

**TOWARDS LUNAR SIMULANTS POSSESSING
PROPERTIES
CRITICAL TO
RESEARCH & DEVELOPMENT
OF EXTRACTIVE PROCESSES**

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Overview

- ⇒ for extractive processes the most important properties are **chemical** and **physicochemical**
 - ☞ lunar simulants must be formulated accordingly
- ⇒ this talk considers three different extractive technologies:
 - ① thermochemical – pyrometallurgical
 - ② thermochemical – in supercritical fluids
 - ③ electrochemical – pyrometallurgical

① Pyrometallurgical Extraction Processes

⇒ observations from earlier work by Lynch at the University of Arizona's Space Engineering Research Center for Utilization of Local Planetary Resources on recovery of oxygen by pyrometallurgical processing of lunar regolith

② Extraction Processes in Supercritical Fluids (SCFs)

- ⇒ observations from recent work by Debelak at Vanderbilt University on the use of surfactants to enhance the extraction of metals in supercritical carbon dioxide from feedstock resembling compounds found in Martian soil

Pressure-dependent solubility in SCFs

- in the SC regime, solubility strongly affected by pressure
- ☞ good for extraction
- few studies of SCFs in extractive metallurgy

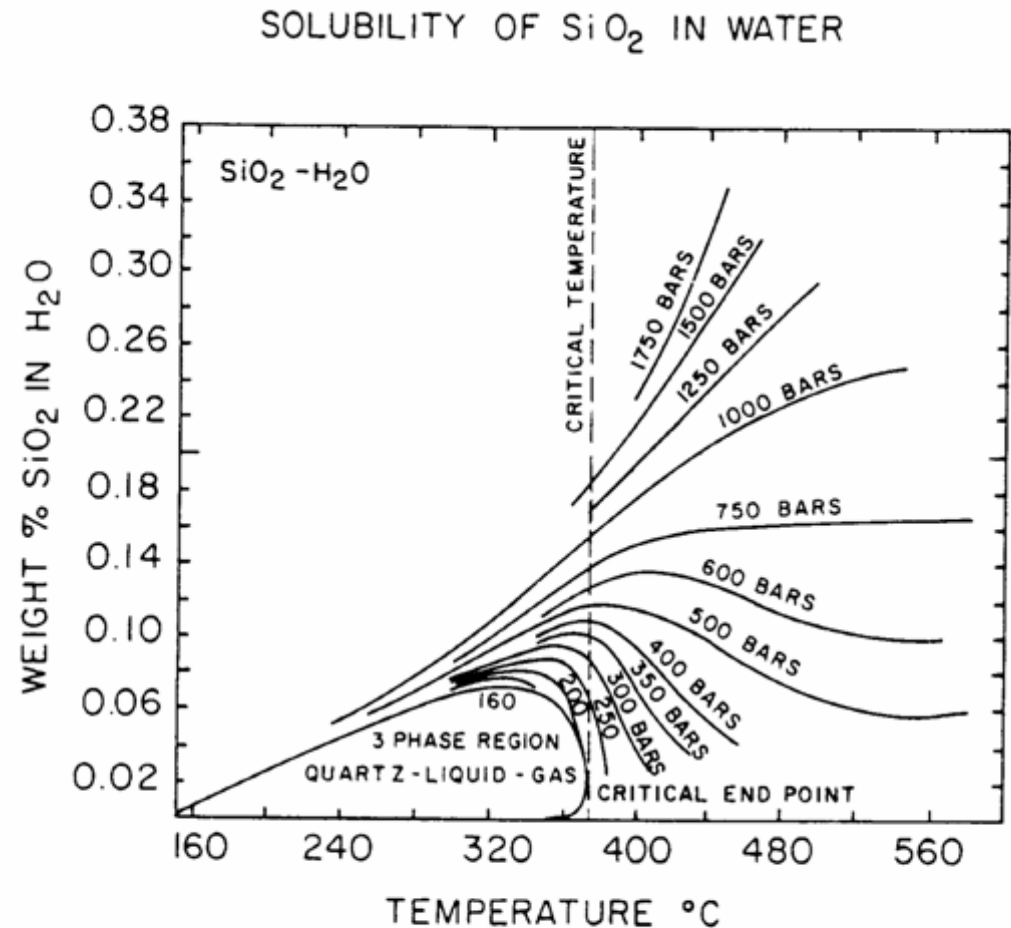


Figure 1 Solubility behavior of solid silica in supercritical water (Kennedy, 1950).

