PSFC

PHYSICS RESEARCH

Understanding the basic physics of plasmas is necessary not only to advance fusion research, but to increase the physics-based foundations of plasma-related scientific disciplines and applications.

Members of the Physics Research Division, including theoretical and experimental plasma physicists, faculty members, graduate and undergraduate students and visiting collaborators, work together to better understand plasmas and to extend their uses.

Research includes:

- **Laboratory experiments**
- **Development of novel plasma diagnostics**
- **Theory of magnetically confined fusion plasmas**
- **Nonlinear wave propagation, turbulence and chaos**
- **Space plasma physics**
- **Plasma astrophysics**
- **Laser-plasma interactions**

Photo by Paul Rivenberg

Dr. Jan Egedal works atop the Versatile Toroidal Facility, a medium-sized tokamak currently used to study magetic reconnection, a phenomenon observed in solar flares.

Theoretical Plasma Physics

Using the fundamental laws of physics, theorists at the PSFC are developing improved analytical and numerical models to better describe plasma phenomena both in the laboratory and in nature. Theoretical plasma research is essential not only to better understand basic plasma physics, but also to support many areas of fusion physics.

In addition to basic plasma theory, topics being pursued at the PSFC include tokamak research on radio frequency heating and current drive, core and edge transport and turbulence, and magnetohydrodynamic and kinetic stability. This research supports the PSFC tokamak, Alcator C-Mod, and the Levitated Dipole Experiment (LDX), as well as other such experiments around the world. Interaction between MIT research staff and scientists at other facilities fosters vital scientific collaborations in the US and abroad.

MIT Theorists also investigate concepts to improve tokamak performance. One promising approach to advanced tokamak operation uses radio frequency waves to control pressure and current profiles in order to control instabilities and achieve steady state operation in high pressure plasmas.

In the area of inertial confinement fusion (ICF), theorists study the ablation process, during which a plasma is created that causes nonlinear scattering of the laser light. This scattering not only reduces how efficiently the target can be heated, but also generates hot electrons that can preheat the core, inhibiting compression. PSFC theorists focus on understanding experimental observations of scattered light due to laser-plasma interactions, hoping to find ways to control the deleterious effects of these phenomena.

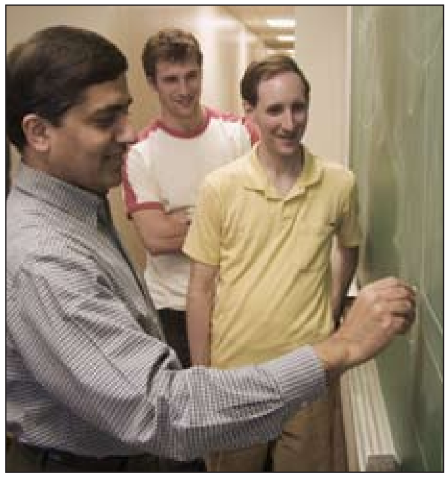
Experimental Plasma Physics

Experiments are conducted both on-site at the PSFC, on small-to-medium-scale experimental devices, and off-site, on large-scale national and international fusion devices.

Experiments include:

- **exploring new confinement concepts, such as the Levitated Dipole Experiment;**
- **developing new diagnostics for measuring plasma parameters;**
- **investigating space physics phenomena through laboratory simulations and off-site ionospheric observations;**
- **developing novel diagnostics for inertial confinement (ICF) physics experiments;**
- **exploring novel scientific uses of plasma phenomena.**

Many theorists work with graduate students on cutting edge research. Dr. Peter Catto advises Natalia Krasheninnikova, who is studying plasma stability. Some of Dr. Catto's research focuses on how the electric field is established in both the edge and core of tokamaks like Alcator C-Mod, MIT's premier fusion experiment.



Dr. Abhay Ram combines teaching with research in the areas of plasma heating and current generation by radio frequency waves, nonlinear plasma dynamics, space plasma physics, and laser-plasma interactions.

Photos by Paul Rivenberg

Nuclear Engineering Professor Jeffrey Freidberg (above left), Associate Director of the PSFC, teaches plasma physics-related courses and supervises student theses.

Photo by MP McNally

DOE Office of Fusion Energy Director of Research John Willis and MIT Associate Provost Alice Gast cut the ribbon for the Levitated Dipole Experiment, joined by members of the LDX team. Graduate students working on the project sit atop the vacuum chamber.

Levitated Dipole Experiment

Physicists at the PSFC are exploring novel magnetic confinement configurations that are fundamentally different from the tokamak. These may lead to alternate reactor concepts, and provide insights into space and astrophysical processes. One such approach, which uses a levitated current-carrying superconducting ring, is being pursued as a collaboration with Columbia University. Such a current ring generates a dipole type magnetic field geometry, which in turn confines a torus of hot plasma. Dipole confinement is observed in nature to be robust (e.g., in the magnetosphere around the planet Jupiter). This Levitated Dipole Experiment (LDX) will improve our understanding of dipole confinement in a laboratory setting.

