White Paper for *Frontiers of Plasma Science Panel*

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Indicate the primary area this white paper addresses by placing "P" in right column.
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	"P", "S"
• Plasma Atomic physics and the interface with chemistry and biology	
• Turbulence and transport	
• Interactions of plasmas and waves	
• Plasma self-organization	
• Statistical mechanics of plasmas	

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	"X"
Oral	
Poster	
Either Oral or Poster	
Will not attend	X

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PLASMA SCIENCE AS A SCIENCE

As stated in the policy report "Plasma Science" issued by the U.S. National Research Council in 1995, "Plasma Physics is frequently viewed not as a distinct discipline, but as an interdisciplinary enterprise focused on a large collection of applications". The situation is commonly recognized as troublesome, because the plasma community aspires to treating Plasma Physics as a true science. But, simultaneously, the community defines its agenda such that these aspirations cannot be achieved.

For example, consider the very first page of the same policy report. The Executive Summary says: "A healthy plasma science can be expected to make many important contributions to our society for the foreseeable future. The purpose of this report is to provide guidance regarding the ways in which plasma science can contribute to society and to recommend actions that will optimize these contributions." Could a similar policy be proclaimed within, say, astrophysics or high energy physics? Certainly not; for a fundamental science this is unimaginable. The quoted text unambiguously positions the field as a basket of applications. It seems somewhat strange then that the rest of the report laments the very same attitude that is affirmed on its first page.

The specific policy report is quoted here only as an illustration, while the outlined problem is general and has been pointed out by many individuals within the community. The fact is, operating Plasma Science as

a science and guiding it based on the anticipation of particular applications are mutually excluding options. Attempting to focus the field at both is not just an indicator of wishful thinking; it effectively results in having no strategy at all. Therefore, strategic planning must not be limited to identifying a list of scientific problems to solve, for that negates the very idea of strategy. Rather, strategic planning should start with determining what the subject and the goals of Plasma Science are; only then looking for specific directions to proceed becomes meaningful.

Without pretending to be original, the present White Paper sketches (or, more precisely, summarizes) some definitions and arguments that aim to position Plasma Science as a true scientific discipline and classify its subfields, such as Plasma Physics, adequately to this status. The definitions and arguments are as follows.

Plasma is the state of matter whose behavior is essentially determined by collective interactions of free charges.

The implication that plasmas consist of free (i.e., not bound) charges distinguishes plasmas from other polarizable media. It is also the reason why the plasma state is often understood as an ionized state; however plasma and ionized states are not equivalent. For example, there exist nonneutral and electron-positron plasmas, where ions *per se* may not be present because there are no atoms and molecules at all. Moreover, environments that do contain atoms or molecules are always ionized to some extent, but that does not necessarily make them plasmas. What distinguishes plasma from other ionized states of matter is having *enough* free charges, such that they significantly affect the system behavior.

Plasma Science is a study of plasma and exploration of plasma applications. Plasma Science consists of several disciplines including, first and foremost, Plasma Physics and Plasma Engineering, but also Plasma Chemistry and Plasma Atomic, Molecular, and Optical Physics (AMO), plus their applications. Below, we focus on Plasma Physics.

Plasma Physics is a study of physical properties and dynamics of plasmas that are essentially determined by collective interactions of charged particles, as well as of single-particle dynamics that is determined by or underlies such collective interactions. Plasma Physics consists of fundamental science, called Basic Plasma Physics, and exploration of its applications, called Applied Plasma Physics.

Basic Plasma Physics is the exploratory fundamental study of elementary plasma phenomena, as well as of new approaches to analyze and model plasma properties and dynamics theoretically, computationally, and experimentally. The goal of this study is to advance and systematize understanding of the plasma state of matter. Hence, the subject of Basic Plasma Physics is ***ways to understand plasma*** (but, contrary to a common misconception, not plasma *per se*).

As a spin-off, Basic Plasma Physics can yield new descriptions of specific plasmas too, thus facilitating practical applications. Basic Plasma Physics is also the only source of knowledge that new plasma applications can feed on in the future, and it is important as such. However, as a fundamental discipline, Basic Plasma Physics does not have a mission of assisting applied research *per se*, and its progress is not measured in applications.

Examples of specific thrusts within Basic Plasma Physics are:

- advancing the fundamental understanding of ***elementary plasma phenomena***, including (but not limited to) basic waves and instabilities, wave-particle and wave-wave interactions, collisions, sheath phenomena, chaos and turbulence, magnetic reconnection, dynamo effects, and single-particle dynamics in prescribed fields;

- advancing and systematizing ***models of complex plasma phenomena***, both by developing fundamentally new theories and by bringing existing theoretical methods from other areas of physics (e.g., quantum mechanics, quantum electrodynamics, AMO) and mathematics (e.g., theoretical mechanics, nonlinear systems, differential geometry) to Plasma Physics;
- developing, yet not applying, new numerical techniques for plasma simulations;
- developing, yet not applying, new experimental techniques;
- reformulating the existing knowledge of the plasma state more efficiently, so that, although constantly expanding, most this knowledge remains practically accessible to future generations of plasma scientists;
- bridging Plasma Physics with other physics disciplines and contributing to the understanding of the Universe in general.

The more traditional definition of Basic Plasma Physics as "non-fusion" plasma research does not seem satisfactory, because it leaves no room for methods as an independent subject of research. As an activity aimed at structuring the knowledge, methodology represents the very essence of fundamental science. It is not surprising then that, after having lost interest to advancing its methods, Plasma Physics is having trouble maintaining the status of a science.

Applied Plasma Physics is the part of Plasma Physics that applies the existing theoretical, experimental, and computational methods toward understanding specific plasmas. Being a collection of researches rather than an integral research program, Applied Plasma Physics does not have unifying goals. Its subject can be defined as ***ways to apply the existing understanding of plasmas***. This is not to be confused with applying plasmas *per se*, which is the subject of Plasma Engineering rather than of Plasma Physics.

Examples of specific topics within Applied Plasma Physics are fusion research, astrophysics, space science, plasma processing, plasma propulsion, as well as studies of beams, accelerators, and radiation sources. Although some of these are basic sciences by themselves, within Plasma Physics they play the role of applied disciplines, because they apply the existing general understanding of the plasma state to describe specific systems.

It often happens that findings stimulated by applied research advance understanding of the plasma state in general; then they become parts of Basic Plasma Physics. Still, Basic Plasma Physics as a field is well separated from Applied Plasma Physics in terms of its subject and goals.

Since the subjects and goals of individual areas of Plasma Science are quite different, the deliverables in these areas are incomparable. Making different areas of Plasma Science compete with each other cannot be justified by references to pragmatism, as it stimulates not the growing complexity, or scientific progress, but rather "survival of the fittest". The commonly recognized decline of Basic Plasma Physics, the unpleasant image of Plasma Physics as a basket of applications, and the field's status of a political pushover all seem to stem from this root. These problems cannot be fixed quickly. However, it seems necessary to at least adopt a consistent terminology so, in the future, the problems can be discussed constructively.