plasma behavior. Plasma theory explains what happens when a plasma moves within electric and magnetic fields. Two fundamental constituents of plasma theory owing primarily to the MFE Program for their development are equilibrium theory and stability theory.

Equilibrium Theory – Fusion equilibrium is the term used to refer to the geometrical configuration consisting of the fusion plasma core, the surrounding magnetic field and vacuum chamber as well as the external magnetic field coils which produce the confining fields. Equilibrium theory explains how the fusion plasma behaves in the presence of the other elements comprising the fusion equilibrium.

Today, a fusion equilibrium is designed through the use of computer programs based on equilibrium theory rather than by experimental trial-and-error as in the early fusion investigations. These programs describe with great precision how to obtain the exact plasma shape needed for a given experiment. They specify the size and shape of the magnets, how to arrange them in relation to other components comprising the plasma equilibrium, and at what electrical currents to operate them.

Experimental results over the past 15 years have validated equilibrium theory and the programs based on it. Foremost among the benefits of equilibrium theory is that expensive experimental reactor magnets (and future power plant magnets) can be fabricated with the certainty that they will produce the plasma shapes and positions specified. Equally important, applications of equilibrium theory enable researchers to modify plasma conditions through external adjustments so they can easily investigate different plasma shapes and locations in a fusion equilibrium without tearing it down to rearrange hardware components.

Stability Theory – Due to its physical nature, a body of plasma inherently resists confinement. Under magnetic confinement in a fusion device, this resistance shows itself in a number of undesirable ways, referred to as **plasma instabilities.** Plasma instabilities tend to hold down the temperature in the fusion device and allow the plasma fuel to escape confinement. Stability theory describes what will happen if a plasma at rest in the fusion equilibrium is disturbed. Applications of the theory enable researchers to better predict and control plasma behavior in the fusion equilibrium.

For the past 10 years, a particular instability, the "ballooning mode," has held down plasma beta values. A ballooning mode is similar to an aneurysm or bulge in the plasma. If it bursts, the plasma loses fuel and energy.

A recent application of stability theory predicted that susceptibility to ballooning mode instabilities in tokamaks could be controlled by altering the cross-sectional profile of the plasma. Computations based on the theory predicted that devices with elongated "D"-shaped, bean-shaped, or peanut-shaped plasma cross-sections rather than the conventional circular cross-section would reduce susceptibility to the ballooning mode.

Experimental tokamaks designed to avoid ballooning have already attained beta levels which, according to fusion engineers, approach those required for commercial fusion plants. For example, the fusion program's Beta Experiment, which achieved the record breaking beta values, was designed using predictions based on stability theory, and the use of such predictions is now standard in all experiments.

Computational Physics – Fusion researchers have significantly accelerated the maturation of plasma science by using computers and mathematics with increasing sophistication. Computers of all sizes assist in theoretical calculations of increasing complexity and precision, and in the design, direction and analysis of experiments.

The computer has been a tool in the evaluation of the physical theories and of the engineering models of magnetic fusion. More recently it has become a means of developing the theories themselves.

Theoretical and computational tools for understanding plasma confinement and heating in magnetic systems have developed to the level where in many instances they can now closely model plasma behavior. From rudimentary one-dimensional models run on the earliest computers, plasma computations have

Magnetic Tearing and Reconnection

Magnetic tearing and reconnection is the phenomenon by which complex magnetic field lines spontaneously rearrange themselves into new patterns. This is a broadly observed phenomenon, which manifests itself as the tearing mode instability in fusion devices. It is a major topic of investigation by scientists because of its importance in space and astrophysics. For example, its occurrence in the earth's magnetic field triggers the spectacular Northern Lights and magnetic substorms that interfere with radio communications.

One of the major advances in general plasma physics over the last 10 years is the considerable progress that has been made in understanding magnetic line tearing and reconnection. Much of this progress results from the extensive study of the tearing mode instability in tokamaks. Recently adding to the understanding of magnetic tearing and reconnection are a number of very precise and experimentally validated computer programs developed by MFE scientists to model these effects.