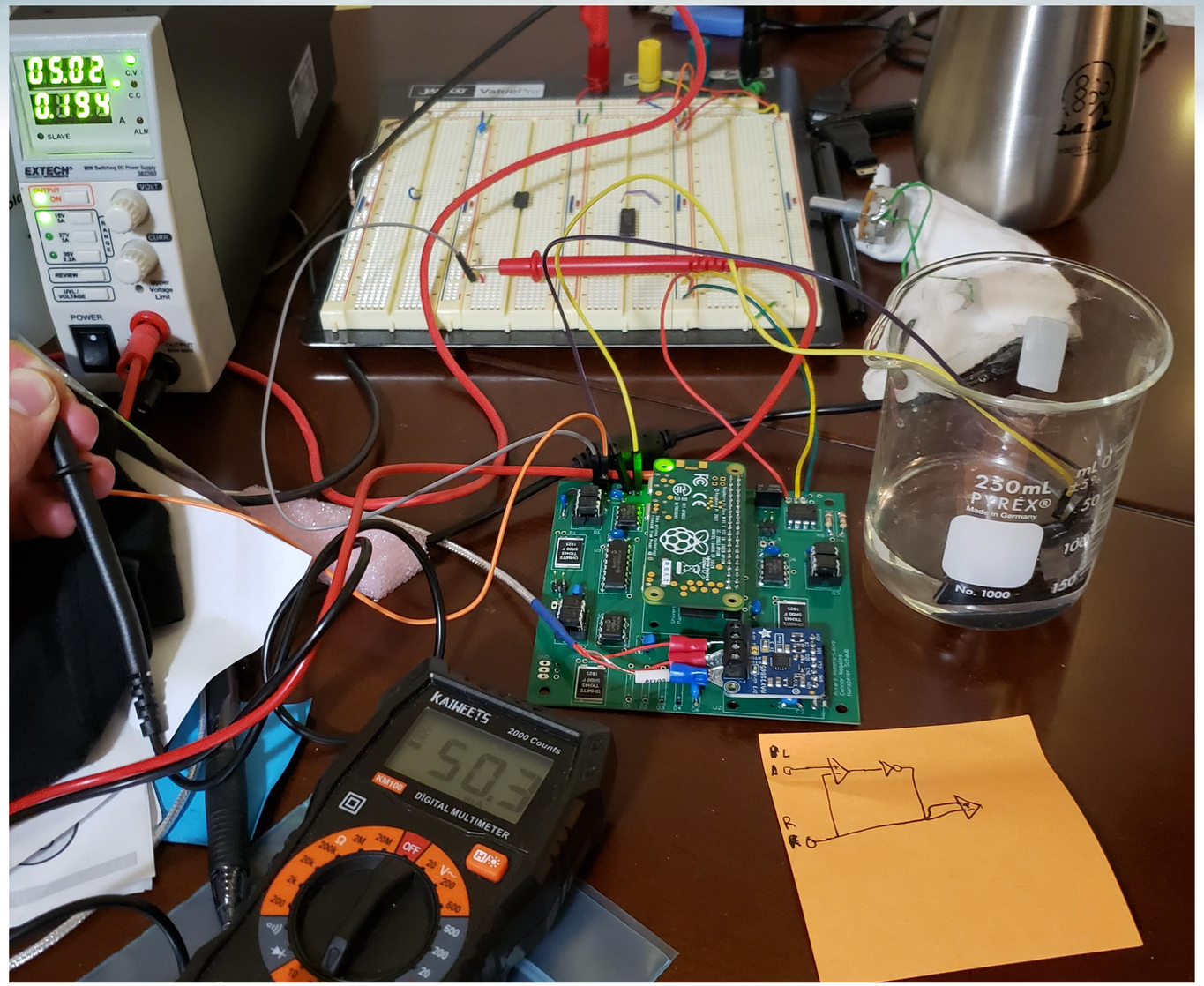


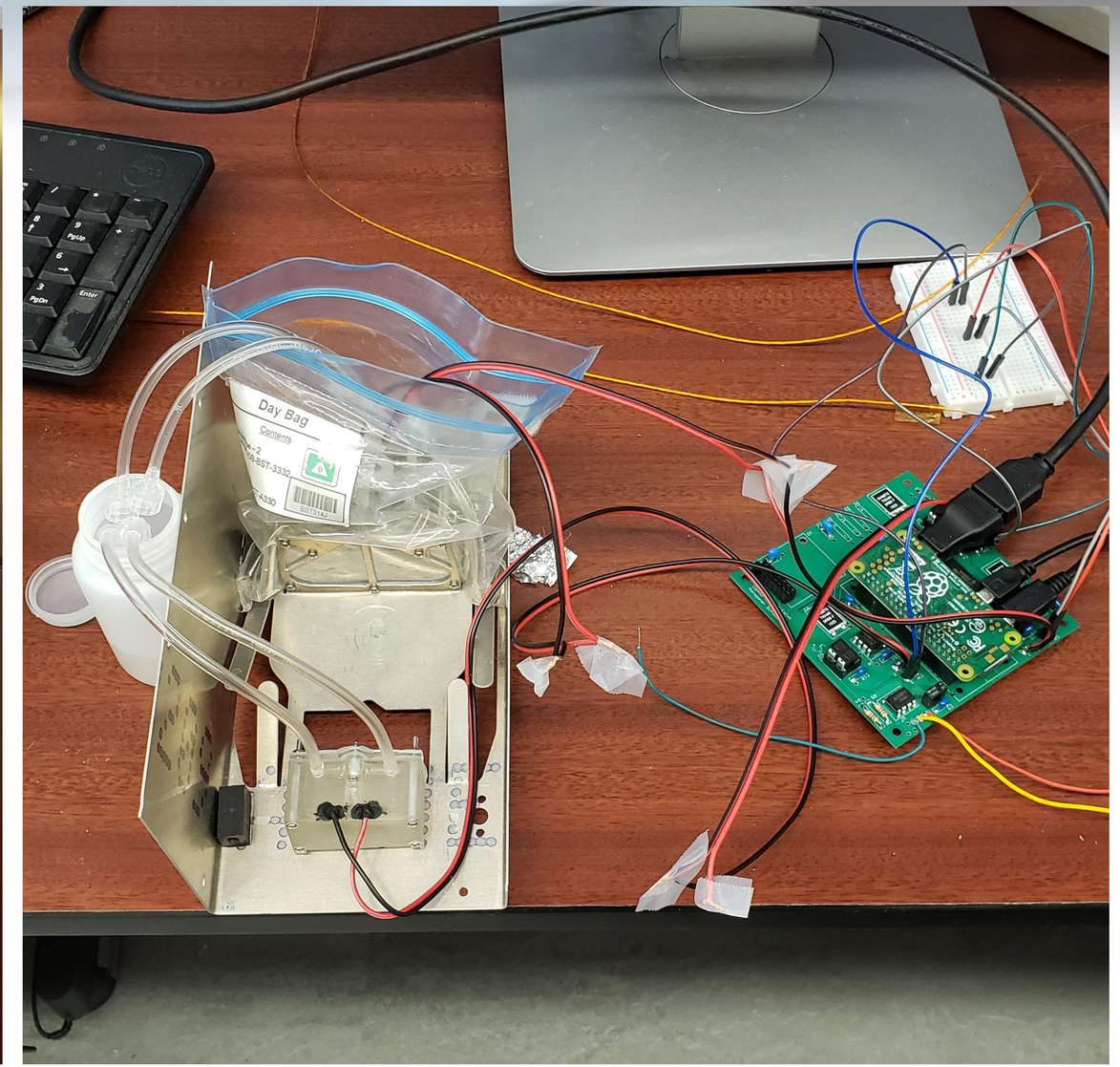
Non-magnetic cell



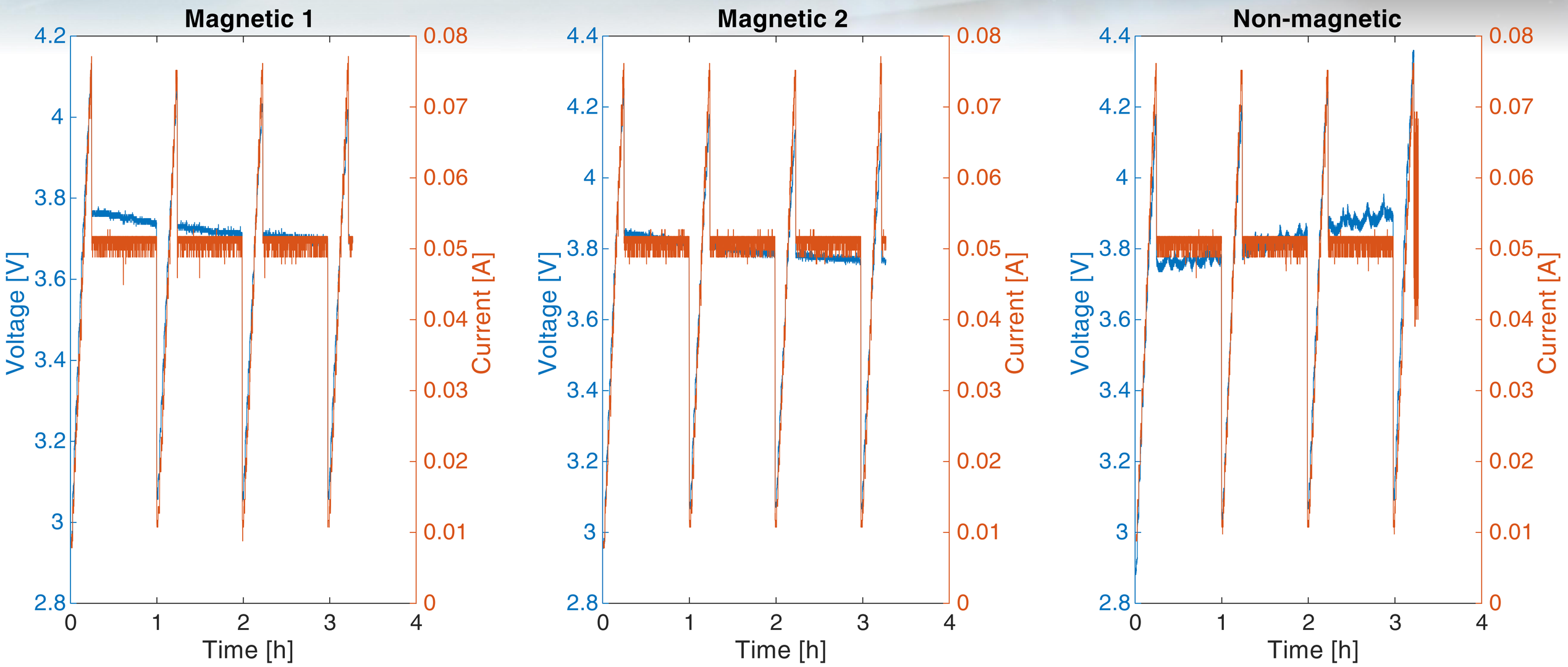
(Some) tests

Electronics

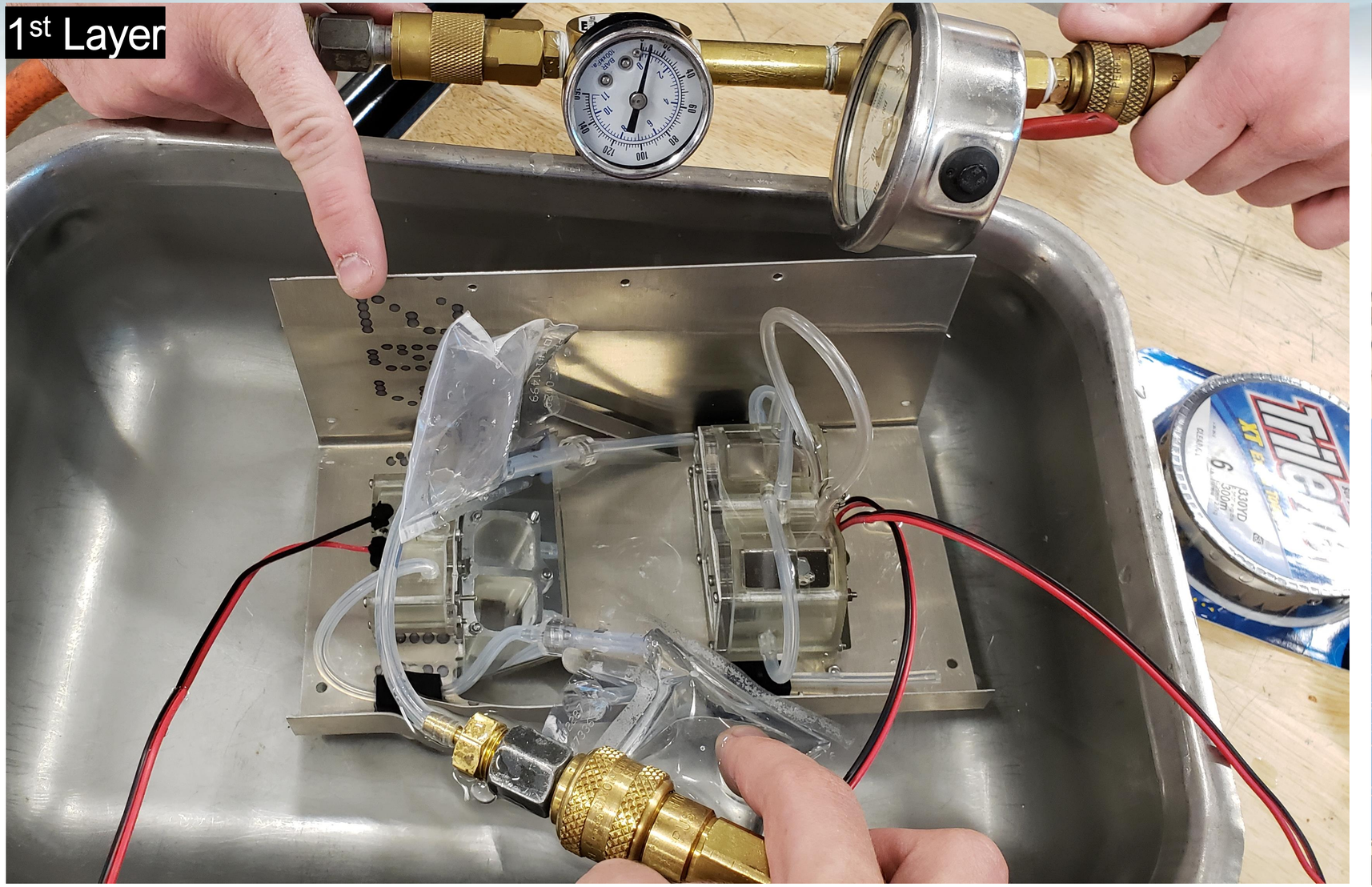




Current control system



Pressure tests (10 PSI)



Conclusions

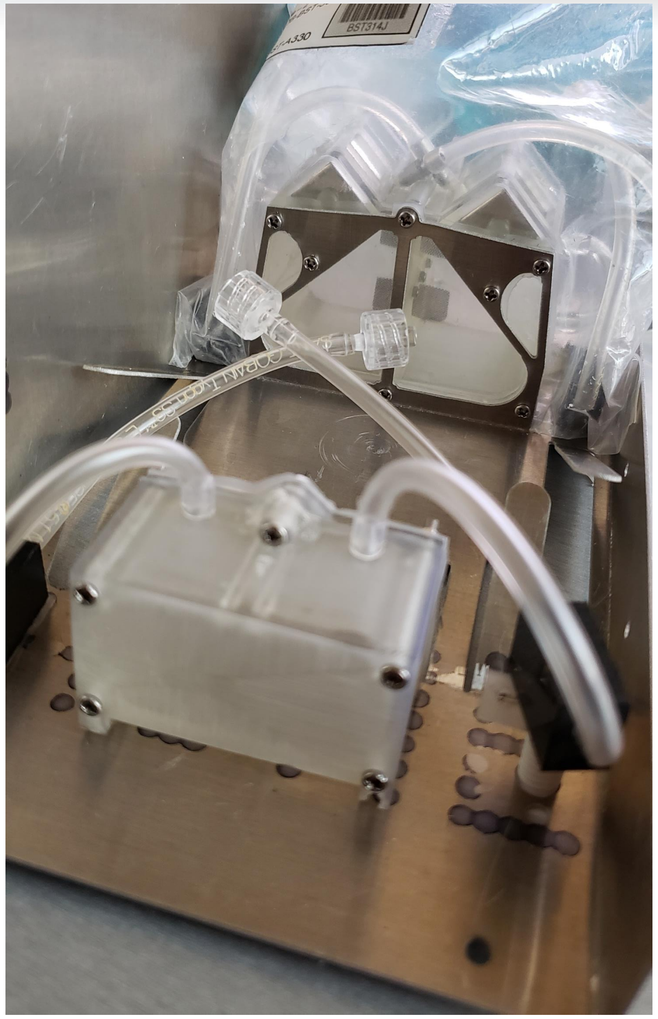
Conclusions

1. **Phase separation** accounts for significant mass and power penalties in low-gravity electrolysis, a problem that may be addressed using **diamagnetic buoyancy**

2. The ASGSR Ken Souza 2020 experiment is a **technology demonstrator** aimed at studying this new approach

