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Compression behaviour of noble gases to lower mantle pressures and implications for their storage in crystalline lower mantle phases

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Abstract

Noble gases are important geochemical tracers allowing reconstructing global volatile cycles in the deep Earth's interior over geological times. Precise data on their compression behavior at deep Earth conditions are therefore needed to constrain these important processes.

Introduction

It is well known, that solid heavy noble gases undergo a pressure induced martensitic phase transition from a face centred cubic (fcc) to a hexagonal close packed (hcp) structure. These two phases coexist in a very wide pressure domain inducing important modifications of the bulk properties of the resulting mixed phase system. However, no detailed studies have been devoted to this subject. Most of the experimental works were focused on the confirmation of the martensitic nature of the transformation and the determination of the equation of state (EoS) of individual solid phases without giving consideration to the impact of the phase coexistence on individual compression behaviors.

Here, we report a detailed in-situ X-ray diffraction and absorption study of the influence of the fcc-hcp phase transition on the compression behaviour of solid Argon (Ar), Krypton (Kr) and Xenon (Xe) in an extended pressure domain up to 150 GPa.

Results

As an example the P-V relationship for the fcc Kr phase are reported in Fig. 1 extracted from [1] together with previous literature data [2-6]. We confirm that the martensitic transition has an important effect on the compression behavior of the fcc phase. This effect needs to be taken into account for calculating the size of a noble gas atomic radii at lower mantle conditions.

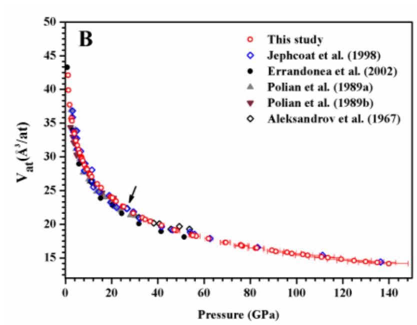

Figure 1: Evolution of V_{at} (Å3) for the fcc phase from [1] and previous works as indicated in the legend. The arrow indicates the pressure were an anomaly in the compression behavior of fcc Kr was observed.

Discussion and implications

We used the new compression data to constrain noble gas solubilities in lower mantle minerals throughout the entire lower mantle.

Storage in crystalline phases at such conditions might become indeed important due to the high compressibilities of noble gases. We applied the lattice strain approach and used recent experimental noble gas solubility data of perovskite ([7] obtained for Ar and Kr at shallow mantle conditions of 25 GPa and 2300 K) and ferropericlase (this work, obtained for Kr up to 60 GPa and 2300 K). This dataset allowed us evaluating the noble gas storage capacity of the entire Earth's lower mantle during magma ocean crystallisation. We show that the crystalline lower mantle has the capacity to retain noble gases in significant quantities. Solubilities are the highest for Ar and Kr followed by neon and xenon.

We used this result to model the effect of noble gas replenishment from the lower mantle into the Earth's atmosphere over geological times. Our model extends the one of [7] and underlines that noble gas replenishment from the entire lower mantle can contribute to the noble gas abundance patterns and xenon depletion anomaly of the present-day Earth's atmosphere.

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