2009 APS April Meeting
Denver, Colorado
http://www.aps.org/meetings/april
The classic MHD stability comparison theorems (Kruskal-Oberman, Rosenbluth—Onsager) state that there is a magnetic field threshold below which no runaways are expected. The second possible explanation is the magnetic field dependence of the criterion for substantial runaway electron production. The growth rates of the most unstable whistler waves are inversely proportional to the magnetic field strength, and it is possible to derive a criterion for runaway generation in tokamak disruptions, which is based on the kinetic theory of partially ionized plasmas. This criterion predicts that the number of runaway electrons produced in disruptions depends on the magnetic field strength. In this work, two possible reasons for this threshold are studied. The first is that the stabilizing effect of plasma compressibility predicted by ideal and kinetic MHD: \( \delta W_{\text{VF}} > \delta W_{\text{MHD}} \). For compressible modes in closed line systems, however, perpendicular resonant particle effects cancel \( \delta W_{\text{VF}} \). Our new result predicts \( \delta W_{\text{kin}} > \delta W_{\text{MHD}} \). This has long justified the \( \delta W_{\text{kin}} > \delta W_{\text{MHD}} \). This has long justified the

\[ \delta W_{\text{VF}} > \delta W_{\text{MHD}} \]


10:30AM G15.00003 Flow stabilization of the ideal MHD resistive wall mode. S.P. SMITH, S.C. JARDIN, P.P.P., J.P. FREDIBERG, MIT, L. GUAZZOTTO, U. Rochester — We demonstrate for the first time in a numerical calculation that for a typical circular cylindrical equilibrium, the ideal MHD resistive wall mode (RWM) can be completely stabilized by bulk equilibrium plasma flow, \( V \), for a window of wall locations without introducing additional dissipation into the system. The stabilization is due to a resonance between the RWM and the Doppler shifted ideal MHD sound continuum. Our numerical approach introduces \( \omega = \omega + \nabla \times V \cdot \nabla \). The wall current is related to the plasma displacement at the boundary by a Green's function. With the introduction of the resistive wall, we find that it is essential that the finite element grid be highly localized around the resonance radius where the parallel displacement, \( \xi \), becomes singular. We present numerical convergence studies demonstrating that this singular behavior can be approached in a limiting sense. We also report on progress toward extending this calculation to an axisymmetric toroidal geometry.

\[ \omega = \omega + \nabla \times V \cdot \nabla \]


Sunday, May 3, 2009 8:30AM - 10:30AM
Session G15 Sherwood DPP: Sherwood I Governor's Square 14

8:30AM G15.00001 From Fundamental Science to Fusion Energy – the First 50 Years of Fusion Theory. STEVEN COWLEY, UKAEA Culham — With ITER, fusion energy research will reach the long anticipated goal of a stable, long-duration burning plasma – one that is largely sustained by fusion reactions. The history of progress towards this goal is intricately entwined with the development of the fundamental physics of plasmas and nonlinear systems. I will examine this history through three examples that highlight the role of theory and the Sherwood meeting. In the first example, I will discuss the development of stability theory. I will begin with the magnetohydrodynamic energy principle calculations of the 1950s and trace advances to the recent sophisticated kinetic calculations of ITER’s stability to alpha particle driven modes. The development and application of chaos theory in fusion research will be my second example. I will trace its growth from field-line tracing for the first stellarators to the design of the ELMy mitigation coils in ITER. In the final example I will examine the development of plasma turbulence theory to describe the transport of plasma heat and particles in fusion experiments. My (abbreviated) history of plasma turbulence will begin with Bohm’s curious formula for turbulent transport and finish with the latest gyro-kinetic simulation of ITER like plasmas.

9:30AM G15.00002 Energetic Particle-induced Geodesic Acoustic Mode. GUOYONG FU, Princeton University — A new \( n=0 \) Energetic Particle-induced Geodesic Acoustic Modes (EGAM) is shown to exist based on analytic theory and numerical simulation [1]. Unlike the conventional GAMs driven nonlinearly by plasma micro-turbulence, the new mode is found to be linearly driven by energetic particles with free energy associated with anisotropic particle distribution function. An integral differential equation is derived for EGAM including the non-perturbative effects of energetic particles with finite orbit width. Analysis shows that when the energetic particle pressure is comparable to the thermal pressure, the frequency of EGAM is substantially lower than the local GAM frequency associated with thermal species. Furthermore, the new mode has a global radial structure with the mode width determined by the energetic particle drift orbit width. For typical experimental parameters in reversed shear plasmas, the mode width can be quite large. Nonlinear simulation results show initial saturation due to the flattening of particle distribution function in velocity space. A bursting feature of the mode amplitude is found following the initial saturation. These results are consistent with the recent experimental results of the beam-driven GAM-like \( n=0 \) mode in DIII-D [2]. In particular, the calculated mode frequency and the global radial structure agree well with the experimental observations. [1] G. Y. Fu, Phys. Rev. Letts. 101, 185001 (2008) [2] R. Nazikian et al., Phys. Rev. Letts. 101, 185001 (2008).