3. At the time of writing, the **design is completed**, pending minor adjustments

4. Current efforts are focused on **ensuring proper sealing** at 10 PSI while **satisfying the mass budget** and **maximizing the capabilities** of the PCB controller



Acknowledgements

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ASGSR

BLUE ORIGIN

NASA JPL

"la Caixa" Foundation

BioServe
SPACE TECHNOLOGIES

Questions…?

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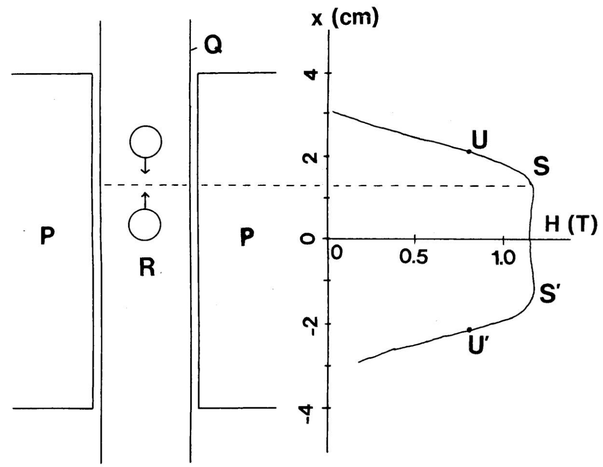
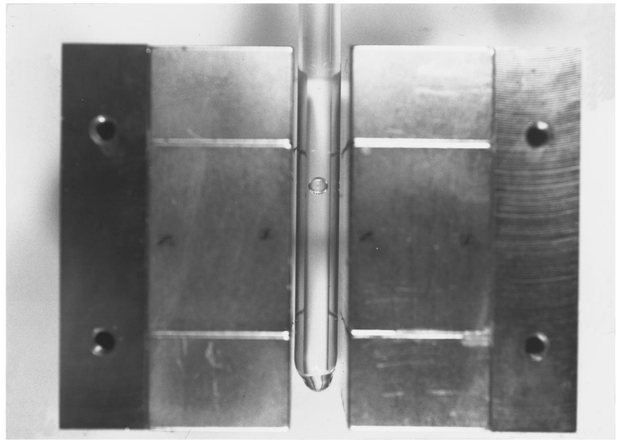
Backup Slides

Previous works



(a)



