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High-pressure behavior of Ar

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We have found that an abundance of solid argon (Ar) may exist in the Earth's deep interior. This conclusion is based on the results of numerical models, as well as high-temperature and high-pressure experiments, conducted on a supercomputer to reproduce the conditions of Ar in extreme environments. Ar, which is the third most abundant element in the atmosphere after nitrogen and oxygen, is also found dissolved in seawater, from which it may be incorporated into oceanic plates and descend into the Earth's interior via subduction along ocean trenches.

1 Introduction

Noble gases are key tracers to understand the evolution of the Earth because of their inert nature and isotope variations. However, the mechanism of the recycling of noble gases in the deep mantle is still an open question. Recently, an experimental study demonstrated high solubility of noble gases in amphibole. Amphibole is commonly observed in the altered oceanic crust, with a significant amount of noble gases measured in natural rock samples. Amphibole has a mineralogical A-site, which is an energetically favourable position for noble gases. Lattice structures of some hydrous minerals, such as serpentine and chlorite, are similar to the A-site in amphibole. This indicates that these hydrous minerals are candidates for the host phases of noble gases. As the breakdown of serpentine finishes at the upper part of the upper mantle (~ 200 km depth), it is difficult to transport to great depths in the deep mantle.

2 Experiment

The high-pressure X-ray diffraction experiments were performed using a diamond anvil cell high-pressure apparatus. After reaching the required pressure, we perfor med the laser-heated annealing, which reduced the diffent ial stress on the compression. The high puarity Ar (purity = 99.999%) was used as a starting material, which was cr yogenically loaded into the sample chamber. The sample was probed using angle-dispersive X-ray diffraction, emp loying the AR-NE1A synchrotron beamline at KEK, Japa n. The angle-dispersive X-ray diffraction patterns were ob tained on an image plate system (Rigaku R-AXIS, Japan). In this study, we determined the pressure-volume relation of Ar at room temperature using diamond anvil cell experi ments. We also performed the first-principles calculations to investigate high-teperature bihaviours of Ar. The combi nation of high-pressure experiments and first-principles c alculations allows us to determine reliable physical proper ties, such as the EOS and melting temperature, over a wid e range of pressures and temperatures.

3 Results and Discussion

Calculated results revealed that the melting temperature of argon increases sharply as its pressure increases, indica ting that argon descends into the Earth's interior in a stabl e, solid condition (Fig. 1). As experimental results indicar ed thtat solid argon is lighter in density than the minerals t hat comprise the mantle, it is possible that solid argon acc elerates mantle upwelling flow. Furthermore, solid argon may stably exist in extreme environments, with temperatu res of 2000ºC or higher and pressures of 100 GPa or mor e, and it is thus believed to occur throughout the entire lo wer mantle (~55% of the Earth's total volume) [1]. These findings provide insight into the mechanism of global arg on cycling, which has previously remained enigmatic. Th ese findings may lead to understand other noble gases, su ch as helium, neon, and xenon, as well as volatiles, such a s water and carbon dioxide, with the aim of understanding the evolution and roles of volatile compounds throughout Earth's history.

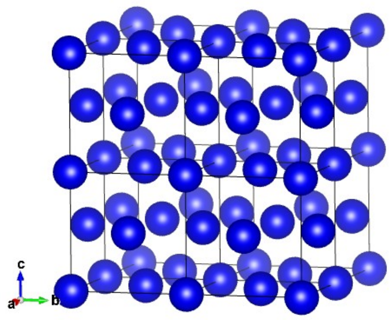

Fig. 1: Fig. 1. Crystal structure of solid argon, which can remain stable under extreme conditions comparable to those in Earth's core [1].

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References

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