Advisory Opinion

Plasma Science

- For its interdisciplinary development and a prosperous future society -

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Science Council of Japan

Committee on Physics
Subcommittee on Physical Science

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Executive Summary

1. Background and Objectives

Plasma is a universal state of matter in the universe and is applied to various core technologies that support modern civilization. Since it was named by Langmuir, the novel properties of plasma have been studied intensively for various purposes. The diverse phenomena that appear in plasma are the key for discovering nature's profound principles, and many general physics concepts and methods have been developed from their exploration. In addition, many mathematical theories have been found by studying equations that describe plasma phenomena, proving that plasma is a fountain of knowledge.

Even though it is simply called plasma, the possible values of parameters such as temperature and density that characterize its state are vast, spanning more than ten orders of magnitude. We have found distinctive research targets depending on the range of the parameter values and have been competing with the world in developing innovative technologies. For example, in the field of ultra-high temperature plasma, Japan, along with Europe and the United States, has been at the forefront of research to develop nuclear fusion reactors with magnetic confinement plasma and high-energy-density plasma using intense lasers. In the field of low-temperature plasma, various chemical reactions that occur in non-equilibrium fields are of major interest. For example, ion etching, a key technology for semiconductor manufacturing, was created in Japan. In the universe, there are plasmas with a wide range of parameters in various regions, such as galaxies, celestial bodies, the magnetosphere, and the ionosphere, and the phenomena that occur in these plasmas sometimes have similarities with nuclear fusion plasma or reactive plasma.

To further develop plasma science and produce world-leading results, we are now in an era in which we need a perspective that surveys the vast field as a whole and the circulation of knowledge that links cutting-edge research with such perspective.

The purpose of this advisory opinion is to concretize the future vision of this field, and to propose measures to promote its interdisciplinary development as a general physics subject by providing an overview of the diverse evolution of plasma science from a broad academic perspective and presenting research themes that will lead to emergent innovations. We also highlight the importance of establishing an academic research infrastructure in Japan as a platform of multidisciplinary collaboration that generates international intellectual collaboration.

2. Contents of the Advisory Opinion

In this advisory opinion, the history and status of plasma science research are briefly summarized in the introduction. What principles of nature can be elucidated by the study of plasma from the viewpoint of general physics, and the specific themes of plasma research in space and the laboratory are summarized. Regarding laboratory plasmas, high-temperature plasma research aiming at the realization of fusion reactors, high-energy-density plasmas generated by high-power lasers, and reactive plasmas aiming at extreme functions are described.

Each field of plasma science deals with subjects that differ by more than ten orders of magnitude in terms of parameters (density and temperature). However, beyond the differences in parameters, common research themes can be found throughout plasma science. In this advisory opinion, we summarize these common research themes as ten specific issues (eight academic topics and two technological innovations). We propose short-term challenges that plasma science should tackle now to solve within ten years and long-term ones that should be targeted for the next 30 years or so. The keywords of the challenges include far-non-equilibrium systems, hierarchy, turbulence and fluctuation, suddenness and collapse phenomena, autonomy and rhythm, phenomena evolving in velocity space, reaction fields, interfaces and structures, realization of fusion reactors, and non-equilibrium plasma technology. These keywords have an expansive interdisciplinary nature that goes beyond plasma. Plasma science is a comprehensive discipline involved in various fields and has had a spreading effect beyond its core. In this advisory opinion, we discuss the interdisciplinary relationship of plasma science with mathematics, complex systems science, particle physics, astrophysics, earth and planetary sciences, biophysics, quantum beam science, materials and device sciences, catalytic chemistry, computational and data sciences, medical science, and plant science as representative fields.

Next, this advisory opinion discusses the future development of plasma science. For the development of plasma science and its broad interdisciplinary approach, we propose that it is essential to share themes from the entire field's perspective and build a solid interdisciplinary collaboration network where intellectual collaboration occurs across the field. Particularly in fusion science, it is important to organize the relationship between developmental and academic research and clearly state how it should be mutually beneficial. It is necessary to build a base for realizing a more open circulation of people and knowledge, where the needs from the front lines of development meet the seeds generated from the diverse challenges of academia.

The role of plasma science in realizing a better society is described. Plasma science has a potential role as the backbone of modern civilization. It will be possible to continue contributing to various social issues such as energy, environment, and pandemics. As an innovative technology that holds the key to carbon neutrality, there are growing expectations worldwide for the early commercialization of fusion energy. Innovations in processing technology for next-generation semiconductor devices using plasma are key to DX (Digital Transformation) because they are essential for improving the performance of information devices. Various plasma applications as reaction fields will contribute to environmental clean-up as well as pandemic control.

Finally, as a fundamental scientific principle, plasma science's problem recognition of understanding collective phenomena of systems in which many elements are combined and exploring the possibility of controlling them shares a common direction with the various sciences of today, which are trying to face the real world of increasing complexity and diversity. As a discipline responsible for this future social challenge, the urgent task of plasma science is to develop a multifaceted approach based on an interdisciplinary and long-term vision.