10:00AM G15.00003 Flow stabilization of the ideal MHD resistive wall mode. S.P. SMITH, S.C. JARDIN, P.P.P., J.P. FREDIBERG, MIT, L. GUAZZOTTO, U. Rochester — We demonstrate for the first time in a numerical calculation that for a typical circular cylindrical equilibrium, the ideal MHD resistive wall mode (RWM) can be completely stabilized by bulk equilibrium plasma flow, \( V \), for a window of wall locations without introducing additional dissipation into the system. The stabilization is due to a resonance between the RWM and the Doppler shifted ideal MHD sound continuum. Our numerical approach introduces \( \omega = \omega + \nabla \times V \cdot \nabla \). The wall current is related to the plasma displacement at the boundary by a Green’s function. With the introduction of the resistive wall, we find that it is essential that the finite element grid be highly localized around the resonance radius where the parallel displacement, \( \xi \), becomes singular. We present numerical convergence studies demonstrating that this singular behavior can be approached in a limiting sense. We also report on progress toward extending this calculation to an axisymmetric toroidal geometry.

\[ \omega = \omega + \nabla \times V \cdot \nabla \]


Sunday, May 3, 2009 10:30AM - 12:30PM
Session H15 Sherwood DPP: Sherwood II Governor’s Square 14

10:30AM H15.00001 COFFEE BREAK —

11:00AM H15.00002 Magnetic field threshold for runaway generation in tokamak disruptions. T. FULÖP, Chalmers University of Technology, Sweden, G. POKOL, Budapest University of Technology and Economics, Hungary, H.M. SMITH, P. HELANDER, Max-Planck-Institut fur Plasmaphysik Greifswald, Germany — Due to a sudden cooling of the plasma in tokamak disruptions a beam of relativistic runaway electrons is sometimes generated, which may cause damage on plasma facing components. Experimental observations on large tokamaks show that the number of runaway electrons produced in disruptions depends on the magnetic field strength. In this work, two possible reasons for this threshold are studied. The first possible explanation for these observations is that the runaway beam excites whistler waves that scatter the electrons in velocity space and prevents the beam from growing. The growth rates of the most unstable whistler waves are inversely proportional to the magnetic field strength and it is possible to derive a magnetic field threshold below which no runaways are expected. The second possible explanation is the magnetic field dependence of the criterion for substantial runaway production determined by the induced electric field available and by the efficiency of the generation mechanisms. It is shown, that even in rapidly cooling plasmas, where hot-tail generation is expected to give rise to substantial runaway population, the whistler waves can stop the runaway formation below a certain magnetic field despite the post-disruption temperature is very low.

