Insulator to semiconductor transition of light and heavy waters at dynamic compression by laser-driven shock wave

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Water is the most abundant condensable molecules occurring in the universe. It forms solid ice to be the primary source of cosmic dust particles, which had coalesced together to develop into icy giant planets during the formation stage of the solar system. At high pressure and temperature conditions relevant to the interiors of these planets such as Uranus and Neptune, water exhibits exotic behaviors by experiencing molecular dissociation yielding free hydrogen cations (protons) and/or free electrons, which now attracts rapidly-increasing attentions of researchers in the field of solid state physics as well as planetary sciences, e.g. [1]. Occurrence of such dissociation of water is one of the best-possible rationale of strong magnetic fields originating from deep insides of the icy giant planets.

Here by using high-power nanosecond laser pulses from GEKKO-XII glass laser at Institute of Laser Engineering at Osaka University, light and heavy water (H_2O and D_2O) are shock-compressed into its high pressure and temperature states. Each sample under a dynamic compression condition at a variety of shock strength was analyzed in situ using fast optical diagnostics for its pressure, volume, temperature, as well as for its optical reflectivity [2]. By observing the onset of rapid reflectivity increase, we found an occurrence of electronically-semiconducting state of densified light and heavy waters at pressures between 55 to 70 GPa and at temperatures around 4500 K. We note that the heavy water samples with 10 % higher initial density experienced higher shock pressures than the light water along their principal Huguenot conditions. In addition to these Hugoniot results, the onset of increasing reflectivity of off-Hugoniot results on these waters were also apparent at the very similar temperature condition, where the pressure of water have exceeded 70 GPa. The latter off-Hugoniot conditions were generated by using sample pre-compression technique with diamond anvil cells where the sample was compressed up to 0.7 GPa of static pressure before laser-driven compression [2]. Starting from such conditions, temperature rise of shock-compressed sample is reduced to make the generated pressure and temperature conditions more directly relevant to the interior conditions of icy giant planets. The current experimental results on the compressed waters provide us new insights about the structures and electronic properties of water occurring within the icy giant planets, and about the origin of magnetic fields generated from their deep interiors.

References: [1] M. Millot et al. Nat. Phys. 14, 297 (2018); [2] T. Kimura et al. J. Chem. Phys. 142, 164504 (2015)