National Aeronautics and Space Administration

Laboratory Electrical Conductivity Measurements for Exploring Ocean Worlds

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Program: FY21 R&TD Topics **Strategic Focus Area: Solar System characteristics and origin of life**

Objectives:
This project seeks to obtain electrical conductivity data needed to interpret magnetic observations of extraterrestrial oceans, to high solute concentrations and pressures, and to low temperatures.

Background

Electrical conductivity is the main measurement for inferring the presence of oceans in the moons of Jupiter in magnetic induction experiments on Galileo, and on the planned Europa Clipper and JUICE missions. In terms of technology development, the combination of seismology with other in-situ methods such as electrochemical impedance spectroscopy (EIS), or dielectric spectroscopy (DS) may be deployed at other ocean worlds to reveal the nature of potential habitats in the ice, ocean, seafloor, and regions below, as the interior density, temperature, sound speed, and electrical conductivity thus characterize their habitability. Recent work shows that the magnetic induction experiments on Europa Clipper and JUICE might be able to infer the temperature and composition of the oceans in Europa, Ganymede, and Callisto, in addition to constraining their thickness and conductivity, because the types and amounts of ions in the ocean affect the ocean's thickness and temperature structure, and the conductivity is a property of the solutes. However, currently available electrical conductivity data does not cover the range of conditions occurring in those oceans, and so it is not yet possible to determine ocean composition using magnetic measurements.

Approach and Results

Our work applies advanced methods of molecular physics modeling in ab initio dynamics simulations (AIMD) and full-atom molecular dynamics (MD) simulations to provide important insights into the ice-salt interactions from quantum and atomistic scale respectively. We are coupling these simulation efforts to specific volume measurements obtained by our colleagues at the University of Washington, in order to improve the accuracy of the predicted electrical conductivities beyond what has been possible to date. We conducted simulations, using high performance computing clusters, of NaCl to 2 molal concentrations, and to pressures up to 1.7 GPa (the bottom of Ganymede's hydrosphere; see Figs. 1 and 2). The results are consistent with recent experimental findings [1,2,3]. This modeling approach guides our electrical conductivity measurements, which we are conducting at JPL. The milestones and deliverables and **status** are as follows:

Q2: Initial experimental results for 1-atmosphere conductivity measurements. **Completed**
Deliverables: Draft paper on the need for new experimental electrical conductivity measurements in the context of magnetic induction measurements at ocean worlds. **Published**: [A]
Q2: Design for sample enclosure and feed-through for high-pressure measurements. **End-closure purchased, sample enclosure to be designed**
Q4: High-pressure measurements of electrical response for relevant fluids**. Delayed due to COVID**
Deliverable: Draft paper on high-pressure measurements. **Delayed due to COVID**

In FY21 we measured the electrical impedance of aqueous NaCl at one atmosphere pressure to low temperature and high concentration. This work allowed us to develop the measurement protocols and electrodes that will be used for high-pressure measurements in year 2. We originally planned to also examine MgSO4, but lab work was delayed due to COVID. This delay also impacted our plan to design the high pressure sample enclosure and obtain our first high-pressure measurements.

Simultaneously, we used MD simulations to investigate molecular diffusion aqueous NaCl to high pressures over a range of temperatures and thereby predict the electrical conductivity that we might measure at those conditions. The results are generally consistent with the handful of published measurements in the range of pressures relevant to Ganymede's ocean, such that we hope
to reduce the number of needed measurements as we iterate between model and measurement. These results will be used in FY22 to predict the magnetic induction in Ganymede's ocean.

In FY22 we will also migrate our measurement approach at 1 atmosphere to high pressures occurring in ocean worlds. In FY21 we purchased the needed high pressure equipment to conduct the measurements. The laboratory equipment for conducting the experiments is already in place, with the exception of a sample holder to be fabricated in the coming months based on the design used in the 1-atmosphere experiments.

