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Deuterium experiment project on LHD and impact of plasma ion species on confinement

LHD重水素実験計画と閉じ込め特性に対するプラズマ核種の効果

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A project of deuterium experiments are planned on the Large Helical Device (LHD). The objectives of the experiment are (1) to realize high-performance plasmas by confinement improvement in helical plasmas, (2) to clarify the isotope effects on plasma confinement in toroidal plasma devices and (3) to demonstrate the confinement capability of energetic ions in helical systems. Various hardwares, such as NBI, ECH and neutron diagnostic, are also upgraded and/or newly installed on LHD with the deuterium experiments. Combining these upgrade of hardwares with the isotope effect on confinement, it is expected that the deuterium experiments will extend the parameter range of LHD plasmas and will provides farther understanding in the physics of toroidal plasmas.

1. Introduction

A project of deuterium experiments are planned on the Large Helical Device (LHD). The objectives of the experiments are;

1) to realize high-performance plasmas by confinement improvement and to provide a wide range of plasma parameter space relevant to the reactor plasmas,
2) to clarify the mass dependence (isotope effect) in the plasma confinement, leading to the establishment of a model for the burning experiment using deuterium and tritium, and
3) to demonstrate that the confinement capability of energetic ions is relevant to the burning plasmas in helical systems.

In addition to these topics related to plasma physics, the engineering issues of hydrogen isotope retentions in vacuum vessels and the plasma-wall interaction by hydrogen isotopes are of our great interests.

After the agreement for the environmental conservation was signed with local governments on March 28th in 2013, the preparation for deuterium experiments was started on LHD. Although the exact date of starting the experiment is not determined yet, the preparation is accelerated so that the experiments can be started within a few years. The schedule of deuterium experiments are shown in Table 1. The deuterium experiments are planned to proceed for 9 years. The first year will be a preliminary experiment and will be mainly dedicated to the commissioning of LHD and various hardwares against neutron radiations and tritium handling. Retention studies of deuterium in the vacuum vessel will be also a major task of this year. From the 2nd year through 6th year, we will try to improve the plasma parameters of LHD with deuterium discharges and to explore the physics of them to investigate the isotope effect of confinement, and to perform the confinement studies of energetic ions, the studies of plasma-wall interactions, and so on. The last three will be dedicated for integrated high-performance experiments on LHD.

Table I. Schedule of deuterium experiments on LHD

FY	1st year	2nd -6th years	7th-9th year
Experiment	Preliminary (commissioning)	Exploration and characterization of deuterium plasmas	Integrated high-performance experiments
Maximum annual yield of Tritium [Bq]	3.7x10^{10} [Bq] (integrated yield)		5.55 x10^{10} [Bq] (integrated yield)
Maximum annual yield of neutron	2.1x10^{19} [n] (integrated yield)		3.2x10^{19} [n] (integrated yield)

3. Plans for device upgrade

Several hardwares are now in the process of upgrade as a preparation for deuterium experiments. The Neutral Beam Injector (NBI) is the one of the major upgraded hardwares for the deuterium experiments. Two of positive-ion based NBIs will increase their injection power of 6MW to 9MW. The Electron Cyclotron Heating (ECH) system will also be upgraded. Currently, we have three gyrotrons of 77GHz and one gyrotron of 154GHz. Each of gyrotron provides about 1MW power of micro waves into LHD. Two more gyrotrons of 154GHz are planned to be installed on LHD. Total heating power by ECH will be extended to 6MW from 4MW.

The neutron diagnostic will be newly installed on LHD. In LHD plasmas, neutron emission rate of exceeding 10^{16}[n/s] are expected by simulations. This number is almost comparable to the neutron rate from DD plasmas in major tokamaks, such as JT-60U, TFTR and JET. The purpose of the neutron diagnostic is to evaluate the fusion output of the LHD deuterium plasmas and also to evaluate the amount of tritium production in plasmas. Since the DD reaction rates are higher at the higher kinetic energies of deuterium ions. This diagnostic will also provide the information of energetic ion contents in LHD plasmas. The confinement studies of energetic ions in helical plasmas will be accelerated by the LHD deuterium experiments.

4. Isotope effects

Evaluation of isotope effects is one of the major tasks in the LHD deuterium experiments. The isotope effect on plasma confinement is widely observed in various devises in the world [1-5]. It is often reported that the energy confinement time (τ_E) is positively scaled with the mass number (A) of plasma ion species, e.g., $\tau_E \propto A^{0.5}$. On the contrary, the gyro-Bohm scaling suggests that the confinement time would be scaled as $\tau_E \propto A^{-0.5}$[6]. Currently, no theoretical explanation was succeeded to explain the isotope effect on the confinement, so far. Thus, the investigation of the physical mechanism of isotope effect is a big challenge for the deuterium experiments on LHD.

The general approach to clarify the isotope effect is based on the assumption that the mass number of plasma ion species directly influences the confinement property. This approach tries to scale the confinement time and thermal diffusivity by the power of the mass number.

In addition to the hypothesis based on the direct effect by the isotope, it is also necessary to consider the indirect effect of isotopes on the confinement property since the neutral penetration in the core plasmas are often pointed out to affect the plasma performances and the penetration length depends on the mass number of isotopes [7]. This idea sounds very natural by considering the fact that the high performance discharges usually require intensive wall conditioning to reduce the neutrals in the core plasmas [8].

Recent nitrogen seeding experiments in JET under the ITER like-wall (ILW) condition [9] suggests that the impact of light-Z impurities on the confinement, where the confinement degradation of about 30% was observed in the JET H-mode discharges under the ILW condition being compared to the all-carbon wall condition and the nitrogen seeding recovers the H-mode performance under the ILW condition. Since the sputtering rate on the carbon material by deuterium ion is greater than that by hydrogen, the light-Z impurity effect could be also a candidate as the indirect effect by the hydrogen isotopes.

5. SUMMARY

A project of deuterium experiments are planned on the Large Helical Device (LHD). The objectives of the experiment are (1) to realize high-performance plasmas by confinement improvement in helical plasmas, (2) to clarify the isotope effects on plasma confinement in toroidal plasma devices and (3) to demonstrate the confinement capability of energetic ions in helical systems. The evaluation of isotope effects is one of the major tasks in the LHD deuterium experiments. In exploring the physics of isotope effects, it is important to look at not only the direct effect of isotopes but also the indirect effect, such as neutral penetration difference and light impurity sputtering difference of hydrogen isotopes. Combining the upgrade of various hardwares on LHD with the isotope effect on confinement, it is expected that the deuterium experiments will extend the parameter range of LHD plasmas and will provides farther understanding in the physics of toroidal plasmas.

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