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Comparison of Local and Non-Local Stability Analyses of a Relativistic E-Layer. R. W. SHORT, University of Wisconsin--A fully kinetic non-local stability analysis has been carried out for the extraordinary electromagnetic modes of a warm plasma interacting with a relativistic E-layer. We find that the charge bunching in the E-layer which drives the unstable modes is limited radially to a narrow interval where the local E-layer gyrofrequency is resonant with the real part of the mode frequency. Thus less energy is available to drive the modes than in the local approximation, and we find significantly lower growth rates than previous calculations based on the local approximation.¹

*Work supported by USDOE

1. C. D. Striffler and T. Kammash, Plasma Phys. 15, 729 (1973).

Microinstability in High and Low β Octupole Plasmas* E.A. ROSE and S.C. PRAGER, University of Wisconsin-Madison--A coherent 30 kHz electrostatic fluctuation is observed in the levitated toroidal octupole with properties remarkably invariant over three orders of magnitude in β and density. No apparent changes occur in any wave property as the equilibrium varies from a collisionless, low β plasma ($\beta \sim .004\%$, $n \sim 10^9 \text{ cm}^{-3}$, $T_e \sim T_i \sim 20 \text{ eV}$, $B \sim 200 \text{ G}$) to a more resistive, high β plasma ($\beta \sim 8\%$, $n \sim 2 \times 10^{12} \text{ cm}^{-3}$). Fluctuations in density and floating potential stand in the poloidal direction (along a field line) with odd symmetry about the midplane, propagate toroidally with $\lambda_{\parallel} \sim 20 \text{ cm}$ and peak in the bad curvature region. The mode only exists at low magnetic field where $K_{\perp} \rho_i \sim 1$. The marked dependence of the instability on ion gyroradius, ρ_i , and curvature implies that it is of the drift-ballooning type with finite gyroradius. Although the wave exists at high electron $\beta_e (\gg M_e/M_i)$ no coupling to Alfvén waves is observed. Despite the high β the wave phase speed ($\omega/k_{\parallel}$) is still 6 times lower than the Alfvén speed. Small magnetic oscillation ($\tilde{B}/B \sim .06\%$) accompany the wave due to diamagnetic current oscillation concomitant with the electrostatic pressure fluctuation.

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Fluctuation Studies with Microwave Scattering
in the Wisconsin Levitated Octupole* S. GARNER,
 University of Wisconsin-Madison--Fluctuation spectra have
 been measured in the absolute min-B and average min-B
 regions of the levitated octupole with a 35 GHz homodyne
 microwave scattering experiment. $|k|$ values accessible
 range from 1 cm^{-1} to 16 cm^{-1} . Plasma and magnetic field
 (B_p, B_T) parameters can be varied over a wide range.
 Fluctuations in plasmas with $\beta \geq 4\%$ have been observed.
 Power spectra as a function of time and plasma conditions
 will be shown.

*Work supported by USDOE.

Current Profile Effects on Tokamak MHD Stability*
 T.H. OSBORNE, R.N. DEXTER, R.J. GROEBNER, and S.C. PRAGER,
 University of Wisconsin-Madison--Since the plasma in
 Tokapole II, a tokamak with a 4 node poloidal divertor,
 is bounded by a magnetic limiter (rather than a material
 one) the current is not clamped to zero at the edge (the
 divertor separatrix). Thus, rather flat profiles of
 current density, j , can result, which would weaken the
 driving force for helical MHD instabilities. The
 temperature ($T \sim 100 \text{ eV}$, $n \sim 10^{13} \text{ cm}^{-3}$) is sufficiently low
 that magnetic probes may be inserted internally to
 directly measure j and q profiles and produce experi-
 mental plots of magnetic surfaces. The measured q
 profile is extremely flat, varying only 25% over most
 (80%) of the plasma width. j profiles are similarly
 flat, although the experimental uncertainty in j is
 roughly 25%. Discharges can be obtained with $q \sim 6$ over
 most of the plasma (except at the separatrix where
 locally $q \rightarrow \infty$). No gross disturbances occur. Low level
 magnetic fluctuations in the 10-50 kHz range are being
 studied in these low q , flat current discharges.

*Work supported by USDOE.

