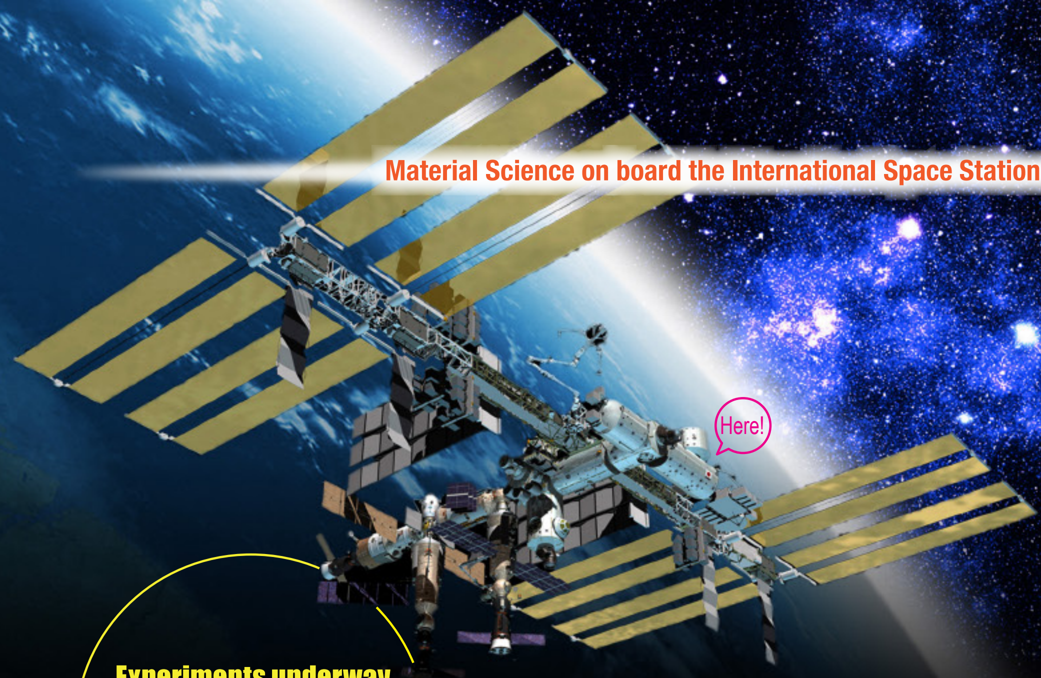
Beautifully Made, Levitating in Space

Thermophysical Property Measurements of High Temperature Melts & Exploration of New Materials

Material Science on board the International Space Station (ISS)



Experiments underway on board the Japanese Experiment Module "Kibo" on the ISS!

Human Spaceflight Technology Directorate

Japan Aerospace Exploration Agency

For inquiries on the leaflet and "Kibo",
contact Kibo Utilization Promotion Office at Z-KIBO-PROMOTION@ml.jaxa.jp

Detailed information about ELF (specifications)
To whom are interested in using ELF, see:
http://iss.jaxa.jp/en/kiboexp/pm/elf/

Ishikawa Lab. (Electrostatic Levitation Targeted Research Laboratory), Institute of Space and Astronautical Science (ISAS), JAXA
http://ishikawa.isas.jaxa.jp/index_en.html

Explore to Realize

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Published in March 2020

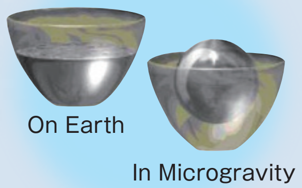
Explore to Realize

Unveil the Unknown Properties of Refractory Materials

Have you ever seen an image in which an astronaut is letting spherical water in the air?
In the Japanese Experiment Module "Kibo" on the International Space Station (ISS) equips a material experiment facility capable of melting materials with high melting points, such as glass, while levitating by taking advantage of the microgravity environment.

1 Levitating materials in space, "container-free"

On Earth, a liquid needs a container to stay put. In the microgravity in space however, liquids can float in the air without containers. This makes it possible to determine the liquid's characteristics, to understand chemical reactions, to develop new materials with new functionality in a containerless environment, and develop new materials free from any contamination from containers.
The method to handle materials without containers is called "containerless processing".



2 Original properties hidden on Earth

On Earth, a material is produced by putting into a container, melting by heating the container.
When the material has high melting temperature the material easily reacts with the container during melting, and then are contaminated. This contamination hinders studying the properties of the melted subject materials accurately, or even handling the experiment itself on Earth.