② Huge gaps in the database

⇒ solubility data known for many organic compounds

☞ solubility criteria have been specified

⇒ solubility data for inorganic compounds spotty

☞ solubility criteria are unknown

② Enhancing solubility of inorganics in SCFs

Debelak proposes the use of a nanoemulsion of water in CO₂ to compensate for the absence of dipole moment and low dielectric constant of CO₂

very small amounts of water are required (~0.2%)

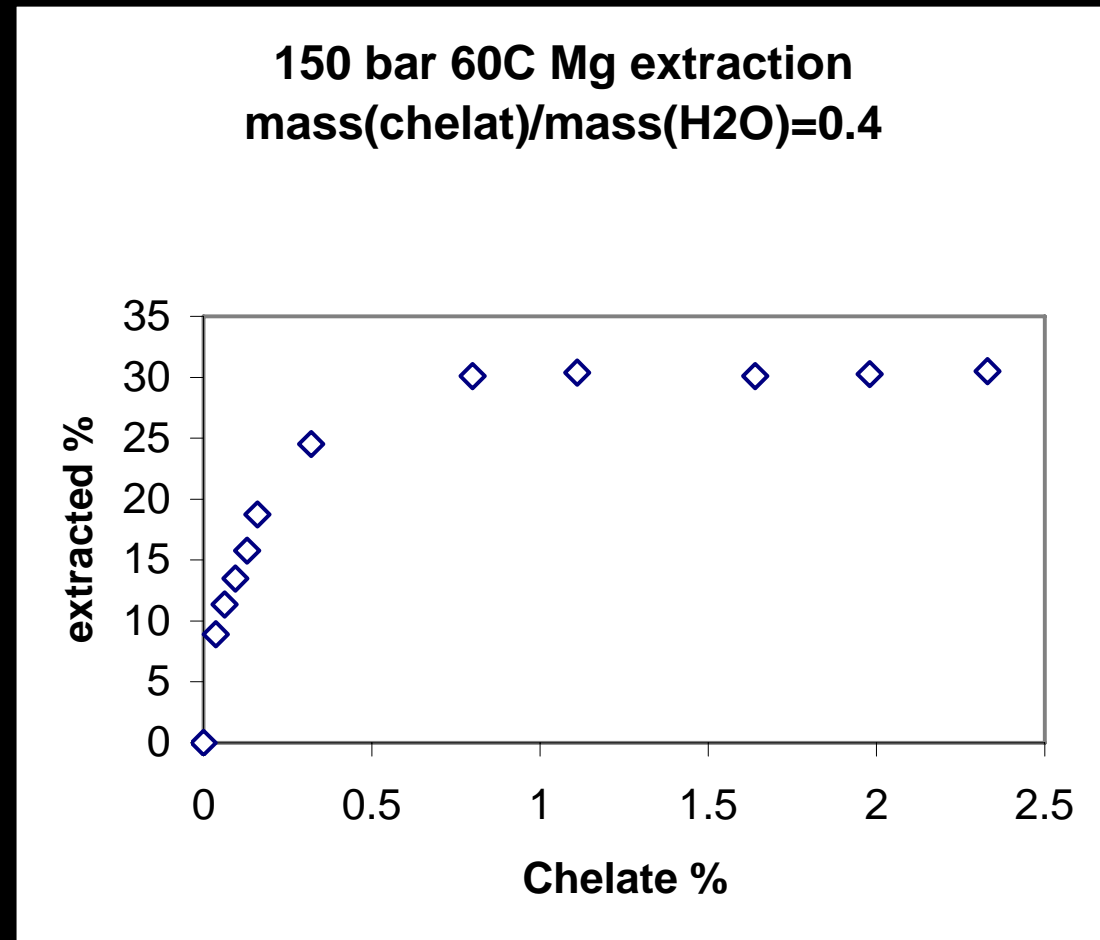
the nanoemulsion is stabilized by the use of a surfactant such as perfluoropolyether

dramatic increases in solubility have been measured with magnesium and copper compounds

② Enhancing solubility of inorganics in SCFs

0.5% chelate with
0.15% water raise
extraction efficiency of
magnesium to 30%

effect of particle size
under study



③ Electrolytic Extraction in Molten Regolith

- ⇒ observations from recent work by Sadoway at MIT on the extraction of metals and the production of oxygen by electrolysis of molten regolith

Why molten oxide electrolysis?