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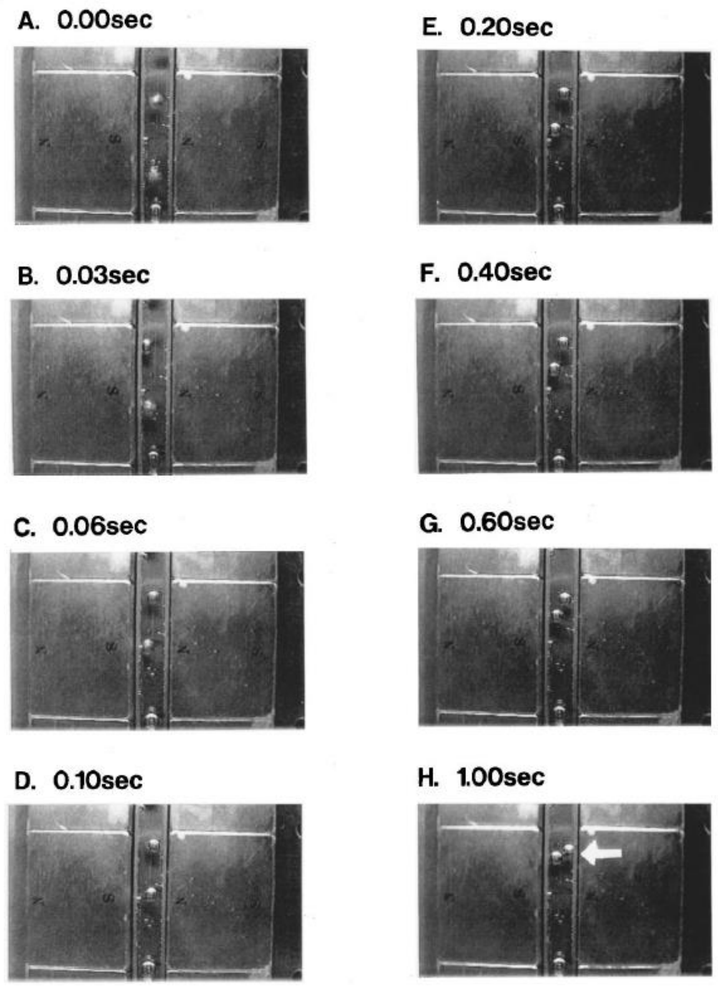
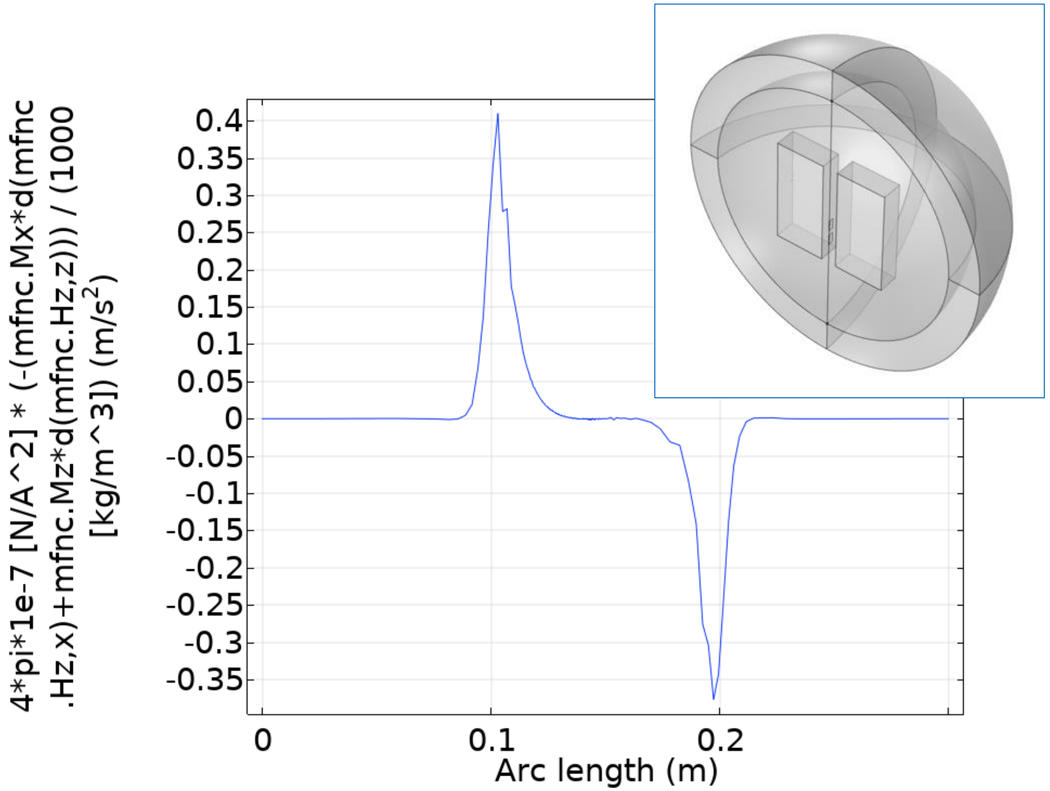




N. I. Wakayama, Magnetic buoyancy force acting on bubbles in nonconducting and diamagnetic fluids under microgravity, Journal of Applied Physics 81, 2980 (1997)

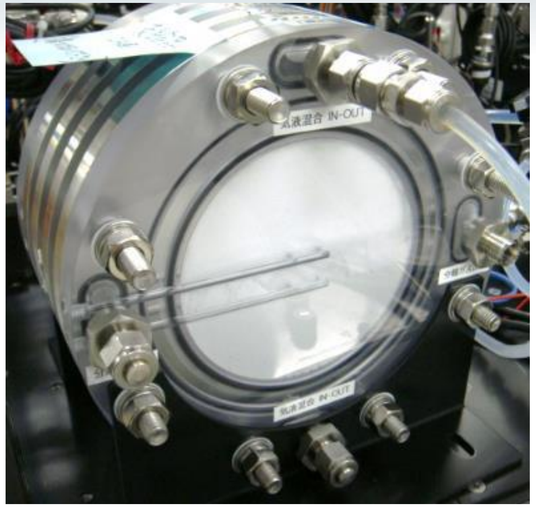
How strong is the diamagnetic force?

https://youtu.be/BxyfiBGCwhQ

- 1.25 cm radius sphere rotating at ~3.5 rad/s → Maximum buyoyancy accelerations of $\sim 5 \cdot 10^{-4}\ \mathrm{m/s^2}$ (increases with r^2)
- Magnetic acceleration of $10^{-3} - 10^{-2}\ \mathrm{m/s^2}$
- Should work!

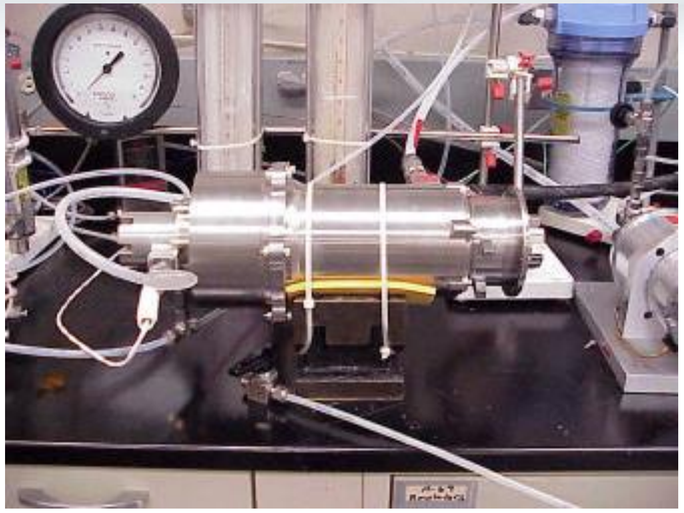
Phase separation technologies

Membranes



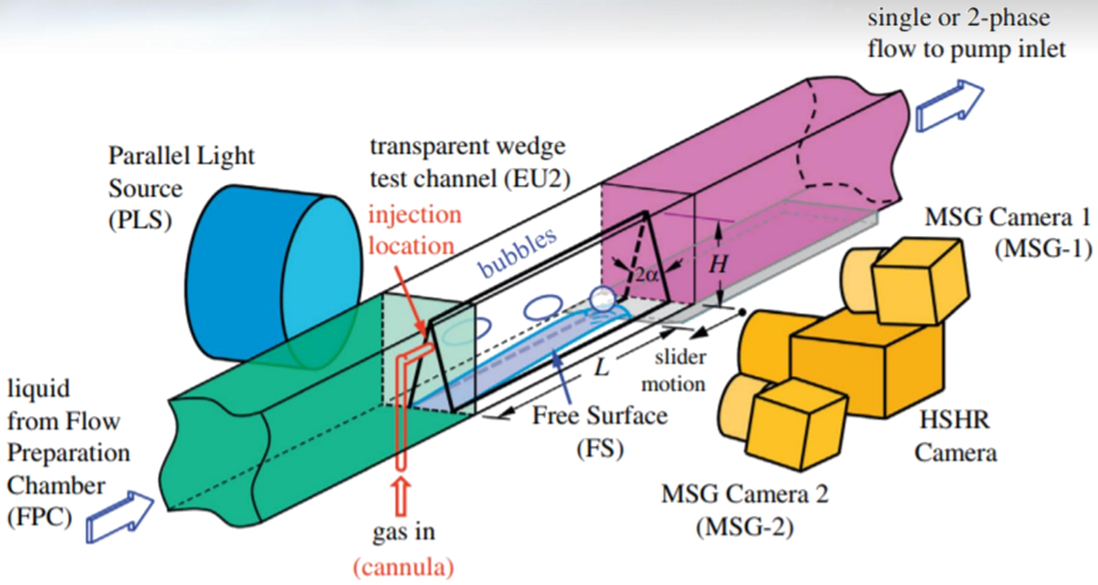
M. Sakurai, andT. Terao, Study of Water Electrolysis Under Microgravity Conditions for Oxygen Generation – Applied to a Ground Demonstration system and Development of New Systems, 46th Int. Conf. on Env. Sys., 10-14 July 2016, Vienna Austria