3 Innovative invention! "Containerless processing" that melts materials while levitating

Containerless processing enables precise measurements of physical properties of molten materials by levitating them and fixing the positions. The method allows for the supercooled condition as well as prevents contamination and nucleation due to no container even when a material is heated up to a high temperature.
JAXA successfully developed an electrostatic levitation furnace after long years of study of the electrostatic levitation method, a containerless processing technique that enables position control by the Coulomb force in the electrostatic field.

The Electrostatic Levitation Furnace (ELF) developed by JAXA enables…

- Measurement of thermophysical properties (density, surface tension, and viscosity) of high temperature melts at 3000 °C or above in a wide temperature range.
- Maintaining and solidification of the melts at the highly purity without using a container. In addition, at the ELF that suppress nucleation, materials can be supercooled.

Feel free to contact JAXA when you need any help on the following:

- Having a material with high melting point and reacts with a container.
- Wishing to obtain highly reliable thermophysical properties by reducing the impact of a container.
- Wishing to investigate the condition of a material in the supercooled phase.
- Wishing to create a new material by solidification from the supercooled phase.

Obtaining data of easily charged materials (including metals and alloys) on the ground!

The Electrostatic Levitation Furnace literally charges materials by using static electricity. When a voltage is applied to the charged materials, it generates the Coulomb force that levitates the material by repulsion with the electrodes. It means that materials charged easily may be levitated and conducts experiments on the ground.

What is aimed for in space?

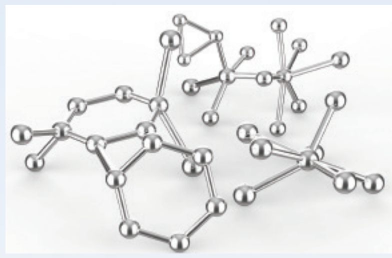
In space, JAXA aims to obtain physical properties of materials difficult to be charged and measured on Earth, including oxides and semiconductors. Furthermore, we will supercool and solidify (quickly solidify at a temperature below its melting point) samples in the ideal environment suppressing thermal convection, return them to Earth and analyze in detail.

4 Demand of high-accuracy data

Heavy industries – Improvement in the accuracy of manufacturing process model

In terms of refractory materials for aircraft and power generation system, such as turbine blades, and structural materials for ships and bridges, their optimum conditions for processes including casting and welding are determined based on the past achievements. However, the recent sophistication of materials demands aide using more highly accurate numerical analysis

Material manufacturers – quantitative evaluation of new materials



The metal material manufacturing industry has seen sophisticated and diversified needs of users along with increasing growth of overseas competitors. Currently demanded are proper evaluation of materials with high potential demands in the growing market and the development of the material-related technology thoroughly focused on performance and price. To achieve this requires quantitative exploration of new materials with an exclusive commitment to the necessity-oriented elucidation of their creation process is anticipated.

Project Flow

Recruiting samples
JAXA accepts application of space experiment samples from universities, research institutes, companies.

Selecting experiments
JAXA selects experiments based on the content and expected result of the experiments.

Examine experiment conditions
In cooperation with researchers, JAXA determines the best conditions of the space experiments by examining the properties of the materials with ground-based equipment.

Screening flight sample
Confirm toxic, laser compatibility, Deliquescent, and vibration tolerance.

Transport to International Space Station
Prepare sample in the sample holder and deliver to ISS.

Conduct experiments on board "Kibo"
Conduct experiments on board "Kibo" and its data is acquired by remote control from ground operator.

Return to Earth, handover to researchers
Solidified samples after the experiments are retrieved, transported to Earth, and handed over to researchers.

The Japanese Experiment Module "Kibo" on the ISS is a space laboratory where unique research is possible. JAXA provides comprehensive support and facilitate utilization so that the many people engaged in research.

From basic research to applied utilization

Thermophysical property measurements of materials with a high melting point and solidification from supercooled phase are expected to contribute to the optimization of the material production process and the creation of new-functional materials.

Target

Basic research

- People working in following research who handle materials with high melting point: thermophysical properties, structural analysis, interface phenomena, crystal growth, containerless processing technique, etc.

Applied utilization

- Numerical calculation researchers of companies that deal with melted metals and oxides, including casting, welding, and spraying. Researchers working at manufacturers of materials, including metals and ceramics, and semiconductors.

The Electrostatic Levitation Furnace(ELF)

Overview

STEP 1 Load a cartridge containing a holder with more than 15 samples.