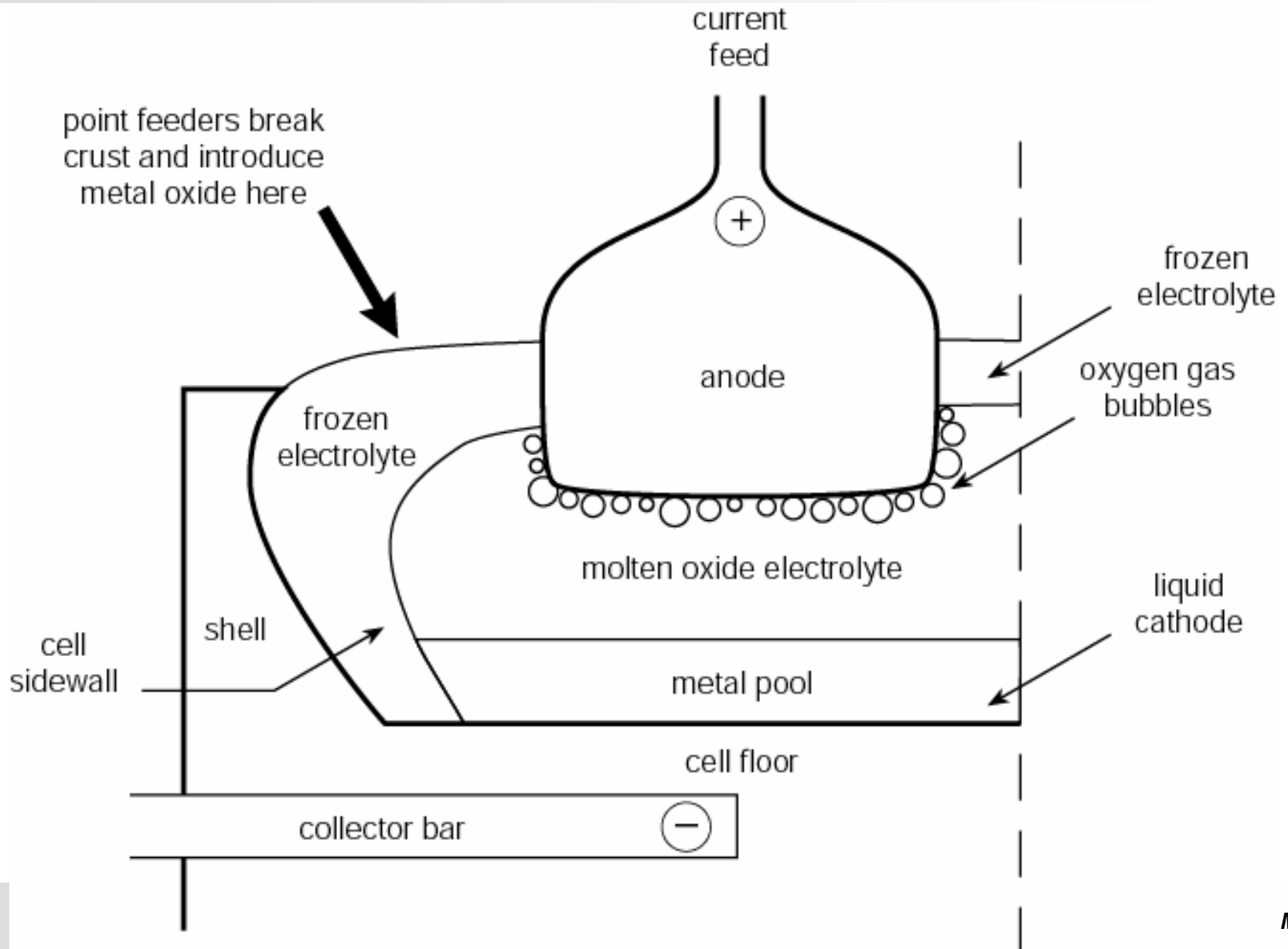
most metals are found in nature as oxides