11:30AM H15.00003 Revisiting MHD stability comparison theorems: Some surprising new results. ANTOINE CERFON, JEFFREY FREDIBERG, MIT PSFC — The classic MHD stability comparison theorems (Kruskal-Oberman, Rosenbluth-Rostoker) of ideal MHD yields the most stringent stability limits according to the hierarchy \( \delta W_{\text{COL}} > \delta W_{\text{kin}} > \delta W_{\text{MHD}} \). This has long justified the use of ideal MHD for conservative predictions of MHD stability boundaries. We reexamine these theorems, with the following conclusions: (1) It is crucial to distinguish between ergodic and closed field line systems (2) It is essential to account for resonant particles in the kinetic MHD model (3) For ergodic systems the original kinetic MHD analysis over-estimates stability: \( \delta W_{\text{kin}} > \delta W_{\text{MHD}} \). Our new result predicts \( \delta W_{\text{kin}} = \delta W_{\text{MHD}} \). For closed line systems plasma compressibility effects become important, and resonant particle effects vanish. Both the original and new analysis predict \( \delta W_{\text{kin}} > \delta W_{\text{MHD}} \). However, using a Vlasov-Fluid model with Vlasov ions and fluid electrons we show that both \( \delta W_{\text{kin}} \) and \( \delta W_{\text{MHD}} \), while mathematically correct, yield the wrong physical result. The V-F model shows that at marginal stability the compressibility stabilization term vanishes identically! For ergodic systems, marginal stability is always incompressible, so \( \delta W_{\text{kin}} = \delta W_{\text{MHD}} = \delta W_{\text{VF}} \). For compressible modes in closed line systems, however, perpendicular resonant particle effects cancel the stabilizing effect of plasma compressibility predicted by ideal and kinetic MHD: \( \delta W_{\text{kin}} > \delta W_{\text{MHD}} > \delta W_{\text{VF}} \).
12:00PM H15.00004 Edge Plasma Characteristics in a Snowflake Magnetic Configuration1, M.V. UMANSKY, R.H. BULMER, R.H. COHEN, T.D. ROGNLIEN, D.D. RYUTOV — A snowflake configuration for a diverted tokamak uses a 2nd order null of the poloidal field instead of the standard 1st order null. Geometrical properties of snowflake divertor are favorable for reducing heat flux on divertor surfaces, due to stronger fanning of the poloidal flux, larger radiating volume, and larger connection length in the scrape-off layer. Additional potential benefits include better control of ELM activity via the effect on the q-profile just inside the separatrix, and blob dynamics via the stronger magnetic shear near the second-order null point. This study presents a quantitative assessment of performance of snowflake divertor for a high-power tokamak. The analysis utilizes the MHD equilibrium code Corsica and edge transport code UEDGE. Divertor performance is compared for a high-power tokamak with standard and snowflake-like configurations for the same core plasma parameters. For a range of studied cases, the snowflake divertor peak heat-load on the target plates is significantly reduced compared to the standard divertor due to larger plasma-wetted area and larger fraction of power radiated in the edge.

1This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Security, LLC, Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Monday, May 4, 2009 10:45AM - 12:45PM –
Session Q15 Sherwood DPP: Sherwood III Governor's Square 14

10:45AM Q15.00001 Turbulent transport of trapped electron modes in collisionless magnetized plasma, YONG XIAO, University of California, Irvine — A prominent candidate for the electron heat transport in high temperature toroidal plasmas is collisionless trapped electron mode (CTEM) turbulence. Our large scale simulations of CTEM turbulence using gyrokinetic toroidal code (GTC) finds the electron heat transport exhibiting a gradual transition from Bohm to gyroBohm scaling when the device size is increased. The deviation from the gyroBohm could be induced by large turbulence eddies, turbulence spreading and non-diffusive transport process. In the CTEM simulation, radial correlation function shows that the turbulence eddies are predominantly microscopic but with a significant tail in the mesoscale. The macroscopic, linear streamers are mostly destroyed by the zonal flow shearing, which is confirmed by our comprehensive analysis of kinetic and fluid time scales. The mesoscale streamers result from a dynamic process of radial streamers breaking by zonal flows and merging of microscopic eddies. It is further found that the radial profile of the electron heat conductivity roughly follows the global profile of fluctuation intensity, whereas the ion transport tracks more sensitively local fluctuation waves. This suggests the existence of a non-diffusive component in the electron heat transport, which arises from the ballistic radial drift of trapped electrons due to a combination of the presence of the mesoscale eddies and the weak detuning of the toroidal precessional resonance.

11:15AM Q15.00002 Rotational Stabilization of Magnetically Collimated Jets, CHRISTOPHER CAREY, CARL SOVINEC, University of Wisconsin - Madison — We investigate the launching and stability of extragalactic jets through nonlinear magnetohydrodynamic (MHD) simulation and linear eigenmode analysis. In the simulations of jet evolution, a small-scale equilibrium magnetic arcade is twisted by a differentially rotating accretion disk. These simulations produce a collimated outflow which is unstable to the current driven $m=1$ kink mode for low rotational velocities of the accretion disk relative to the Alfvén speed of the coronal plasma. The growth rate of the kink mode in the jet is shown to be inversely related to the rotation rate of the disk, and the jet is stable for high rotation rates. The effect of rigid rotation on the kink mode in a cylindrical plasma is investigated via linear MHD initial value and eigenvalue calculations. The results from both treatments of the problem are shown to be in agreement. These calculations show that rigid-rotation distorts the $m=1$ kink eigenmode reducing its growth rate and reducing the range of unstable non-resonant wave numbers. We surmise that the change in the linear spectrum explains the undistorted propagation in the nonlinear jet simulations in the large disk rotation regime. By removing individual terms in the momentum equation we show that kink stabilization is due to distortion of the eigenmode via the Coriolis force.