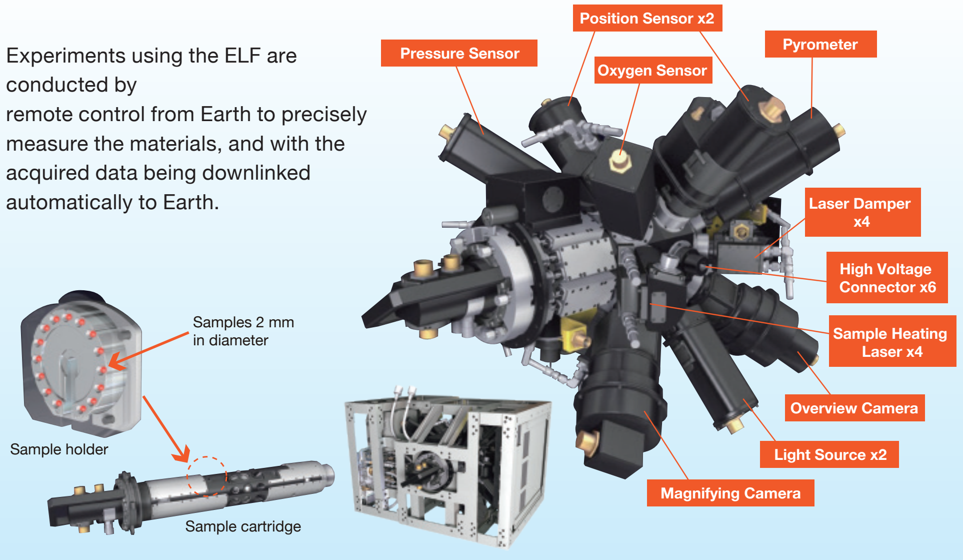
STEP 2 Charge a sample approximately 2 mm in diameter, and position it with 3-axis control using the Coulomb force.

STEP 3 Heat the sample with heating lasers and melt the material without a crucible.

STEP 4 Measure the density, surface tension, and viscosity of the sample in its molten state.

STEP 5 After stopping lasers, observe the cooling and recrystallization phases of the material.

Experiments using the ELF are conducted by remote control from Earth to precisely measure the materials, and with the acquired data being downlinked automatically to Earth.



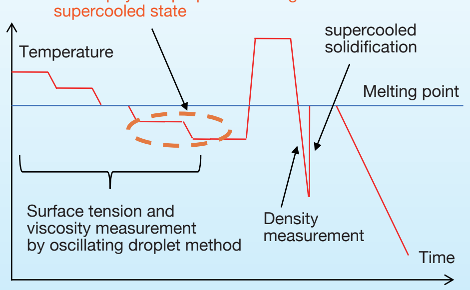
Major specifications

Type	Sample type	Sample size	Ambient	Heater	Temperature measurements
On Earth	Elemental metals and alloys	φ2 mm (several tens mg)	・Vacuum (Ultimate vacuum approx. 10^{-5}Pa)	・Carbon dioxide laser 200 W ・Nd; YAG Laser 500 W	299 – 3500 °C
In space	Mainly oxides. Semiconductors, insulators, alloys, and elemental metals are also available	Standard: φ2 mm	・Ar, N_2, the air, etc.(Up to 2 atm)	・980 nm semiconductor laser Up to 40W x 4 directions	299 – 3000 °C

Type	Obtaining properties during the process			Change of materials		
	Surface tension	Density	Viscosity	Levitation	Melting	Supercooling
On Earth	Metals available					
In space	Available	Available	Available	Available		

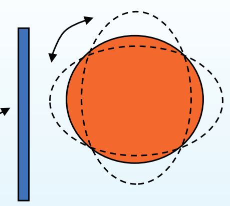
Tip of ELF – melting while levitating!

