Time-resolved neutron diffraction studies about ices

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Water molecules are dipolar, and neutron diffraction studies provide evidences that ices VIII and IX (the proton ordered phases of ices VII and III) exist as stable low-temperature phases at high pressure. However, under 200 MPa, the proton of normal ice Ih is disordered even though a very low temperature. A question that has long fascinated researchers is whether there is an existence of ferroelectric water ice (FWI) named ice XI as a stable low-temperature phase of ice Ih, which caused by aligned water molecules (i.e., the proton ordering). This old debate is implicated in our understanding of condensed matter and hydrogen bonds, and recently the ferroelectricity in ice becomes an earnest subject: FWI exists on outer planets, such as Pluto and Charon? Recent time-resolved neutron diffraction studies of the growth process of FWI tell new aspects in this subject.

Based on the neutron studies, I report a structural evidence of the growth process of FWI and the conjectured area where FWI exists in the solar system. Furthermore, I discuss further directions of ice and water research in planetary and neutron sciences.

The mobility of the protons in ice is very low at low temperatures and the phase transition from ice Ih to ice XI is considered to require a long period over our life time. Thus, nobody observes pure ice XI. However, some specialists in ice research have strongly believed the hypothesis that ice XI is a stable structure at low temperatures.

The hypothesis comes from a series of neutron studies about a partial ordering of protons in ice containing potassium. Studies claiming the protonic ordering in the doped ice from electrical and thermodynamical data have been reported for the several decades. Those suggest that the doping speeds the transition from ice Ih to ice XI, and the function of the KOD molecules is to act as a catalyst.

To investigate whether ice XI is a stable low-temperature phase or an ordered-region caused by the impurity, Fukazawa et al (e.g., J. Crystal Growth 2005) measured time-resolved neutron powder-diffraction from 0.1- and 0.01-M KOD doped ice in the research reactor, JRR-3M, at the Japan Atomic Energy Agency. Based on the results, I analyze the growth process of ice XI. Furthermore I discuss whether pure ice XI exists in the universe.