11:45AM Q15.00003 Driving toroidally asymmetric current through the tokamak scrape-off layer to suppress edge-localised modes1, I. JOSEPH, R.H. COHEN, D.D. RYUTOV, Lawrence Livermore National Laboratory — The dangerously high divertor heat fluxes impulsively delivered by edge localized modes (ELMs) can be controlled by non-axisymmetric magnetic perturbations that induce enhanced stellarator-like transport and reduce the edge pressure gradient below the peeling-balooning MHD stability threshold. Unfortunately, the design of the needed perturbation coils is complicated by engineering constraints in a high field and high neutron-flux environment. We suggest driving the needed perturbation current through the scrape-off layer (SOL) itself. Current densities as large as the ion saturation current density, can be driven if the sheath potential differs from the floating potential by $O(T_{e}/e)$. If the sheath potential is made to vary toroidally, a non-axisymmetric surface current is generated in the SOL; and the resulting magnetic perturbation can exceed the ELM suppression criterion, as shown by numerical calculations. The combination of non-axisymmetric SOL current and driven convection cells, which radially spread heat flux in the SOL, may be a powerful technique for solving the problem of high target heat fluxes.

1Work performed for U.S.D.O.E. by LLNL under Contract DE-AC52-07NA27344.

12:15PM Q15.00004 The destabilising effect of dynamical friction on fast particle-driven waves1, M.K. LILLEY, Imperial College London, B.N. BREIZMAN, Institute for Fusion Studies, S.E. SHARAPOV, EURATOM/UKAEA Fusion Association — The non-linear evolution of waves excited by the resonant interaction with energetic particles is known to depend on relaxation processes that restore the unstable distribution function. With Krook type collisions and velocity space diffusion the wave may exhibit steady-state, amplitude modulation, chaotic and explosive (‘hard’) regimes near marginal stability. However, our recent analysis surprisingly shows that only the explosive behaviour is possible in the near-threshold nonlinear regime when dynamical friction (drag) is the dominant collisional process in the phase space region surrounding the wave-particle resonance. These results indicate that the nonlinear evolution of, e.g., Alfvénic instabilities driven by super-Alfvénic neutral beam injection (NBI), or by fusion-born alpha-particles with drag-determined distribution functions should be more prone to the ‘hard’ regime than those driven by ion-cyclotron resonance heating (ICRH) with dominant RF quasi-linear diffusion. The experimental observations differed between the steady-state, amplitude modulation and chaotic regimes of ICRH-driven TAE instabilities on the Joint European Torus (JET) and the bursting frequency-chirping TAEs on MAST are then considered. Possible nonlinear scenarios of Alfvénic instabilities driven by fusion-born alpha-particles in ITER are also discussed.

Tuesday, May 5, 2009 10:45AM - 12:45PM –
Session W15 Sherwood DPP: Sherwood IV Governor’s Square 14
of near helical symmetry and thus least flow damping along $\vec{e}_h$ will facilitate future comparison between NTV-induced rotation in QHS stellarators and tokamaks. \[1\] K.C. Shaing, Phys. Plasmas, both electron and ion NTV. In particular, the transition from ion to electron dominated NTV is presented in a single equation for the first time. This research analytic ‘toroidal’ rotation equation is developed which smoothly transitions between previously asymptotic low-collisionality regimes \[1\], while incorporating variations in symmetric Stellarators.\[1\] have often been able to match certain observed features of ELMs in the precursor and collapse onset phases.\[1\] may explain why in experiments and simulations, the nonlinear ELM filament strongly resembles the structure of a linear ballooning filament, and linear analyses reference frame. The analytic prediction of the nonlinear exponential growth phase is in excellent agreement with the first-principle full MHD simulations. This process for the type-I large edge-localized-modes (ELMs). The evolution equations for ballooning instability in the intermediate nonlinear regime are derived in an ideal MHD description. This nonlinear regime is operative when the MHD displacement of the plasma filament across the magnetic surface becomes the order of the linear mode width in that same direction. For application to ELM dynamics, this displacement amplitude is comparable to the pedestal width for intermediate-$n$ instabilities. A remarkable feature of this nonlinear regime is that a perturbation that evolves from a linear ballooning instability will continue to grow exponentially at the same growth rate, and maintain the filamentary mode structure as described in the Lagrangian instabilities. A remarkable feature of this nonlinear regime is that a perturbation that evolves from a linear ballooning instability will continue to grow exponentially at the same growth rate, and maintain the filamentary mode structure of the corresponding linear phase as described in the Lagrangian reference frame. The analytic prediction of the nonlinear exponential growth phase is in excellent agreement with the first-principle full MHD simulations. This may explain why in experiments and simulations, the nonlinear ELM filament strongly resembles the structure of a linear ballooning filament, and linear analyses have often been able to match certain observed features of ELMs in the precursor and collapse onset phases.\[1\] Supported by Grants DE-FG02-86ER53218 and DE-FG02-08ER54975.

