PLASMA SCIENCE AND FUSION CENTER

The timely development of practical fusion energy in the 21st century is arguably one of the most important challenges facing the scientific and engineering community worldwide. The Plasma Science and Fusion Center (PSFC) provides a focus for experimental and theoretical studies in plasma science, magnetic and inertial fusion research, and the development of related enabling technologies. The center fosters independent creativity and provides the intellectual environment for the educational training of students, research scientists, and engineers. Research activities at the Plasma Science and Fusion Center fall into six major programmatic divisions as described below.

The Magnetic Fusion Experiments (MFE) Division is developing a basic understanding of the stability and transport properties of high-temperature magnetically confined toroidal plasmas at reactor-relevant conditions. The group’s present research program seeks to understand energy, particle, and momentum transport, coupling between the core plasma and boundary plasma, pedestal physics, and heating and current drive in fusion plasmas. The division is actively researching ways novel divertors can withstand the first wall power loadings comparable to those of future fusion reactors. In addition, the group seeks to optimize plasma performance with Radio Frequency (RF) heating and non-inductive current profile control using novel configurations and deployment of high-power RF transmitters (8 MW at 40–80 MHz) and microwaves (3 MW at 4.6 GHz frequency). The experimental team of scientists, postdocs, students, and engineers collaborates with other fusion facilities, domestically primarily at DIII-D, and internationally with European and Asian facilities. High performance computing at national supercomputing centers, as well as local clusters, plays a critical role in validating models with experiments; close collaboration between experimentalists and computational physicists is a foundational aspect of research in MFE at PSFC. The high magnetic field tokamak approach, long a focus of the division’s research on the Alcator series of facilities, is a promising avenue to practical fusion energy production, enabled by the recent commercial development of high temperature rare-earth barium copper oxide superconducting tapes. Starting in 2018, the MFE Division, working closely with the Magnets and Cryogenics Division, has entered a partnership with a private company, Commonwealth Fusion Systems (CFS). CFS is sponsoring research at the PSFC to develop this new superconducting technology. After successful development of fusion-scale magnets, we intend to design, build and operate the world’s first net energy gain tokamak, SPARC.

The Plasma Theory and Computation Division is composed of scientists, students, and faculty. It carries out research in support of the national and international magnetic fusion energy programs as well as research on basic plasma science, and space and astro plasma physics. The research consists of elements involving analytic theory, high performance computation and integrated modeling, verification of computational models, validation of theoretical/computational predictions against experimental results, and the development of advanced reduced models applicable to whole device simulations. The division collaborates extensively with major plasma and fusion research centers in the US, England, Europe, Japan, China, and Korea.

The High-Energy-Density Physics Division designs and implements experiments on national facilities, such as the OMEGA laser facility at the University of Rochester Laboratory for Laser Energetics, and the National Ignition Facility at Lawrence Livermore National Facility. This division discovered the existence of megagauss magnetic fields in laser-compressed pellets. This division also performs related theoretical calculations to study and explore the nonlinear dynamics and properties of plasmas in inertial fusion and those under the extreme conditions of density (~1000 g/cc), pressure (~1000 gigabar), and field strength (~megagauss). Most recently the division has conducted pioneering nuclear science experiments using high-energy-density plasmas, ushering in a new and exciting field of research, plasma nuclear science, blending the separate disciplines of plasma and nuclear physics.

The Plasma Science and Technology Division conducts experimental and theoretical research on a wide range of topics, primarily in plasma-related areas, that are not directly part of the program of fusion energy research. A major research effort investigates the physical principles of novel sources of high-power, coherent radiation ranging from the microwave to the terahertz region of the electromagnetic spectrum. Current research focuses on the gyrotron (or cyclotron resonance maser), a novel source of millimeter wave and terahertz radiation using high magnetic fields, and on novel forms of the traveling wave tube amplifier. One promising application of the gyrotron, being studied experimentally and theoretically, is in boring through hard rock by melting and vaporizing the rock material. In addition, the division conducts research on novel concepts for high-gradient acceleration of electrons to demonstrate the principles required for future generations of electron linear accelerators. Research is also conducted on the use of low-temperatures plasmas and ions in the modification of materials. A strong effort is also carried out on spintronics, novel topological insulator systems and spin polarized transport in nanostructures of metals and semiconductors.

The Magnets and Cryogenics Division provides critical engineering support to the national fusion energy sciences program for both operating magnetic confinement fusion experiments and advanced fusion design projects. The division has extensive experience in design, analysis, development, and fabrication of advanced high-field copper and superconducting magnet technology. Present research is focused on developing second-generation high-temperature superconductors for high-field, high-current cables for fusion magnets, and for applications of superconducting DC power transmission and distribution. The division is also developing very high-field, compact cyclotron accelerators for applications such as proton and carbon radiotherapy for cancer treatment, active detection of strategic nuclear materials for protection against...
weapons of mass destruction, and variable energy, heavy-ion accelerators for fusion materials research.

The Magnetic Resonance Division, including the members of Francis Bitter Magnet Laboratory, encompasses the research focused on the use of magnetic resonance for scientific investigation, and the development of experimental tools to carry out those investigations. The division seeks to develop sophisticated technologies for magnetic resonance in the areas of solution-state nuclear magnetic resonance (NMR), solid-state NMR, electron paramagnetic resonance (EPR), and dynamic nuclear polarization (DNP); to apply those technologies to biologically and medically significant research, both in-house and collaboratively; to operate a state-of-the-art instrument facility to serve needs of researchers in chemistry, biology, and medicine; and to openly disseminate and provide training in technological developments at the center. In addition, the division has programs to design and construct the next generation NMR magnet operating at a 1H frequency of 1.3 GHz using high temperature superconductor.

Many academic departments are affiliated with PSFC, including Physics, Nuclear Science and Engineering, Electrical Engineering and Computer Science, Materials Science and Engineering, Mechanical Engineering, Chemical Engineering, and Aeronautics and Astronautics. The center’s programs and laboratories provide excellent forums for training students and professional researchers, and offer world-class research facilities to faculty members from many departments. Fifty-five graduate students are currently involved at all levels of thesis work. Undergraduates also can participate through the Undergraduate Research Opportunities Program.

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