- **Thermophysical properties measurable in a wide temperature range within 30 minutes covering from melting to solidification**



- **Levitating sample is spherically shaped Obtain images of a sample during supercooled**

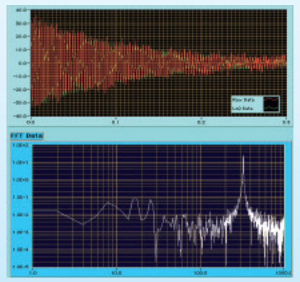
→Calculate density by obtaining the volume from image analysis (Mass is obtained by weighing after returning to Earth)



$$\eta = \frac{\rho r_0^2}{5\tau}$$

$$\gamma = \frac{\omega_2^{\ 2} \rho r_0^3}{8}$$

ρ : Density
r_0 : Diameter of sample
γ : Surface tension
η : Viscosity coefficient
ω_2 : Resonance angular velocity
τ : Attenuation coefficient



Obtain viscosity coefficient of the melted liquid based on the attenuation of oscillating droplet

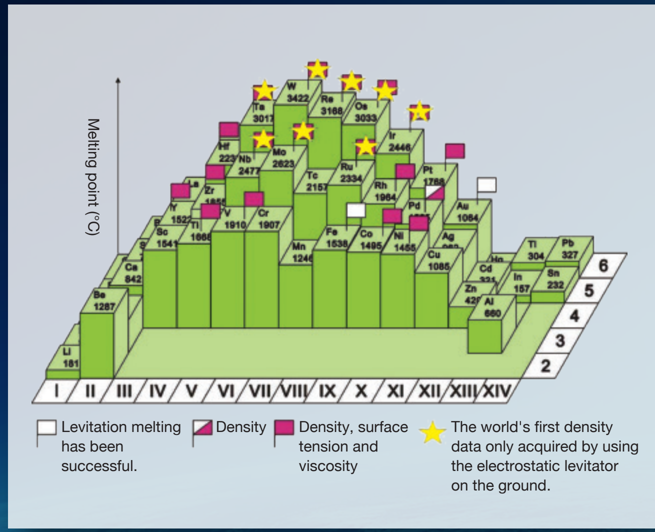
Obtain surface tension of the melted liquid based on the resonance frequency of oscillating droplet

Road to Big Innovation

Thermophysical properties of metallic element melts acquired by measuring with the Ground-based electrostatic levitator

The ground-based electrostatic levitator experiments have made many achievements, as exemplified by improvement in the thermophysical properties measurement for its application in experiments on board the Japanese Experiment Module "Kibo" and acquisition of high-temperature thermophysical properties data of elemental metal molten.

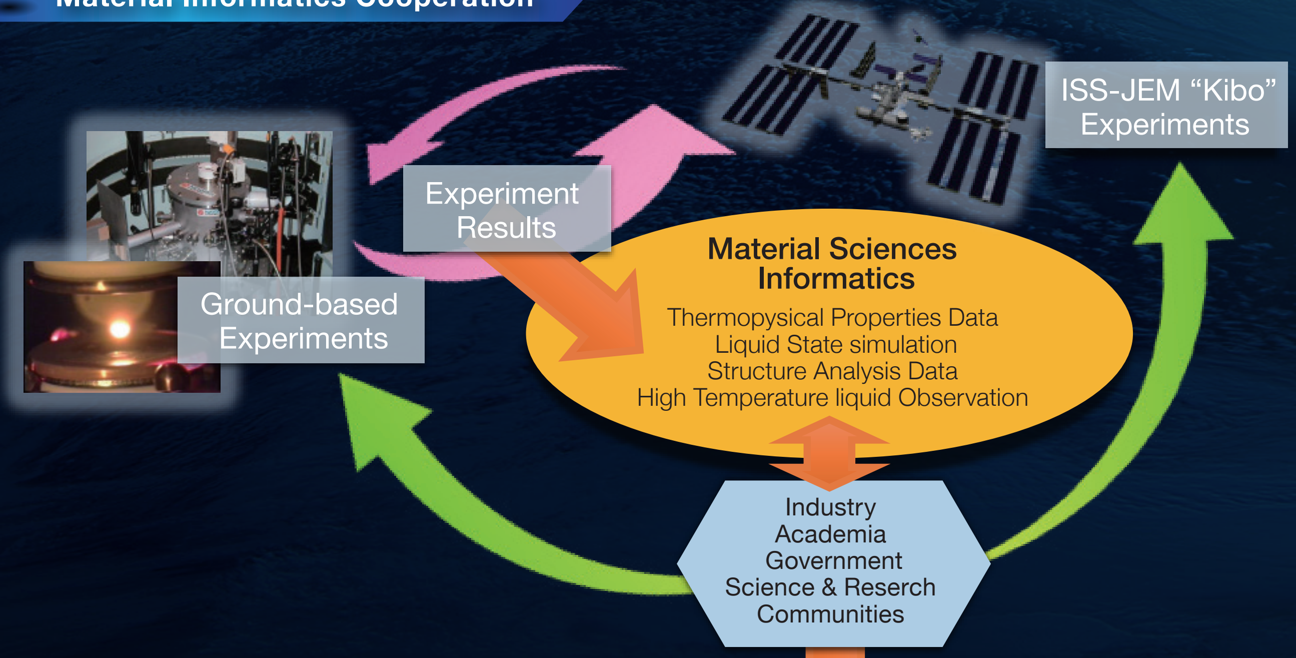
With the ground-based levitator we have already acquired viscosity coefficient data of refractory metals having a melting point higher than 3,000°C, including tungsten (chemical symbol: W) that has the highest melting point among metals. (Shown with stars in the figure).
In addition, a wide-ranging temperature coverage data has been acquired for the first time in the world.