“like dissolves like”

- ☞ molten oxide electrolysis:
extreme form of molten salt electrolysis
where pure oxygen gas is by-product



Prototype electrolysis cell: schematic



Simulant properties critical to electrolysis

⇒ in molten oxide electrolysis, the solid state properties of the simulant, e.g., particle size, crystal structure, and porosity, take a back seat to melt behavior

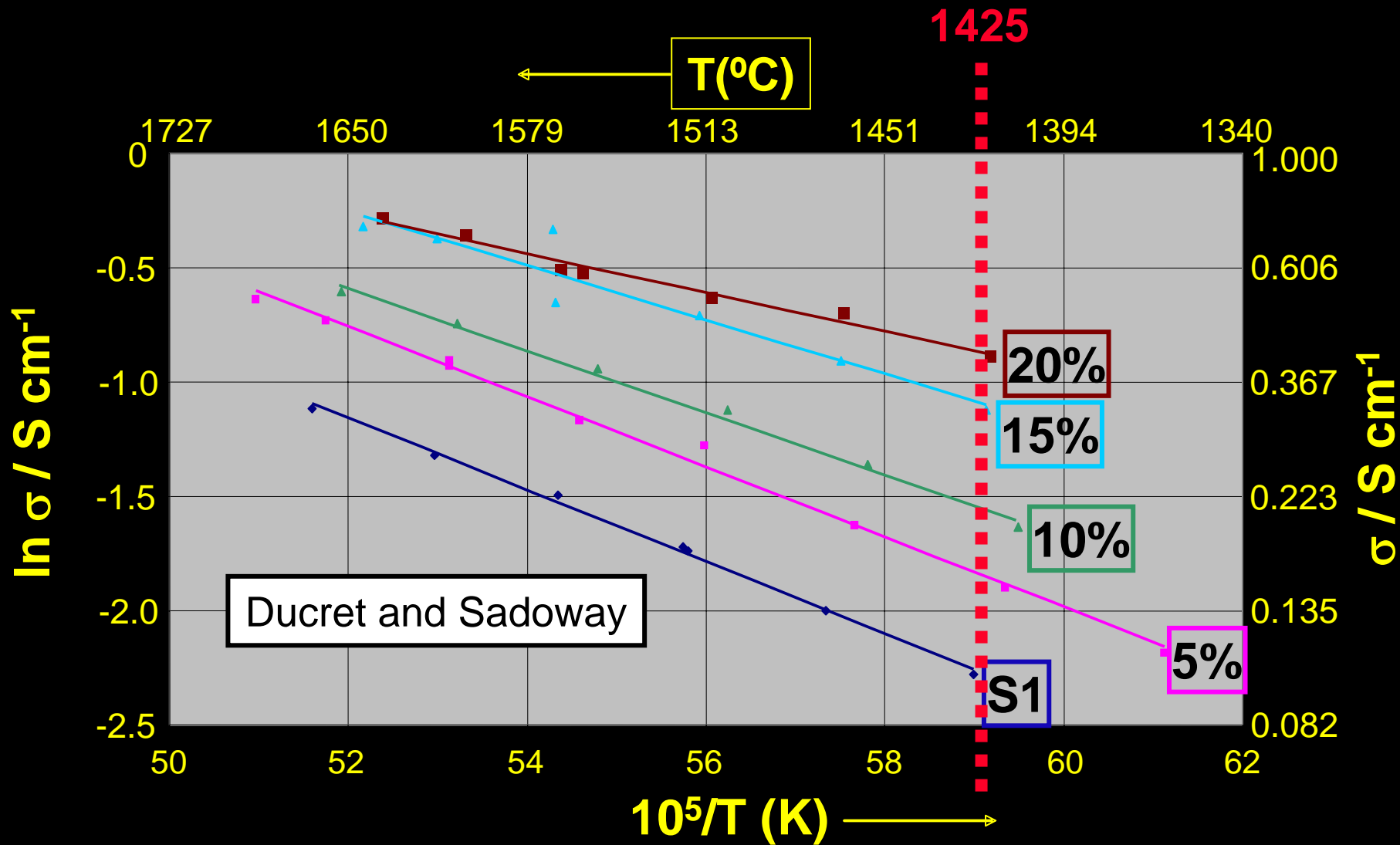
☞ electrical conductivity
density
viscosity
surface tension
vapor pressure