Axisymmetric Instability in a Tokamak: Experiment and Theory* B. LIPSCHULTZ and S.C. PRAGER, University of Wisconsin-Madison, A.M.M. TODD and S. DeLUCIA, Princeton University--The stability of dee, inverse dee and square cross-section plasmas to axisymmetric modes has been studied experimentally in Tokapole II, a tokamak with a four node poloidal divertor. Experimental results are closely compared with predictions of two numerical stability codes--the PEST code (ideal MHD, linear stability) adapted to tokapole geometry and a code which follows the nonlinear evolution. Experimentally, the square is stable and both dees are unstable to a vertical nonrigid axisymmetric shift. The central magnetic axis displacement grows exponentially with a growth time $\approx 10^3$ poloidal Alfvén times $\approx$ plasma L/R time. Experimental poloidal flux plots are produced directly from internal magnetic probe measurements. The PEST code, ignoring passive feedback, predicts all equilibria to be unstable with the square having the slowest growth. With passive feedback, all are stable. Thus experiment and code agree that the square is the most stable shape, but experiment indicates that passive feedback is partially defeated by finite plasma resistivity. Further comparisons between experiment and theory (and with PDX equilibria) will be presented.

*Work supported by USDOE.

Stable Confinement of a High β Octupole Plasma* J.H. HALLE, M.W. PHILLIPS, R.S. POST, S.C. PRAGER, and J.C. TWICHELL, University of Wisconsin-Madison--Plasmas with β greater than 8% have been confined in the Wisconsin levitated octupole. Single fluid, zero gyroradius, local, linear theory, using the self-consistent finite pressure equilibrium, predicts instability onset at the plasma edge at $\beta \approx 6\%$; the instability progresses inward as β increases. The calculation predicts the pressure gradient at marginal stability and the spatial structure (along a field line) of the displacement. Although this β value has been approached experimentally, no ballooning instability is observed. β decays with a decay time ≈ 2 msec, $\approx 10^4$ Alfvén times. No deleterious effects accompany the high β . Plasma density decays at roughly four times the classical rate ($n \sim 2 \times 10^{12} \text{ cm}^{-3}$, $T_e \sim T_i \sim 20 \text{ eV}$, $B \sim 200 \text{ G}$). The observed stability of the plasma is most likely due to finite ion gyroradius effects not included in the theory. The experimental limit to β to date is probably due to capabilities of the plasma source and not a stability limit.

*Work supported by USDOE.

MHD Equilibrium and Stability of Multipoles*

M.W. PHILLIPS, University of Wisconsin-Madison—

A computer code has been developed for studying the ideal magnetohydrodynamic equilibria and stability in multipole devices. The equilibria are calculated by solving the Grad-Shafranov equation for a prescribed pressure profile. Stability against high toroidal n number ballooning modes is determined by solving for the pressure gradient at which a given flux surface would be marginally stable. The code is used to study the effects that shaping the magnetic field and optimizing the pressure profile have on the β limit for various multipole configurations.

*Work supported by USDOE.

Bifurcation of Sharp Boundary Beta Equals One

Multipole Equilibria* ROSS L. SPENCER**, University of Wisconsin-Madison—Sharp boundary $\beta=1$ linear multipole equilibria without walls are studied by means of the hodograph method of complex analysis. In the limit of low pressures (still with $\beta=1$), simple formulas are obtained for the free boundary shapes of multipole cusps of arbitrary order. At low pressure, the equilibria are uniquely determined by specifying four quantities: the wire currents and their positions, the fluid pressure, and the ratio of the lengths of adjacent free boundary segments. At higher pressures, however, bifurcation occurs and these four quantities no longer uniquely determine an equilibrium. In fact, as many as four different equilibria are shown to exist for certain values of these four quantities. For many combinations of the four parameters two equilibria are found, one that is cusp-like and one with fluid completely surrounding the wires; similar bifurcation should also be seen in calculations at high beta of diffuse boundary multipole equilibria using the Grad-Shafranov equation.

*Supported in part by USDOE and the Danforth Foundation.

**Current address: Los Alamos Scientific Laboratory.

Experimental Test of the Feasibility of Poloidal Ohmic Heating in a Multipole* D.J. HOLLY, S.C. PRAGER, and J.C. SPROTT, University of Wisconsin-Madison--Poloidal ohmic heating of a multipole may have distinct advantages over the toroidal ohmic heating used in tokamaks and stellarators. The greatly enhanced resistivity, due to the deep magnetic mirrors, allows large power deposition into the plasma for a given current magnitude. Additionally, it is not known whether a current limit exists. We have studied poloidal ohmic discharges in Tokapole II, operating the machine in the octupole mode. Enhanced resistivity is observed (it is typically enhanced by a factor of 20 to 50 over the mirrorless Spitzer value). Large values of ohmic power (≥ 1 MW) are coupled into the plasma, but the confinement appears to be degraded (typically by a factor of 100) by the heating. Ion saturation current percentage fluctuation is not greatly changed by the ohmic heating.

*Work supported by USDOE.