Thermophysical Property Database (NIMS-JAXA)
https://thermophys.nims.go.jp/index_en.html

Network Database System for Thermophysical Property Data (AIST)
https://tpds.db.aist.go.jp/index_en.html

Material Informatics Cooperation



- Global access to world's first thermopysical properties data
- Breakthroughs of innovation & discovery leading to increased economic growth
- Acceleration from ideas to develop efficient turbines, aircraft, and jet engines
- Enhancement & verfication of numerical & analytical liquid state models
- Advancement of fundamental reseach of material science

ELF Utilization

If you are interested in using ELF, please contact JAXA. z-kibo-promotion@ml.jaxa.jp

Q What is the difference between JAXA's ELF and levitation furnace (electromagnetic levitator) of other agency on board the ISS?

A JAXA's electrostatic levitation furnace (ELF) is the world's only equipment capable of measuring the properties of insulators with a high melting point by melting at an very high temperature (3000 °C) while levitating, which is impossible by electromagnetic levitators.

Q What results is the ELF expected to produce?

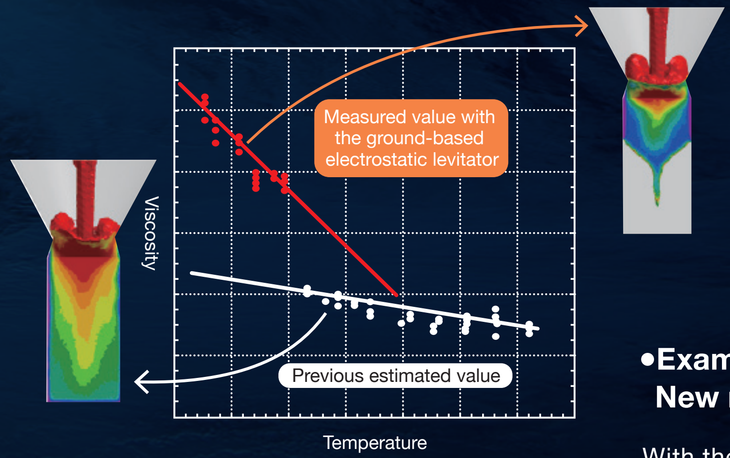
A Our ELF is expected to contribute to the improvement in accuracy and reliability of numerical simulation which models the manufacturing process using materials in a liquid state for casting, welding, spraying and crystallizing. The contribution of the ELF will lead to the decrease in the number of experiments required for narrowing parameters and verification, improvement in the reliability, sophistication, and precision of simulation data, speeding of new material development, hold-down of the development costs.

Q Could you introduce the size and the number of samples to be launched?

A Each sample is 1.5 – 2.1 mm in diameter and up to 15 samples can be installed in the sample holder and launched on board the ISS.

Example of commissioned business

•Example of Heavy industry: casting of turbine blades and reproduction of welding defects



Comparison of the fluid simulation results for casting using the values of viscosity actually measured by experiments on Earth, using the ground-based electrostatic levitator with the previously estimated values. The accuracy of the simulation has been improved by using the measured physical property values.

Thermophysical peroperties data by the ground-based electrostatic levitator can reproduce the flow condition at melting with the thermophysical properties of a high melt was applied to simulation of high-temperature melt phenomena which include melting defects caused at casting and welding. The application ground-based electrostatic levitator contributed to the consideration of measures for improving the yield ratio and review of the optimum conditions.

•Example of Manufacturer: New material development

With the ground-based electrostatic levitator, the measurement of thermophysical properties in the development materials for semiconductors and circuit boards used for solar power generation and rechargeable batteries was conducted and brought performance evaluation and manufacturing process evaluation of new materials and the data serving the manufacturing process assessment.