key attributes

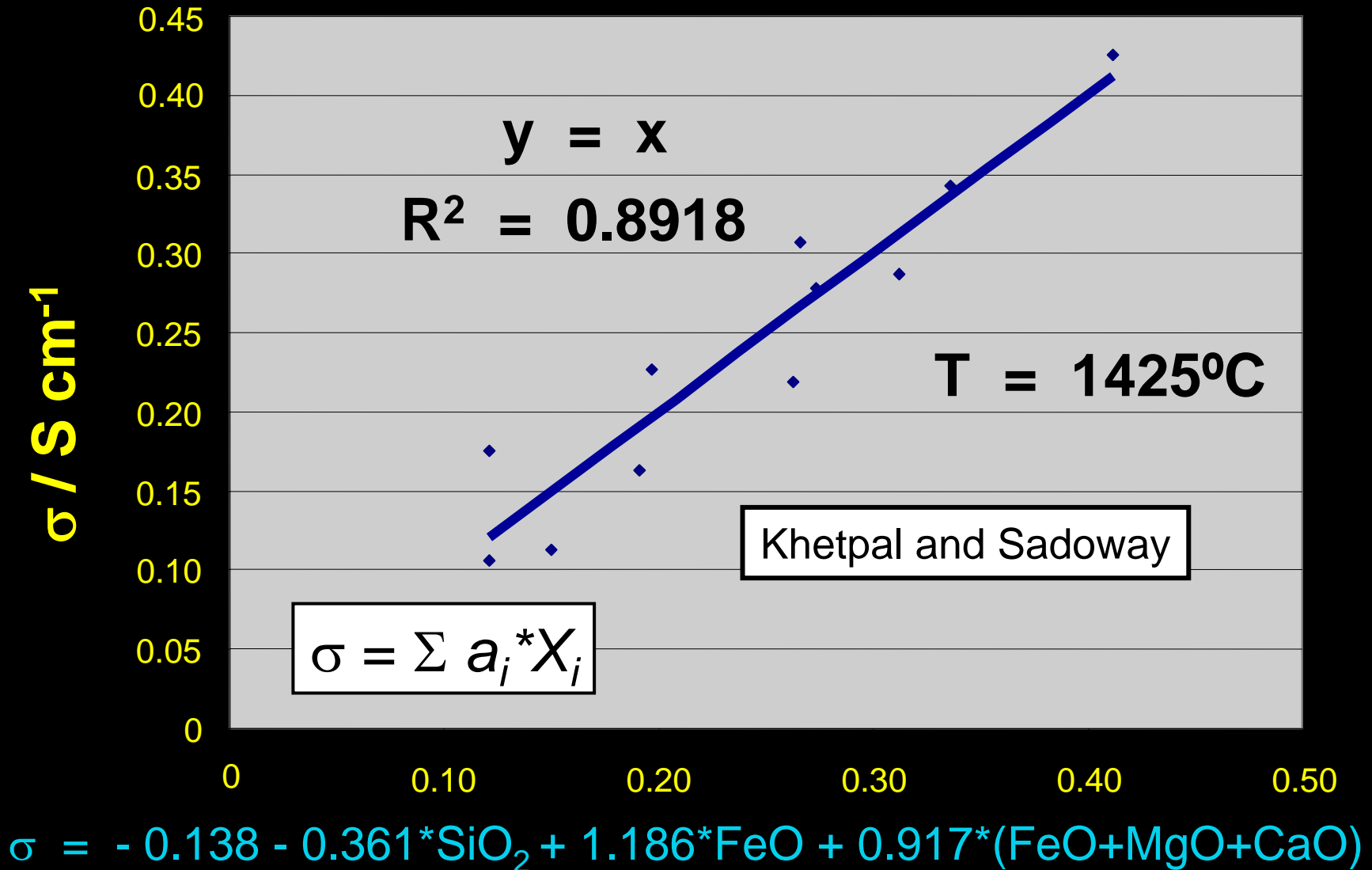
Electrical property measurements

- ⇒ studies of the FeO – MgO – CaO – SiO₂ system demonstrate the complex interplay of ionic and electronic conductivities which have a huge impact on process viability
- ⇒ database is sparse and we are far from developing deterministic models of transport properties of oxide melts

