Computational fusion plasma physics

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World research in magnetic fusion is aiming at the scientific and technological demonstration of an environmentally benign, virtually inexhaustible source of primary energy. The recent decision to proceed with the ITER project is an important milestone. This project is based on the tokamak concept, which as of today is the most advanced for the confinement of hot hydrogen plasmas by magnetic fields. Theory and numerical simulation are essential to understand the intricate physical processes taking place in such a system. This paper focuses on the physics of the plasma core. The difficulties lie in the wide range of space and time scales spanning several orders of magnitude, the strong anisotropy caused by the magnetic field, the multitude of collective effects in the form of waves and instabilities, kinetic effects requiring the description of a phase space with up to 6 dimensions, the presence of energetic particle populations and the many nonlinearities in the system. Both fluid and kinetic theories have been developed and examples of various competitive numerical approaches that are used to solve them will be presented. Among the most challenging problems is that of anomalous transport caused by turbulence. Lagrangian, Eulerian and semi-Lagrangian approaches and their respective merits will be discussed. The physics of magnetic fusion plasmas is characterized by its sensitivity to the geometry of the confining field. Alternative approaches to the tokamak magnetic configuration such as the stellarator offer intrinsic potential advantages. Their geometrical complexity poses additional challenges to the numerical schemes. In general, adaptation of the algorithms to massively parallel platforms in order to tap the high end HPC power is obviously a crucial part of the developments. Some examples of strategies adopted and results obtained will be given.