Significance/Benefits to JPL and NASA:

This work is timely due to the Juno flybys of Ganymede, and the planned investigation of Ganymede by Europa Clipper and JUICE. Our team has the expertise to help respond to new magnetic field measurements, and through this project we are developing the needed data to do so. In fact, partially as a result of this project, we published a significant paper on the importance of detailed salinity information for magnetic induction measurements [A], and contributed to the development of the Trident Discovery concept to explore Neptune's moon Triton. We also partnered with the Strategic RTD team looking at possible future missions to Uranus.

The work responds to recently published electrical impedance measurements in the NaCl system [4,5], which were inspired by our group's modeling of ocean worlds [6].

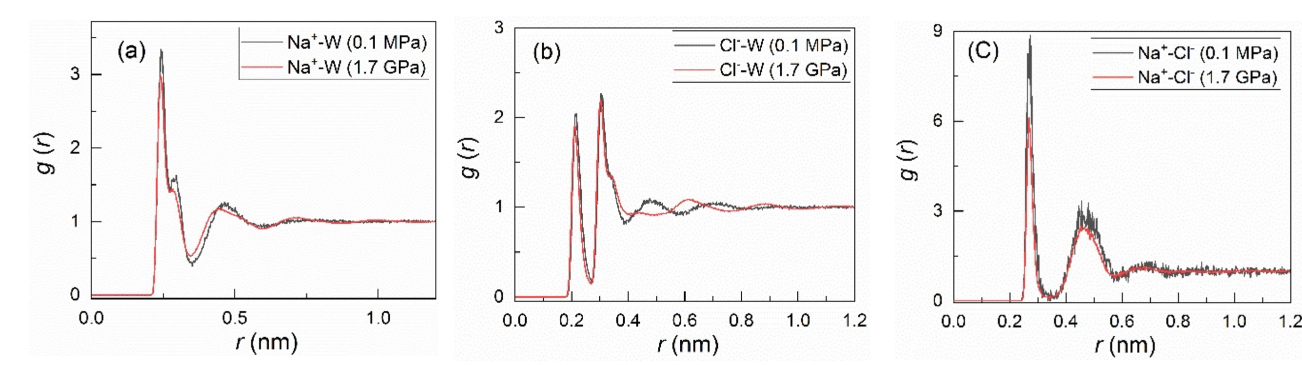

Figure 1: Radial distribution function of Na^+/water, Cl^-/water and Na^+/Cl^- for 2 M NaCl solution at 0.2 MPa and 1.7 M.