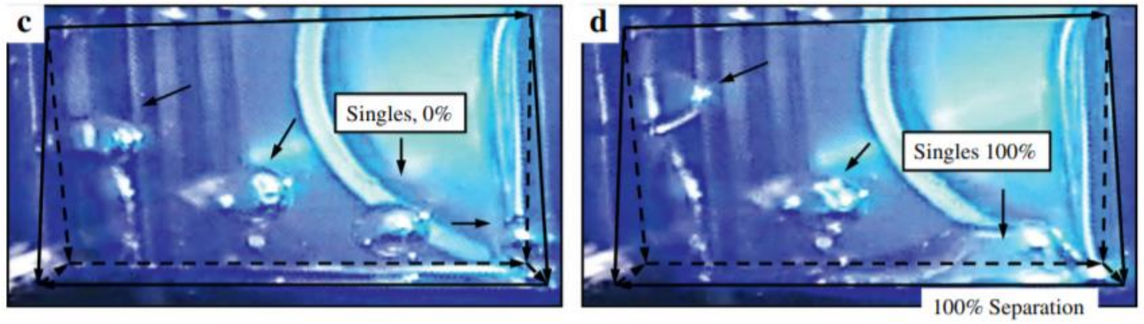
Rotary devices



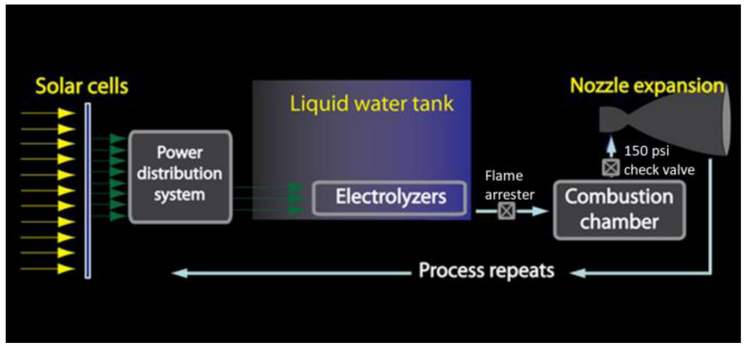
D. J. Samplatsky, and W. Clark Dean, Development of a Rotary Separator Accumulator for Use on the International Space Station

Conduit geometries





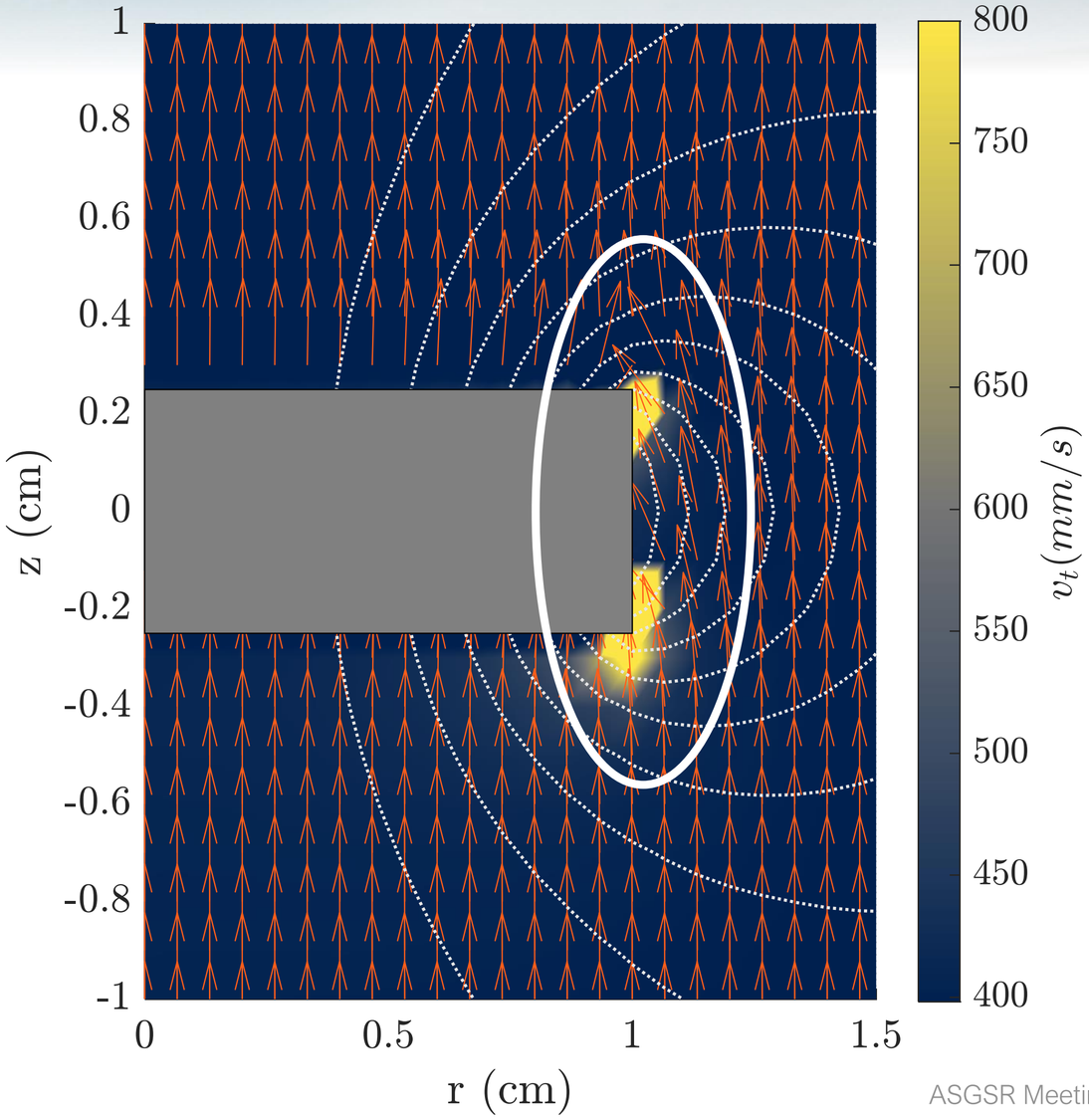
F. Jenson et al. "Passive phase separation of microgravity bubbly flows using conduit geometry", International Journal of Multiphase Flow 65 (2014), 68-81



SC Spin

K.P. Doyle and M.A. Peck, Water Electrolysis Propulsion as a Case Study in Resource-Based Spacecraft Architecture, IEEE ASE Systems Magazine (34) 9, 4-19, 2019

Diamagnetic approach in Lunar environment



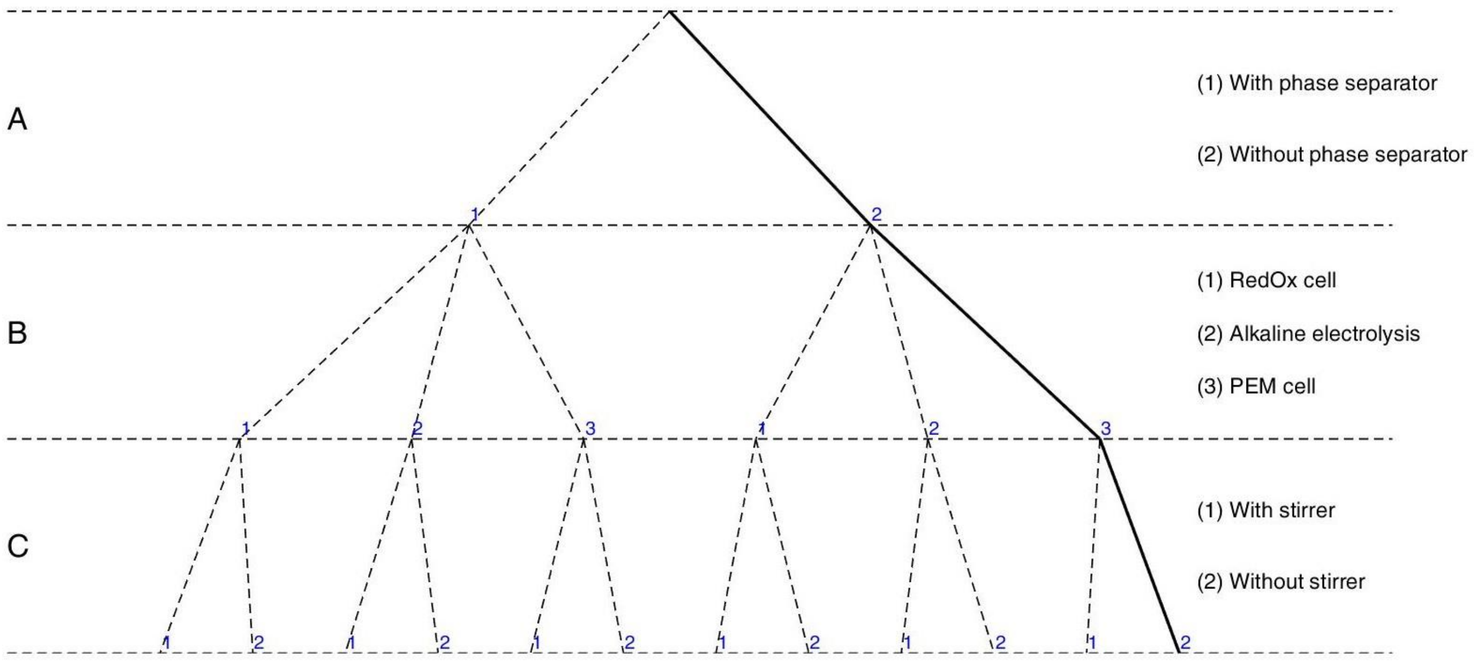
- 1 mm O_2 bubble in deionized water at 25º C and 1 atm
- Magnet with residual magnetic flux density of 1430 mT
- Lunar conditions ($g \approx 1.62\ m/s^2$)

- Diamagnetism does not determine **mass transport** in a lunar setting*.
- However, **micro-MHD enhancements** may be induced with suitable electrodes**