MIT undergraduates work with the All Sky Imaging System (ASIS) designed to diagnose plasma turbulence occuring in space and laboratory plasmas. ASIS can record infrared, visible, and ultra-violet emissions to determine the profiles of plasmas and the structures of plasma turbulence.

Phase Contrast Imaging on DIII-D and C-Mod

It is now widely believed that micro-turbulence in magnetically confined fusion plasmas results in excessive loss of particles and heat. To better understand such turbulence, PSFC researchers have developed a new diagnostic using CO_2 lasers and a special imaging technique widely used in microscopy - phase contrast imaging. This diagnostic, which provides detailed measurements of the density fluctuations with extraordinary sensitivity and fine spatial and temporal resolution, is being used to study turbulence and RF waves on the DIII-D tokamak in San Diego, and on the Alcator C-Mod tokamak at the PSFC. Recent upgrades will allow tests of some of the latest theoretical predictions regarding the stabilization of microturbulence, leading to improved confinement and RF wave propagation.

Magnetic Reconnection

Research staff and students investigate magnetic reconnection using the Versatile Toroidal Facility (VTF), a toroidal facility built largely by graduate and undergraduate students and PSFC staff. Magnetic reconnection is the breaking and reconnecting of magnetic field lines interacting with plasma. Reconnection controls the spatial and temporal evolution of explosive plasma phenomena such as solar flares, coronal mass ejections and internal disruptions in magnetic fusion devices. VTF has made it possible to measure the plasma response to reconnection with unprecedented accuracy in the laboratory, stimulating the development of new theoretical models for reconnection.

Joint European Torus (JET)

This program conducts collaborative experiments at the Joint European Torus (JET) in England, the world's largest tokamak and the major experimental tool of the European Fusion Development Agreement. In these experiments researchers study instabilities driven by high-energy particles, such as radio frequency-driven energetic ions and fusion-generated alpha-particles. These studies lead to an improved understanding of plasma stability and transport that will be important in a burning plasma experiment such as the international collaboration ITER, where the fusion process generates a substantial alpha-particle component. The results of our research have clarified the relation between these waves and the plasma to such a point that information about some of the plasma's most important parameters can be obtained from the wave measurements.

JET, in England, is the largest tokamak in the world, and is improving understanding of plasma stability and transport.

Ionospheric Plasma Research

Researchers and students in this program perform field and laboratory experiments to understand plasma turbulence due to radio frequency heating. They travel to Alaska, Puerto Rico and other sites for their investigations. Students use the Ionospheric Radar Integrated System (IRIS) at Millstone Hill, Massachusetts, for remote sensing of space plasma turbulence, and the All Sky Imaging System (ASIS), to study the spatial structures of this turbulence. Understanding turbulence will aid satellite communications, and will help control plasma turbulence in future fusion devices.

One of the novel diagnostics PSFC scientists have developed for the National Ignition Facility (NIF) would use 31 MeV protons, generated within the NIF capsule, to help scientists determine whether NIF has achieved its goal of producing substantial themonuclear gain during pellet implosion.

Photo courtesy of LLE

PSFC Group Leader Richard Petrasso (bottom right) looks on as the MIT-designed charged particle spectrometer (upper right) is installed on the target OMEGA laser at the University of Rochester Laboratory for Laser Energetics (LLE).

Laser-Plasma Interaction

The Division is collaborating with the University of Rochester Laboratory for Laser Energetics (LLE) and the Lawrence Livermore National Laboratory (LLNL). This effort is designed to provide extensive diagnostic information about Inertial Confinement Fusion (ICF) plasmas by making spectral, spatial, and temporal measurements of charged fusion products with novel instrumentation. Current experiments on the OMEGA laser facility at LLE have provided information about fusion yield, plasma temperature and density, implosion symmetry, implosion dynamics, burn symmetry, stopping power of hot plasmas, and laser-plasma interactions.

National Ignition Facility

PSFC scientists are also active in defining the science that can be studied at the future National Ignition Facility (NIF) at LLNL. This $2.1 billion facility will ultimately be the center for inertial fusion research in the US. NIF will offer unique opportunities to explore the properties of matter under extreme pressures (~500 billion atmospheres) and densities (~1000 g/cm^3). PSFC scientists have developed two novel diagnostics for NIF that could be used in addition to many of the charged-particle diagnostics they have developed for OMEGA. The first new diagnostic would use 31-MeV protons, generated within the NIF capsule, to help scientists determine whether NIF has achieved its goal of producing substantial thermonuclear gain during pellet implosion. The second new diagnostic would measure the energy spectra of fusion neutrons that are downscattered by the compressed capsules, to determine the amount and symmetry of capsule compression. Because this diagnostic has a wide dynamic range it will be useful during all stages of NIF development, from low-yield initial experiments to high-yield ignition.

Massachusetts Institute of Technology