Multipole Ballooning Mode Analysis Using an Annular Model for the Bridge Regions*, DARRELL A. SKINNER, University of Wisconsin-Madison--In an approach to the study of ballooning mode instabilities in multipoles, the bridge region around the hoops has been modeled as part of an axisymmetric annular plasma column. Normal mode analysis is carried out on the annular system, and the structure of some modes is explicitly demonstrated. Portions of these annular normal modes are used to construct trial functions for use with the energy principle in order to make statements about multipole stability. Examination of normal mode structure illuminates the meaning of the usual short wavelength marginal stability analysis made with energy principle arguments. Ballooning mode effects on equilibrium profiles can be simulated by constructing pressure profiles which include large marginally stable regions.

*Work supported by USDOE.

Confinement Limits for Energetic Ions in Tokapole II* C.E. KIERAS and D.A. SKINNER, University of Wisconsin-Madison--One of the current experiments on the Tokapole II device is designed to increase the population of high energy ions via ICRF heating techniques.¹ The ion temperatures obtainable in this device will be limited by the presence of velocity space loss regions. Conservation of particle energy, magnetic moment, and canonical toroidal angular momentum has been used to define the single particle-orbit loss regions. Preliminary calculations indicate that ion energies at least as high as 200 eV can be successfully confined to the central tokamak-like channel of the discharge. Loss curves describing orbits which escape from the tokamak-like channel, and loss curves describing orbits which escape from the tokamak-multipole field configuration to the internal conducting rings or the walls will be presented. Some aspects of the orbit topology in the natural divertor of the device will also be considered.

¹A.P. Biddle and J.C. Sprott, High Power ICRF Heating in Tokapole II, abstract this meeting.

*Work supported by USDOE.

Observations of Alfvén Resonances in Tokapole II F.D. WITHERSPOON, S.C. PRAGER, and J.C. SPROTT, University of Wisconsin-Madison--We are experimentally investigating the possibility of performing a high-power, low-frequency (~1 MHz) rf heating experiment utilizing the shear Alfvén resonance in a tokamak-like plasma. To this end, wave propagation studies have been performed in Tokapole II using a 1.3 MHz oscillator with a maximum power output of 100 kW. Tokapole II is a tokamak with a four-node poloidal divertor formed by 4 internal rings. These rings also serve as the launching structure, eliminating the need for specially constructed antennas. By grounding a ring to the tank at one of its supports, and driving one of the other two supports, rf currents can be driven through the rings, with the current returning through the tank itself. The third support remains insulated and unused. Driving all 4 rings in phase produces an octupole field. Poloidal mode number can be chosen from $m=1, 2$, or 4 simply by choosing the proper number and phase of the rings driven. Local magnetic field resonances have been detected using magnetic coils inside quartz tubes inserted directly into the plasma. The results of these initial studies will be presented.

*Work Supported By USDOE.

High Power ICRF Heating in Tokapole II*

A.P. BIDDLE and J.C. SPROTT, University of Wisconsin-Madison--Doubling of ion temperatures has been observed at $\omega=2\omega_{ci}$ in normal hydrogen discharges using both Doppler broadening and charge exchange techniques. Resonance dependent temperature increases of 30% with $\omega=\omega_{ci}$ at the plasma edge and increases of 15% with only $\omega=3$ and $4\omega_{ci}$ in the plasma have also been observed. The increase of ion temperature saturates at an RF power level of ≈ 150 kW in a clean machine and ≈ 350 kW when impurity radiation is high. At high ion temperatures and for low plasma currents, significant losses to the internal rings are expected¹ and evidenced by increasing copper line radiation. The possibility of modifying this loss mechanism and the resultant impurity reflux by electrically biasing the internal rings is being explored. Additionally, continued RF discharge cleaning has also been efficient in reducing impurity levels by as much as 80%. This cleaning has resulted in an anomalously high ohmic discharge ion temperature suggesting turbulent heating mechanisms.

1C.E. Kieras and D.A. Skinner, Confinement Limits for Energetic Ions in Tokapole II, abstract this meeting.

*Work supported by USDOE.

Lower Hybrid Wave Measurements on the Wisconsin Octupole.* P.O. NONN, T.L. OWENS,⁺ and J.E. SCHARER, University of Wisconsin--Wave measurements taken across the density profile near the lower hybrid turning point using coaxial RF probes show that both the slow and fast wave modes are excited. The dominant fast mode ($|A_f/A_s| = 2-4$) is weakly damped and has an eigenmode structure for $\omega_{pi}^2/\omega^2 > 2.5$. Common fast mode signals to two closely spaced probes are subtracted to observe the shorter wavelength slow mode. Its dispersion relation is obtained by monitoring the phase shift between the probes as density and temperature decay. From perpendicular wavelengths obtained in this way we infer a $k_{||}$ enhancement near the lower hybrid turning point consistent with heating results. The enhancement can be explained by plasma inhomogeneities along magnetic field lines.

* Research supported by USDOE.

+ Present address, McDonnell-Douglas, St. Louis, MO.