\[12:15PM \text{ W15.00002 } \text{ On radial electric field, edge flows, and the L-H transition power threshold in tokamaks}\] \[1\], A.Y. AYDEMIR, Institute for Fusion Studies, The University of Texas at Austin — At the collisional edge, there is a residual vertical electric field associated with the Pfirsch-Schlüter currents that drives an ExB flow. The poloidal flow is in the direction of increasing major radius, regardless of the orientation of the fields and currents, and the toroidal component is anti-symmetric about the mid-plane for an up-down symmetric system. These flows have many features in common with the edge flows observed in tokamaks like C-Mod. A more careful analysis leads to a radial electric field that depends on the edge temperature gradient and shear. Without up-down symmetry, total contribution to the toroidal momentum and the edge $E_\psi$ clearly depends on the toroidal field direction. When the grad-B drift direction points towards the X-point, the net effect is positive; with toroidal field reversal, $E_\psi$ and the toroidal flow oppose the ambient flows and electric field due to, for example, the ion-orbit loss mechanism. The magnitude of this positive/negative contribution is also plasma- shape dependent. These features provide a compelling explanation for the grad-B drift-dependence of the L-H transition power threshold.\[1\] Supported by the US DoE.

\[10:45AM \text{ W15.00001 } \text{ Fusion-Fission Transmutation Scheme-Efficient Destruction of Nuclear Waste}\] \[1\], MIKE KOTSCHENREUTHER, SWADESH MAHAJAN, PRASHANT VALANJU, ERICH A. SCHNEIDER, University of Texas — A fusion-assisted transmutation system for the destruction of transuranic (TRU) waste is presented. Subcritical fusion-fission hybrids burn the intransient transuranic residues (with most of the long lived bio-hazard) of a new fuel cycle that uses cheap light water reactors (LWRs) for the easily burned majority of the TRU. In the new fuel cycle, the number of hybrids needed to destroy a given amount of original LWR waste is 5-10 times less than the corresponding number of critical fast reactors. (Fast reactors, due to stability constraints, cannot burn the very poor quality TRU residue.) The new system comparably reduces the expensive reprocessing throughput. Realization of these advantages should lead to a great reduction in the cost of transmutation. The time needed for 99% waste destruction would also be reduced from centuries to decades. The centerpiece of the fuel cycle is a high power density compact fusion neutron source (CFNS-100 MW, with major radius + minor radius $\sim 2.5$ m), which is made possible by a super-X divertor. The physics and technology requirements of the CFNS are much less than the requirements of a pure fusion power source. Advantages of the system as part of a timely strategy to combat global warming are briefly described.\[1\] Work supported by USDOE (DE-FG02-04ER54742 and DE-FG02-04ER54754).

\[12:15PM \text{ W15.00004 } \text{ Neoclassical Toroidal Viscosity Induced Rotation in Tokamaks and Quasi-symmetric Stellarators}\] \[1\], A.J. COLE, C.C. HEGNA, J.D. CALLEN, University of Wisconsin — Non-axisymmetric magnetic perturbations generate variations in $|B|$ along a field line that induce non-ambipolar radial transport and a global toroidal force on the plasma, known as neoclassical toroidal viscosity [NTV]. A strong correlation exists between the flow evolution physics of tokamaks and quasi-helically symmetric [QHS] stellarators. In QHS-mode, there exists a helical symmetry angle $\alpha \equiv m\vartheta - n\zeta$, with $m, n$ fixed integers that is analogous to the poloidal direction in tokamaks. As a result, there exists a direction of near helical symmetry and thus least flow damping along $\vec{e}_h$ such that $\vec{e}_h \cdot \nabla \alpha = 0$, analogous to the toroidal tokamak direction. In this paper, a model analytic ‘toroidal’ rotation equation is developed which smoothly transitions between previously asymptotic low-collisionality regimes \[1\], while incorporating both electron and ion NTV. In particular, the transition from ion to electron dominated NTV is presented in a single equation for the first time. This research will facilitate future comparison between NTV-induced rotation in QHS stellarators and tokamaks. \[1\] K.C. Shaing, Phys. Plasmas, \textbf{10}, 1443 (2003).\[1\] Research supported by U.S. DoE grants DE-FG02-86ER53218, DE-FG02-92ER54139, and DE-FG02-99ER54546.