Effect of FeO concentration on conductivity

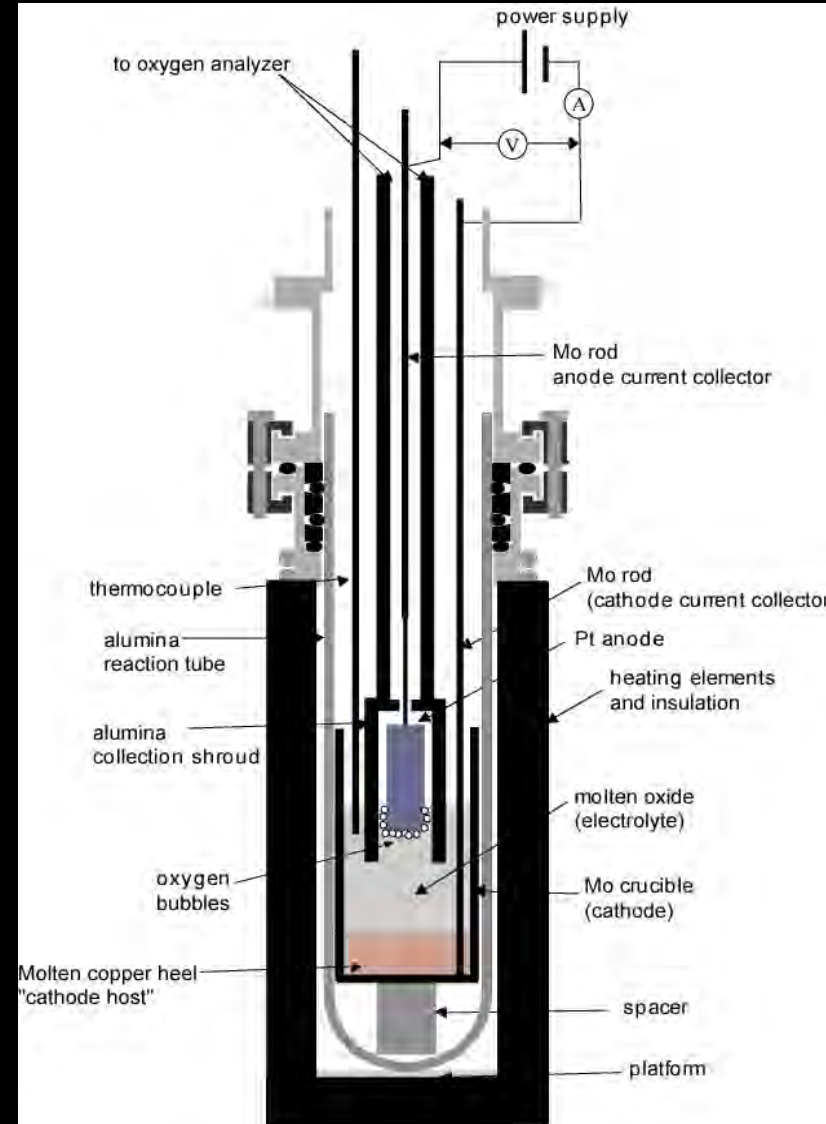


Isothermal regression of composition



Laboratory-scale electrolysis cell

- ⇒ towards electrolytic extraction of structural metals (Fe, Ti), photovoltaics (Si), and propellants (O_2)
- ⇒ oxygen production demonstrated in laboratory cells



... In summary

- ⇒ one size does not fit all: different extraction processes are sensitive to different simulant properties
- ⇒ is it time for a greater role for computational materials science, i.e., how good are state-of-the-art models of thermodynamic and transport properties of lunar regolith?