【Grant-in-Aid for Specially Promoted Research】

Science and Engineering

Title of Project：Light elements in the Earth's core revealed by ultrahigh-pressure experiments

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【Purpose and Background of the Research】

In this study, physical properties of iron alloys under high pressure and high temperature of the Earth's core will be clarified and the core "light elements" will be elucidated mainly by experiments using a diamond cell (DAC) device. The core has a solid inner core and a liquid outer core (95% of the core is the outer core). The iron-based core is known to contain a large amount of light elements in addition to about 5% nickel. For 70 years since 1952, the identity of the light elements of the core (candidates are sulfur, silicon, oxygen, carbon, hydrogen) has been actively discussed, but it is still left as a first-class problem in earth science.

In this study, by overcoming experimental technical problems that have hindered the elucidation of the core composition and supplementing the experiments with first-principles calculations, liquid and solid iron alloys containing these five light elements will be examined for their density, sound velocity, phase diagram, and element partitioning under core pressures. These results will be compared with seismological observations, and the composition of the five light elements in the outer core will be elucidated based on eight independent constraints. The light element composition of the core is a key to understanding not only the current state of the core but also to its dynamics and the formation of the earth's magnetic field, the chemical composition of the entire earth, and the process of Earth accretion and core formation.

【Research Methods】

This research mainly involves experiments using a laser-heated diamond anvil cell (DAC, photo) in an ultra-high pressure and high-temperature environment equivalent to the Earth's core. By static compression experiments using this device, it is now possible to conduct experiments under extreme environments that exceed the pressure and temperature at the center of the Earth. In addition to experiments at the University of Tokyo and Tokyo Institute of Technology, X-ray diffraction and inelastic X-ray scattering (IXS) measurements will be performed at the radiation facility SPring-8 to determine the density and sound velocity of the iron alloy under high pressure and high temperature. Furthermore, iron alloy containing hydrogen will be analyzed using Hokkaido University's low-temperature secondary ion mass spectrometry (cryo-SIMS) to determine the phase diagram and elemental distribution.

Using such high-pressure experiments and theoretical calculations to supplement them, the density and sound velocities of the liquid and solid iron alloys containing the five light elements will be determined, and they will be compared with observations of the outer core and inner core, giving us the possible range of each light element composition. The compositions of the outer and inner cores must be consistent with the partitioning of the light element between liquid and solid iron that will be revealed in this study. Furthermore, the composition of the outer core must be within the compositional range of the liquid iron alloy in which solid iron, which is poor in light elements, crystallizes that will also be determined in this study. Also, the current outer core is likely to be saturated with SiO_2. From the initial core composition based on the metal-silicate partitioning of light elements during core formation, the current core composition can be constrained considering its chemical evolution. In this way, the composition of the five light elements of the outer core and inner core will be elucidated using a total of eight independent constraints.

【Expected Research Achievements and Scientific Significance】

The melting temperature and physical properties of Fe alloys strongly depend on the composition of light elements. As it is currently unknown, the core temperature estimates differ by more than a thousand degrees. The thermal conductivity of iron alloys also change largely depending on the light elements (that is, impurities). Elucidation of the light element composition of the core will greatly advance the understanding of the current state of the core and its thermal history.

In addition, the mass of the core is one-third of the whole Earth. Since the light element composition of the core is unknown, the chemical composition of the bulk Earth is also unknown. Therefore, Earth building blocks and the transport of volatile components (water, organic matter, etc.) to the Earth and its timing remain uncertain. Elucidation of the composition of light elements in the core is the key to understanding the origin of the Earth.

【Publications Relevant to the Project】

- Ohta, K., Kuwayama, Y., Hirose, K., Shimizu, K., Ohishi, Y., Experimental determination of the electrical resistivity of iron at Earth's core conditions, *Nature*, 534, 95-98, 2016.
- Hirose, K. et al., Crystallization of silicon dioxide and compositional evolution of the Earth's core, *Nature*, 543, 99-102, 2017.

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