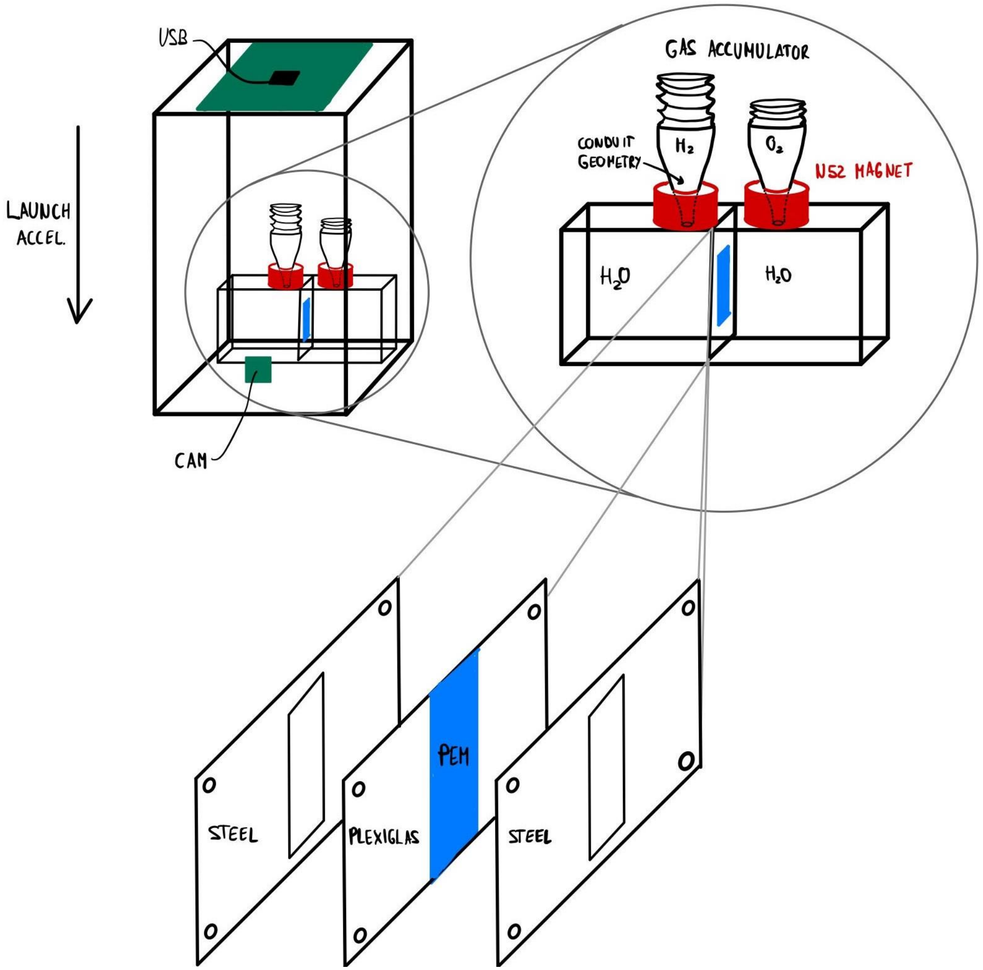
* Discarding superconducting electromagnets (30-60 times stronger)

** Farmani and Nasirpouri, "Boosting hydrogen and oxygen evolution reactions on electrodeposited nickel electrodes via simultaneous mesoporosity, magnetohydrodynamics and high gradient magnetic force", J. Mater. Chem. A 8, 24782, 2020