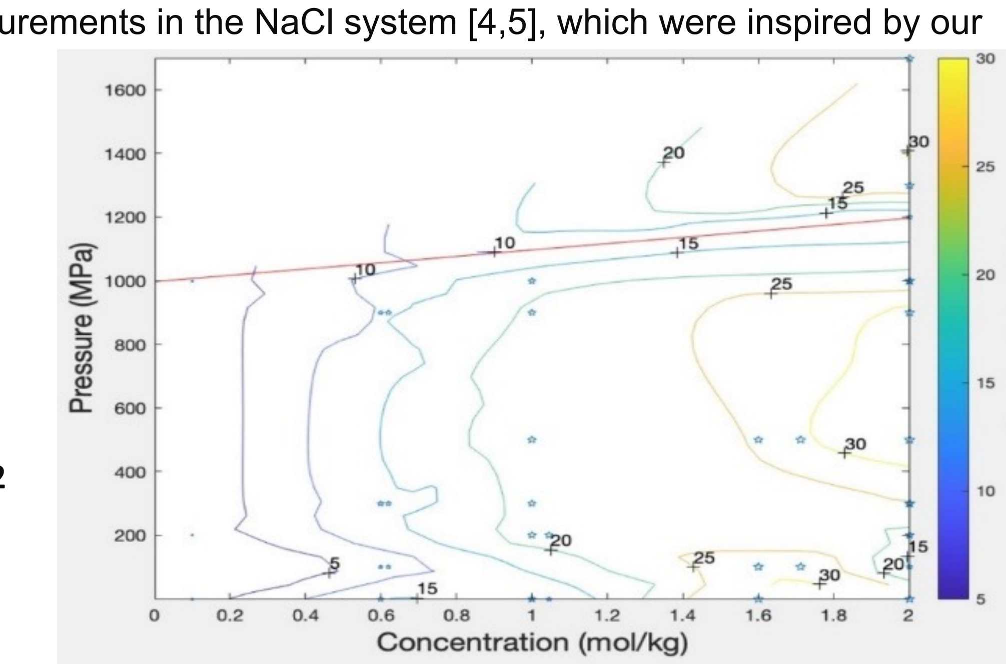

Figure 2: Ionic conductivity as a function of pressure, temperature and concentration predicted with atomistic MD simulations. Red line indicates the phase separation.

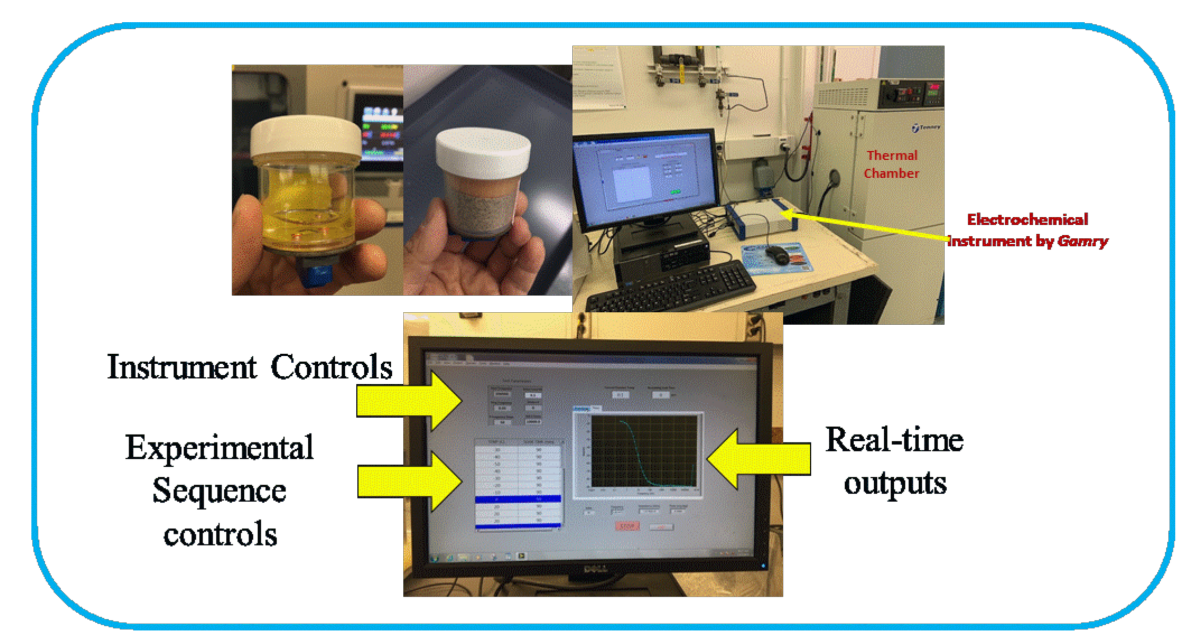

Figure 3: Experimental Setup for electrical conductivity measurements at the *'In-situ Geochemical Electrochemistry Sensor Lab'* at JPL.

Figure 4: Pictures of galvanic corrosion using the stainless-steel sensing electrodes for measurements on electrolytes > 1 Molal concentration of NaCl.

