Press Release

Keio University

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Discovery that Thin Hydrogen Films are in a State on the Verge of Superfluidity

A research group including Takahiko Makiuchi, a doctoral student at the Keio University Graduate School of Science and Technology (at the time of research; currently a postgraduate researcher at the University of Tokyo Graduate School of Engineering, Saitoh Spin Quantum Rectification ERATO program) and Professor Keiya Shirahama and Yusuke Nago, a research associate, of the Faculty of Science and Technology discovered that thin films of hydrogen molecules remain in a liquid state at extremely low temperatures and exist on the verge of superfluidity (*1).

Similar to the superconductivity of metals, superfluidity is a dramatic quantum phenomenon that occurs at low temperatures, but it is only observed in very limited substances such as liquid helium (*2). Molecular hydrogen (H_2) has been attracting attention as one of the few candidate substances that can exhibit superfluidity. From elastic measurements of thin hydrogen films, in this study, it was discovered that the surface of the thin films behaves like a liquid down to an extremely low temperature of minus 272 degrees Celsius (absolute temperature of 1 kelvin) and are in a state on the verge of superfluidity. This finding is groundbreaking as it quantitively showed for the first time how close hydrogen is to being a superfluid, as well as opening up the possibility of making superfluid hydrogen a reality through new methods such as the application of high-frequency sound waves. Hydrogen is not only important for the formation of the universe and life, but there are also expectations that it will develop superconductivity under extremely high pressure. The realization of a superfluid hydrogen will not only demonstrate an aspect of hydrogen's diversity but is also expected to contribute greatly to the development of science.

The outcomes of this research were published in the American scientific journal "Physical Review Letters" on December 13, 2019 (local time).

＜Reference＞

1. T. Makiuchi, M. Tagai, Y. Nago, D. Takahashi, and K. Shirahama, “Elastic anomaly of helium films at a quantum phase transition”, Physical Review B **98,** 235104 (2018).
2. T. Makiuchi, K. Yamashita, M. Tagai, Y. Nago, and K. Shirahama, “Elastic Anomaly of Thin Neon Film”, Journal of the Physical Society of Japan **88**, 034601 (2019).

＜Details of original paper＞

Multiple diffusion-freezing mechanisms in molecular-hydrogen films

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＜Reference diagram＞

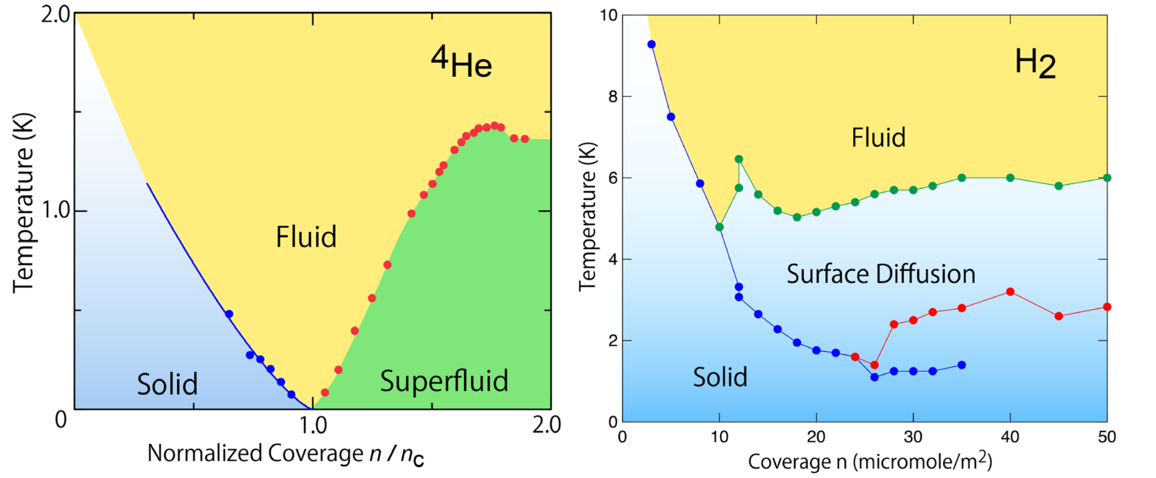

Figure: Phase diagrams obtained from elastic anomaly temperatures. The left is the phase diagram for helium while the right is that for thin hydrogen film. In both cases, the solidification temperature decreases rapidly as the film thickness increases. Helium becomes a superfluid at the quantum critical point. In the case of hydrogen, diffusion of surface molecules is maintained until about 1 kelvin (blue dots).

＜Glossary＞

*1 Superfluidity: This is a phenomenon exhibited by substances with strong quantum properties, such as liquid helium, at extremely low temperatures. Superfluidity is the name given to describe their unique behavior including the loss of viscosity and persistent rotation in a pipe. Superfluidity occurs when many particles occupy a single quantum state (Bose–Einstein condensate). In addition to liquid helium, ultracold atoms such as lithium and polariton condensates in semiconductors are known as superfluid substances. Neutron stars are also thought to be superfluid substances. Superconductivity can also be regarded as superfluidity of electrons.

*2 Liquid helium: Helium becomes a liquid at about minus 269 degrees Celsius (4 kelvin), making it the most difficult of all substances to liquefy. Helium is not only used as a cryogen for superconducting magnets but is also actively studied as it exhibits quantum phenomena that are representative of superfluidity. It is the only substance that does not solidify under standard pressure at absolute zero.

※Please direct any requests or inquires to the contact information provided below in advance.

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