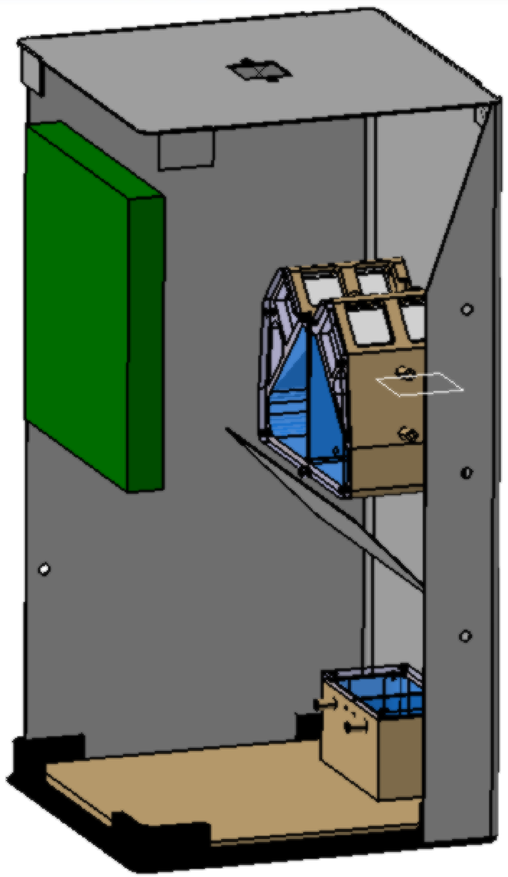
Architecture selection

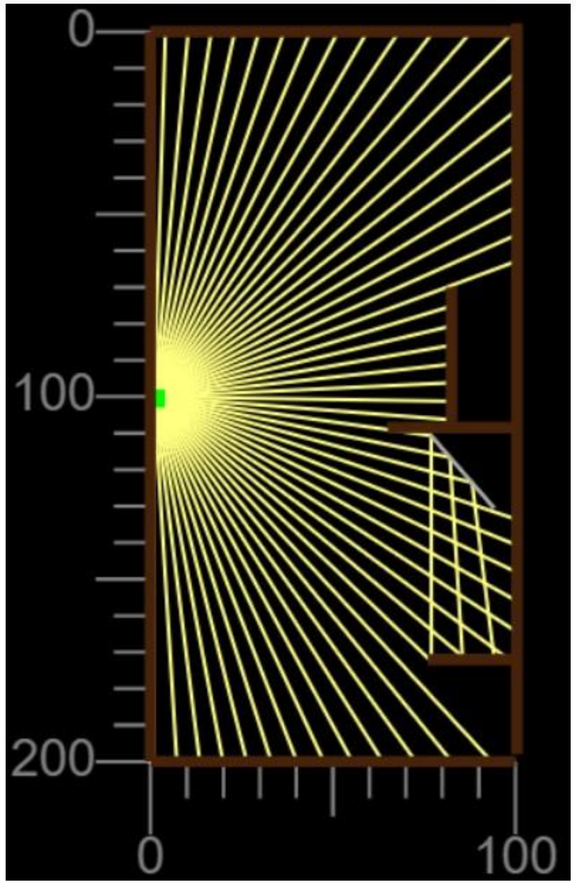


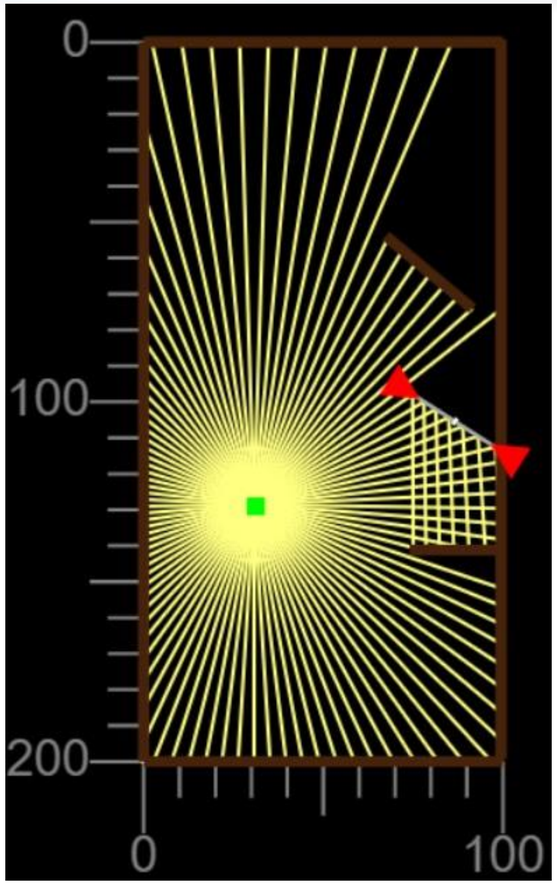
12 Design Options

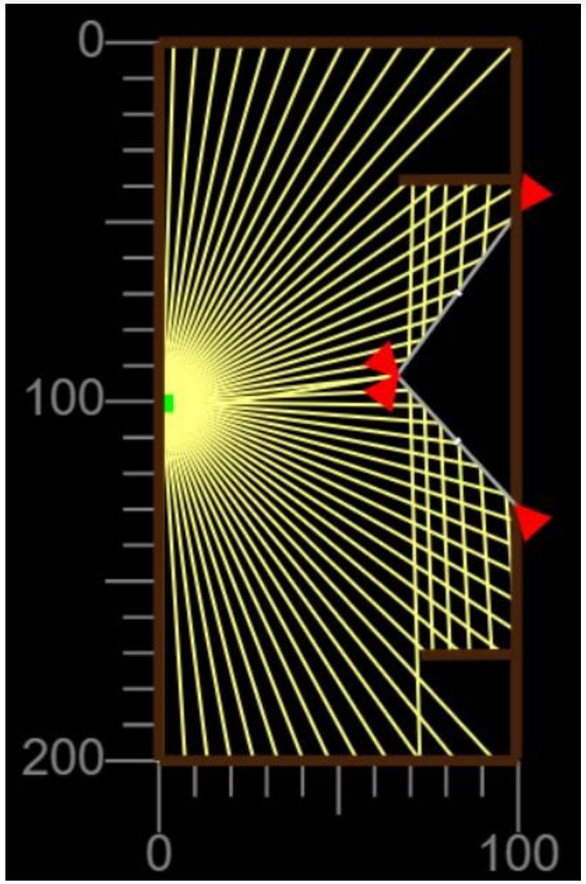


Optical design

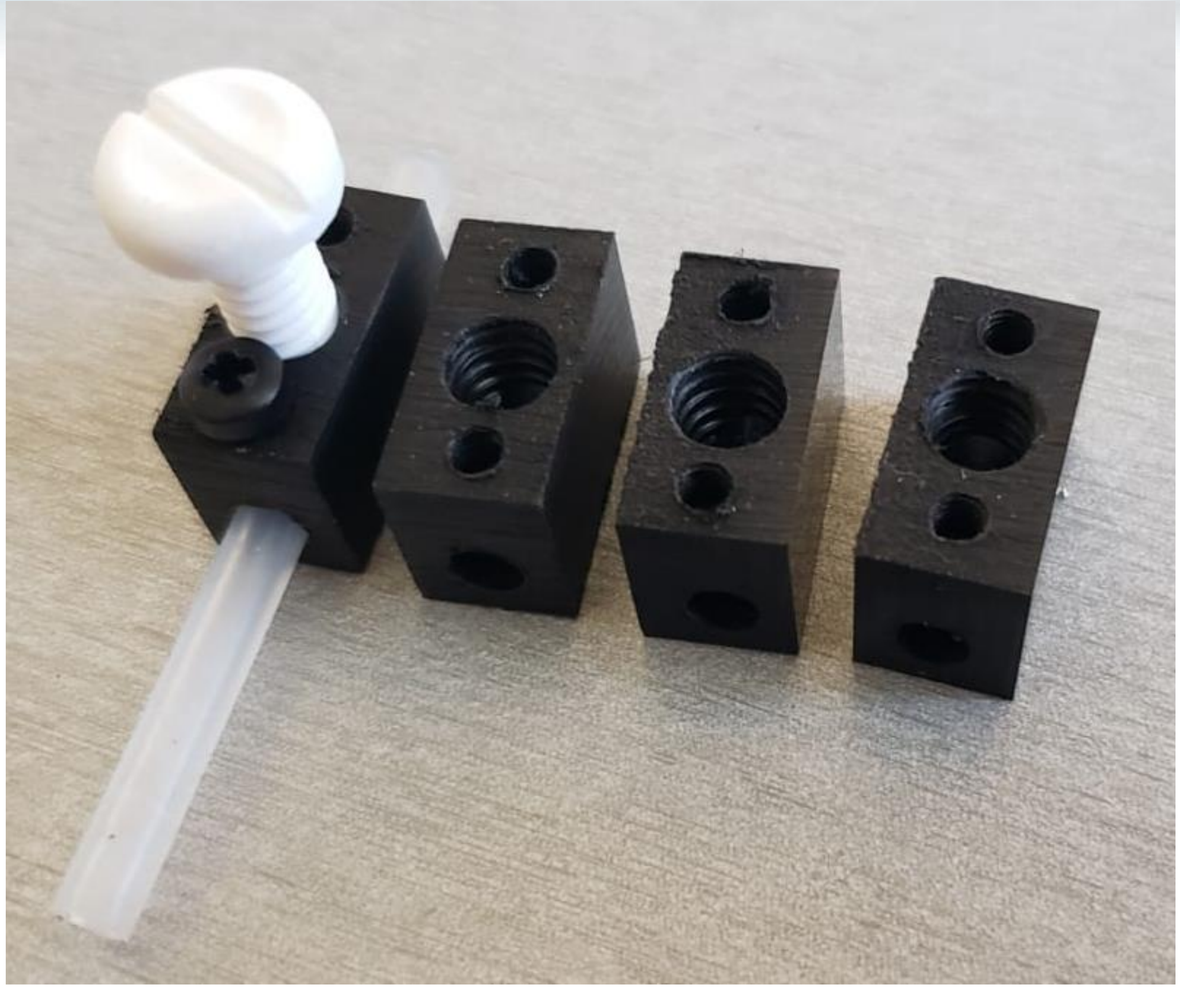