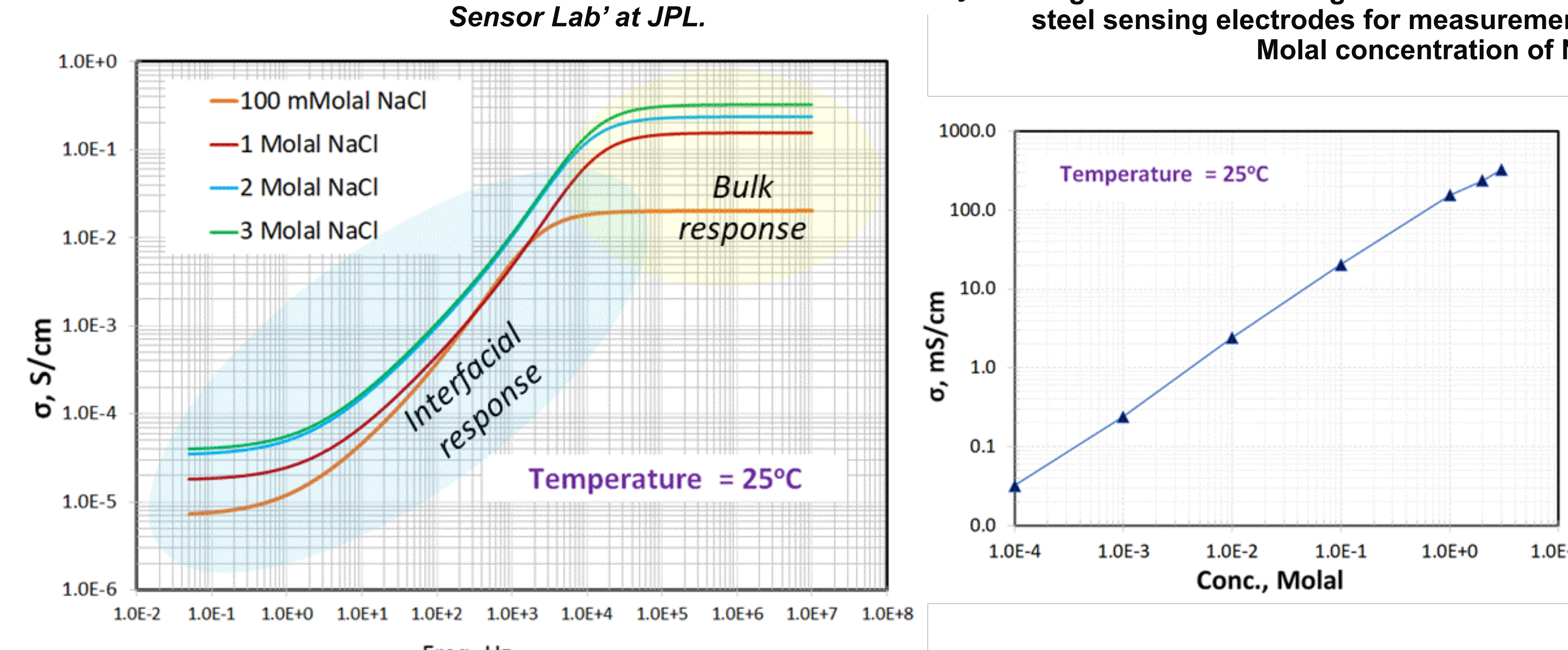

Figure 5: Comparison of equivalent modeling results at various concentrations. Left Plot) Compares the model spectra results over the frequency range of 50 mHz to 10 MHz. Right Plot) Summary of NaCl bulk conductivity from both model and measurement results at 25°C.

Publications

[A] Vance, S. D., Styczinski, M. J., Bills, B. G., Cochrane, C. J., Soderlund, K. M., Gómez- Pérez, N., and Paty, C. (2021). Magnetic induction responses of Jupiter's ocean moons including effects from adiabatic convection. Journal of Geophysical Research: Planets, 2020je006418.

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