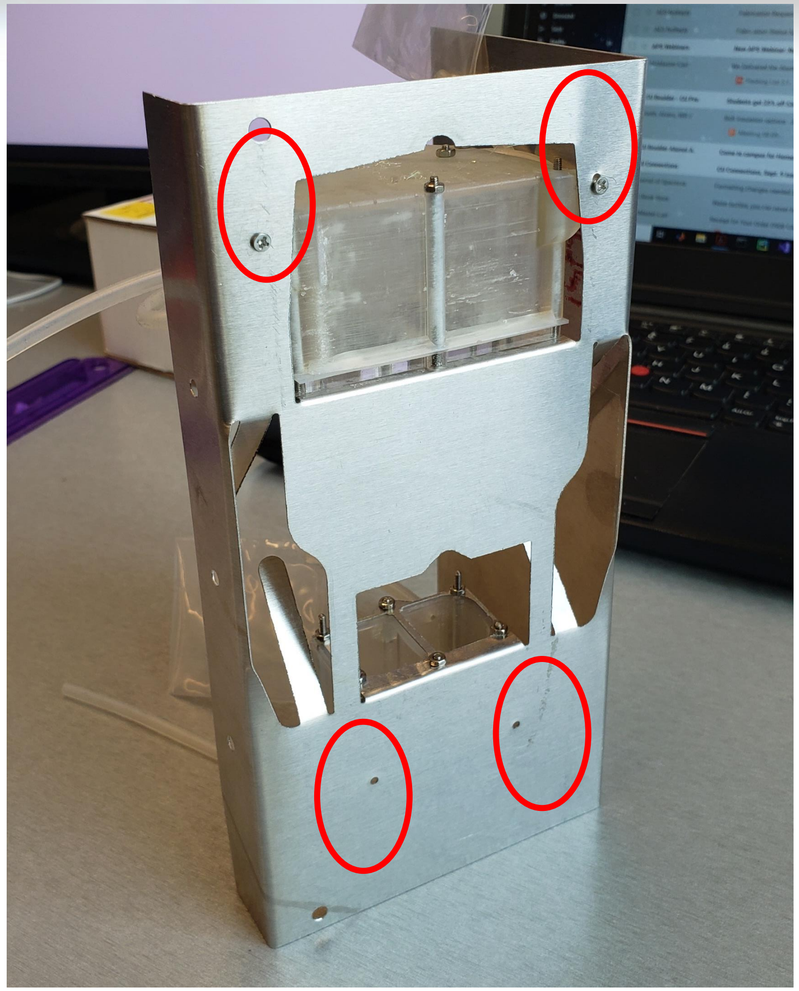




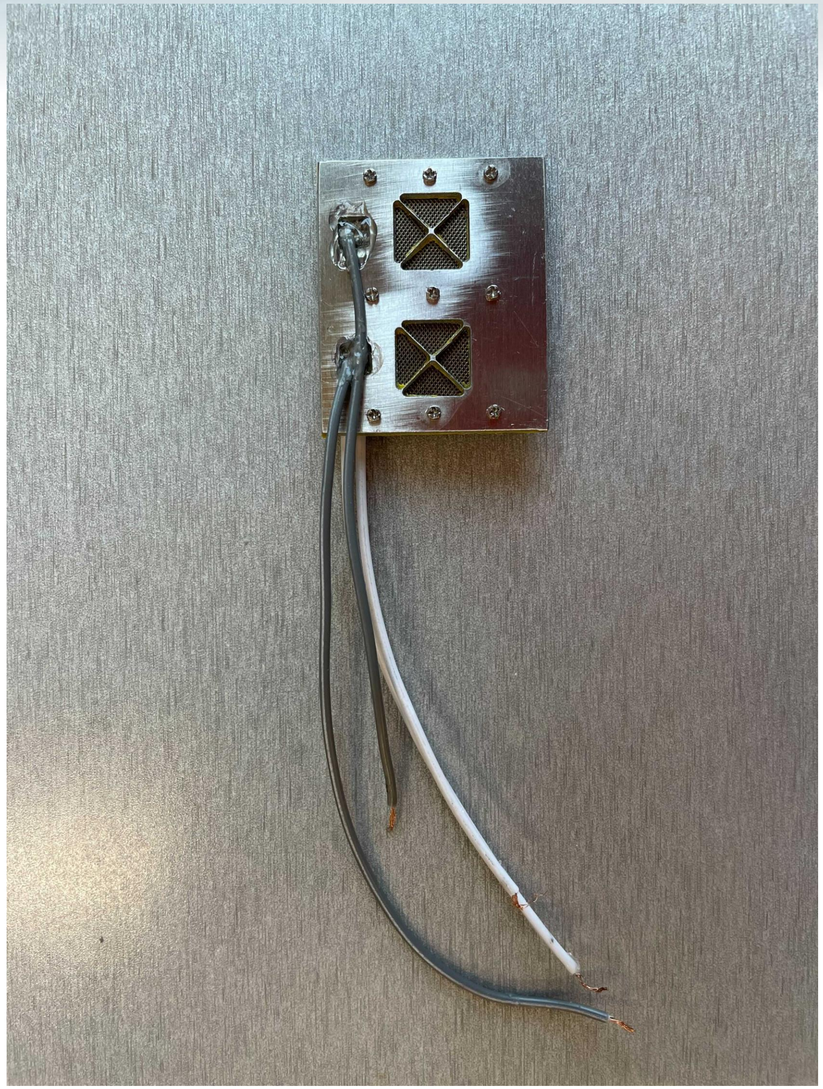


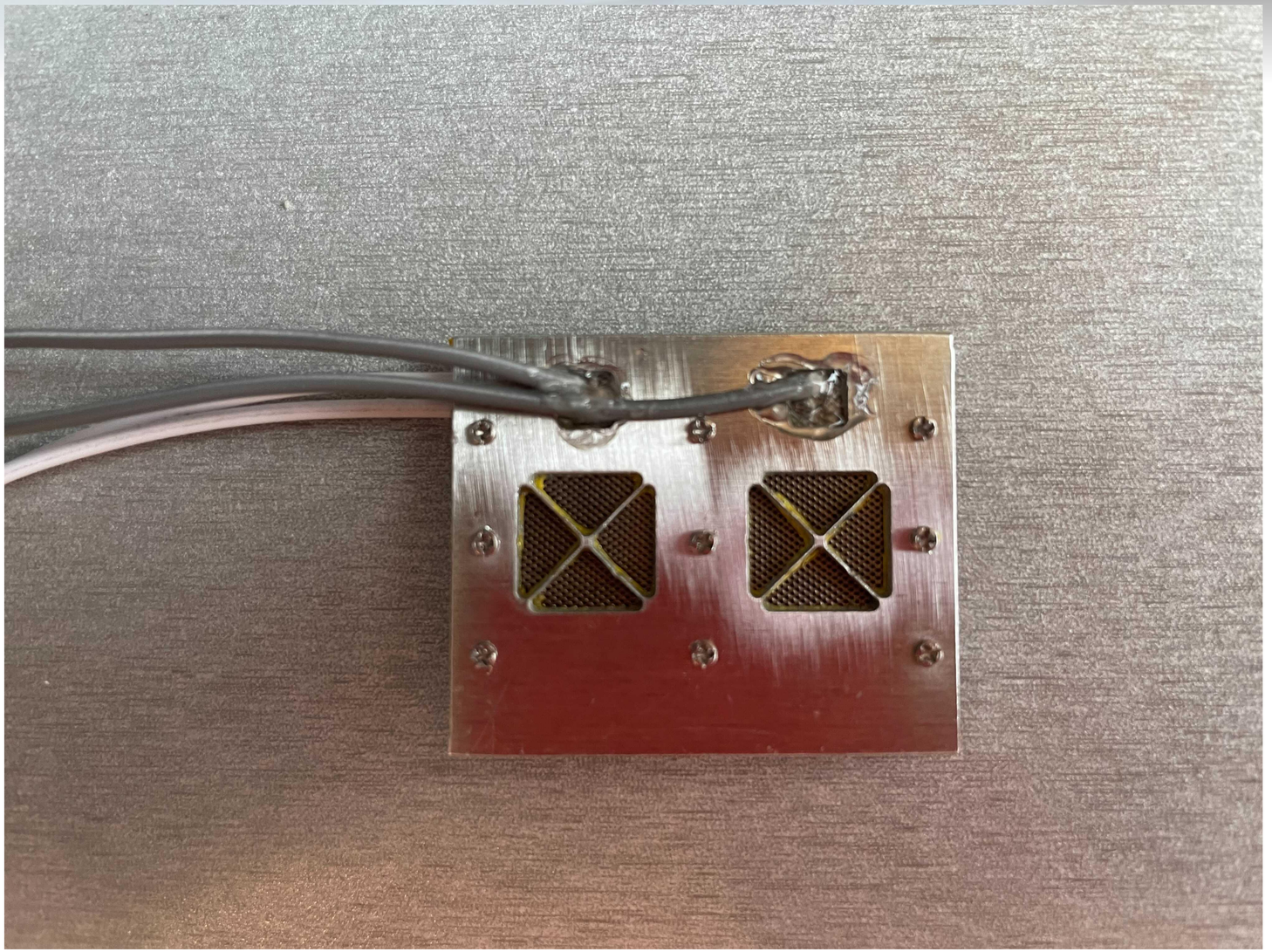
Anti-vaporization valves



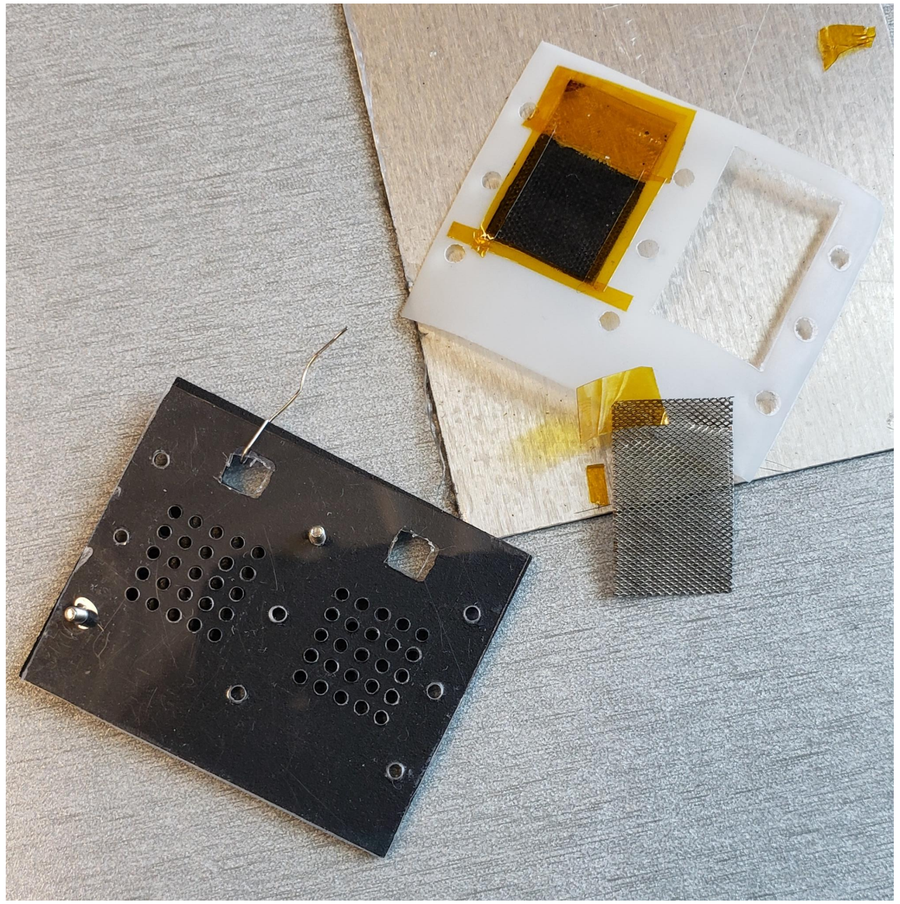


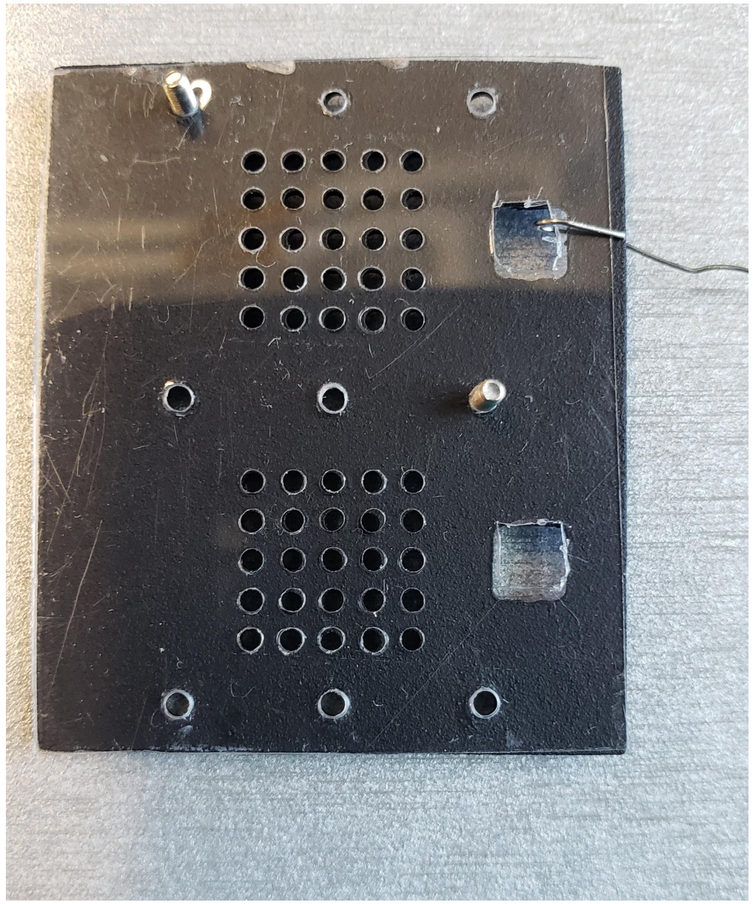
Cell design 1

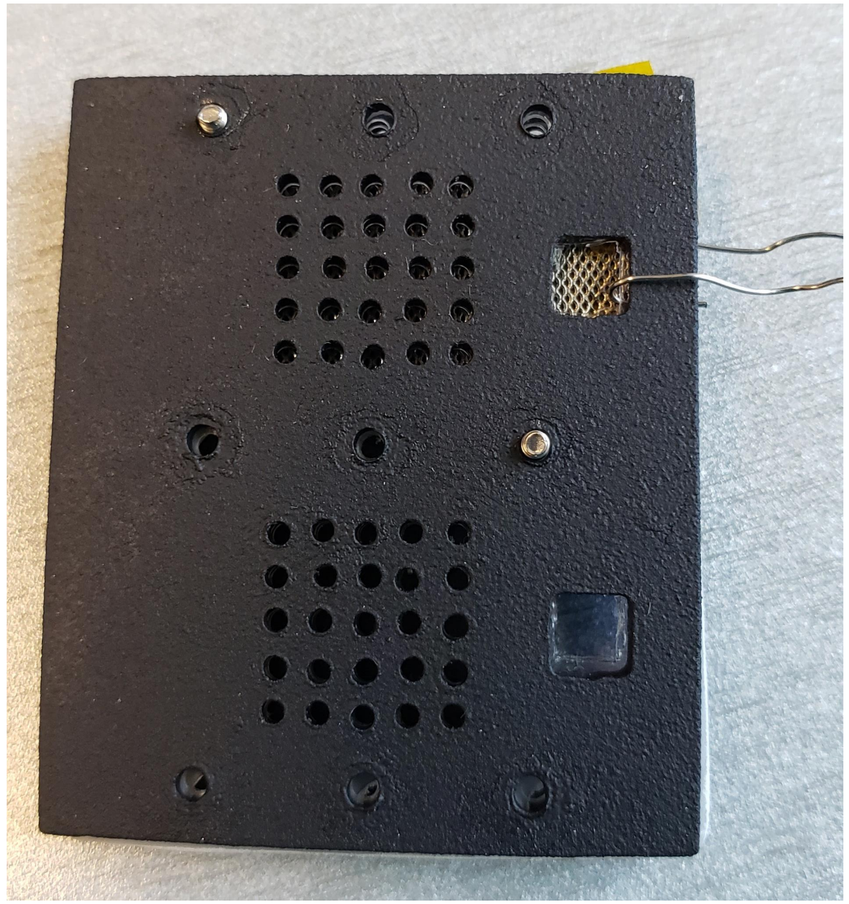




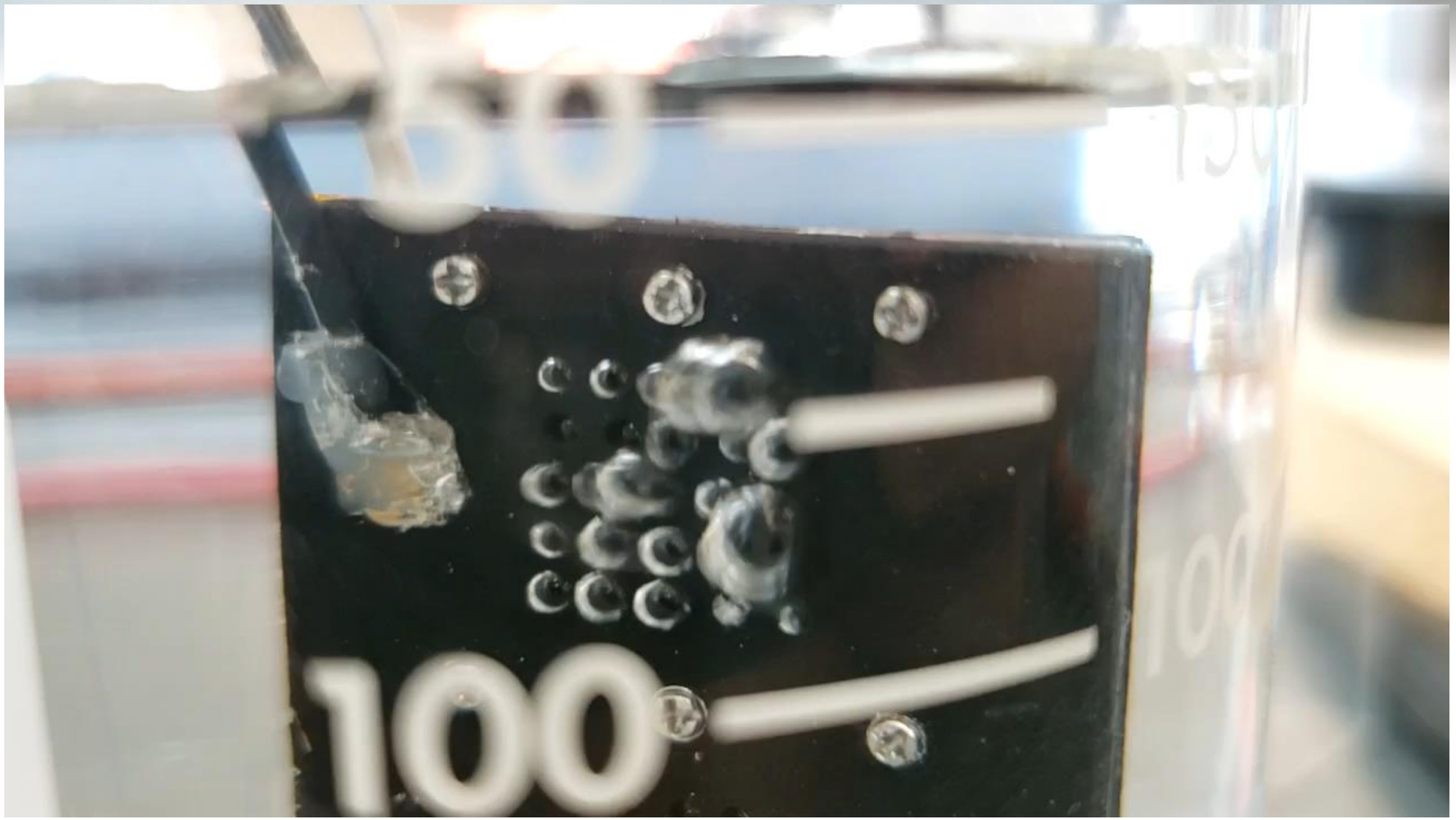
Cell design 2



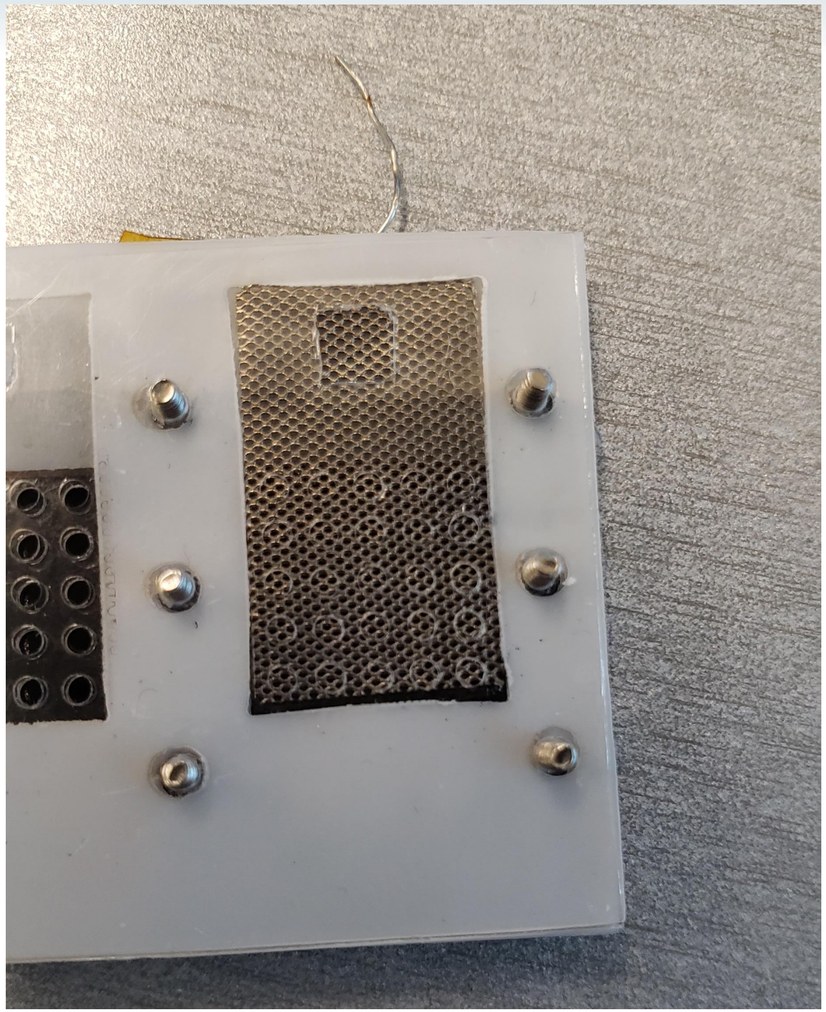


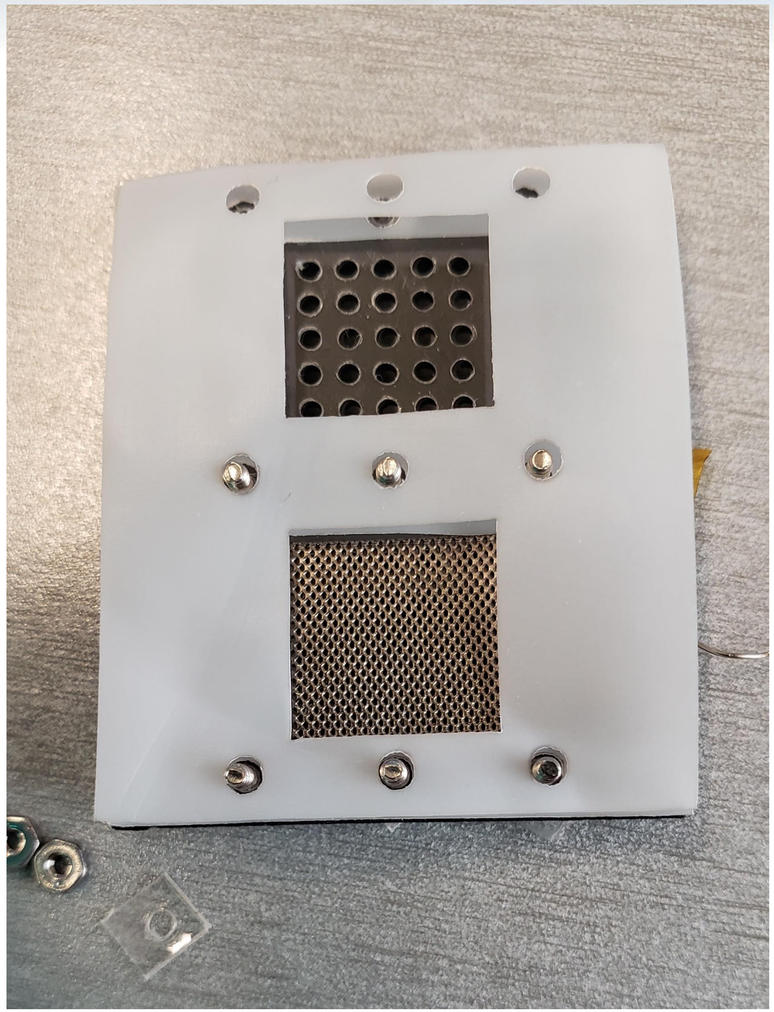


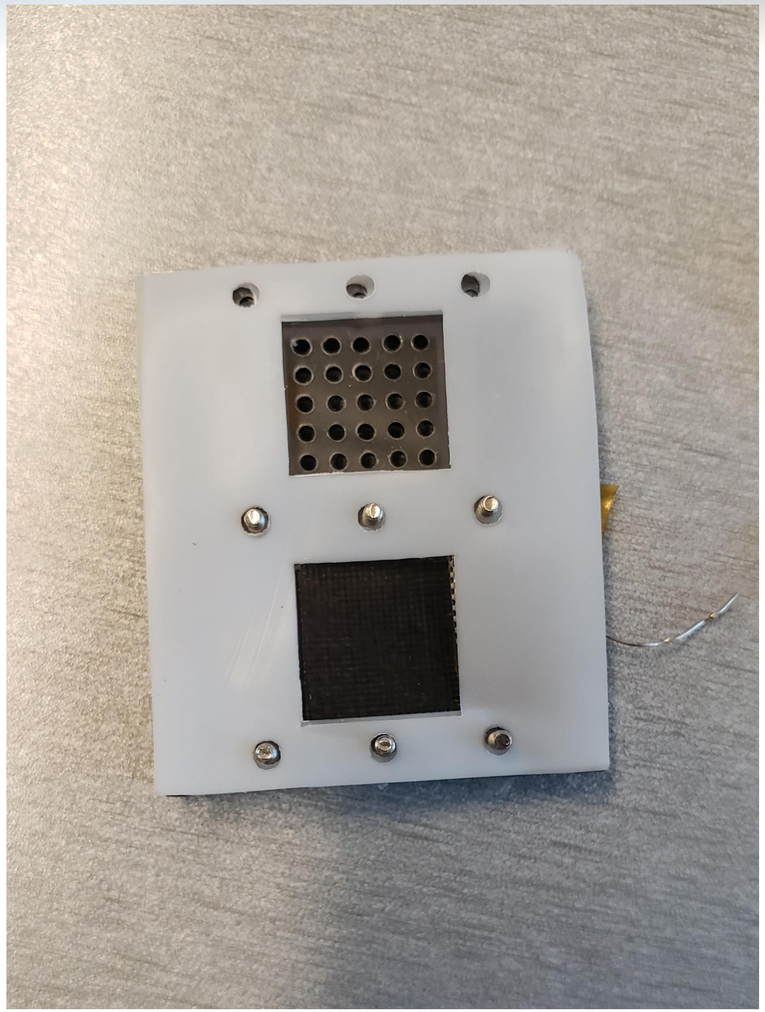
Cell design 2



Cell design 3







Problems with cell design 3