Lower Hybrid Heating Experiments on the Wisconsin Octupole.* T.L. OWENS⁺ and J.E. SCHARER--University of Wisconsin. Up to 40 kW of wave power at 140 MHz is coupled to the octupole. Ion temperature increases of 37 eV ($\Delta T_i/T_{i0}=12$) with $n=8 \times 10^{11} \text{ cm}^{-3}$ in helium plasma are measured from Doppler broadening of the He II 4680 Å line using a Fabry-Perot interferometer. At 20 kW power levels, ion heating measured with a miniature energy analyzer is obtained in hydrogen plasma for $\omega^2/\omega_{pi}^2 > 1.4$ with $\omega^2/\omega_{ce}\omega_{ci} = 0.5$. As the magnetic field is lowered, the minimum density for ion heating increases. No heating is obtained for $\omega^2/\omega_{ce}\omega_{ci} > 2.3$. Results are consistent with mode conversion theory if we assume that the wave $k_{||}$ power spectrum increases from its edge value by a factor of 8-15. Ion temperature profiles for peak densities between $3 \times 10^{11} \text{ cm}^{-3} < n < 8 \times 10^{11} \text{ cm}^{-3}$ show that the heating zone follows the wave turning point for the upshifted values of $k_{||}$. Parametric decay spectra are observed but do not appear to be responsible for ion heating.

* This research was supported by the USDOE.

+ Present address, McDonnell-Douglas, St. Louis, MO.

Poloidal Divertor Experiment with Applied $\vec{E} \times \vec{B}$ Drift* E.J. STRAIT, University of Wisconsin-Madison-- It has been proposed that the $\vec{E} \times \vec{B}$ drift due to an applied radial electric field can be used to enhance, and provide external control over, the "unload" action of a divertor in a toroidal device.¹ An axisymmetric poloidal magnetic divertor in the Wisconsin Levitated Octupole reduced the fraction of outwardly diffusing plasma which reaches the wall by up to a factor of 5, but at some cost in confinement volume and hence confinement time. When a radial electric field is applied in the scrape-off region, the fraction of plasma reaching the wall is further reduced by up to a factor of 5, with essentially no effect on confinement. Probe measurements confirm that, in the region far from the divertor, the additional transport is due to the poloidal component of $\vec{E} \times \vec{B}$ drift. Modification of the electrostatic sheath at the divertor's neutralizer plate by the applied electric field reduces the divertor's cooling effect on T_e .

*Work supported by USDOE.

¹D.W. Kerst, Bull. Am. Phys. Soc. 20, 1334 (1975).

Non-ambipolar Parallel Flow in a Divertor Scrape-off Zone* C.M. STRAWITCH and G.A. EMMERT, University of Wisconsin-Madison--Non-ambipolar parallel and thus also perpendicular flow has been observed in a magnetic divertor configuration in the Wisconsin D.C. machine.^{1,2} This flow is characterized by separate areas of net local electron and ion outflow to the conducting collector plate, where the flux of the dominant outflowing species in one area can be as large as five times the flux of the other species. This unequal flow has been measured, and it is found that the net charge outflow is globally equal to zero, when the flow in the separate outflow areas is added. The existence of non-ambipolar flow requires current flow in the divertor plate. When this current path is interrupted, we experimentally observe that the flow becomes ambipolar, with a correspondingly smaller diffusion coefficient as expected theoretically. Non-ambipolar flow in a tokamak divertor would result in undesirable local dumping of electrons and creation of a "hot spot" on the divertor plate. Also an enhanced sheath potential over the ambipolar case could result in increased ion sputtering and unipolar arcs.

¹A.H. Boozer, Phys. of Fluids 19, 1210 (1976).

²A. Simon, Phys. Rev. 98, 317 (1955).

*Work supported by USDOE.

Impurity Recycling Experiments in Tokapole II* NANCY BRICKHOUSE, CLEMENT BURTON, and R.N. DEXTER, University of Wisconsin-Madison--The fractional change in impurity spectral line intensities per added dopant atom is roughly proportional to the atomic mass of the dopant in experiments on Tokapole II discharges ($T_e = 100$ eV, $T_i = 20$ eV). It is suggested, in accord with results on Macrotor¹, that ions accelerated in the sheath potential release impurities through ion-induced desorption effects. Line intensities of O, C, N, and Cu (originally from the 4 internal hoops) are studied as functions of concentrations of extra H₂, D₂, He, CH₄, N₂, O₂, Ne, Ar, and other gases. The dopant mass dependence persists in studies of different ionic states but fractional intensity changes can increase significantly with ionic state of the impurity, an effect understood, only in part, as an effect of spatial profile modification. Late in the discharge, dopants can reduce Cu evolution from hoops by suppressing arcs. Information on time-dependent wall-trapping and desorption terms in a recycling model results from using reactive and non-reactive gases which cover a wide mass range.

*Work supported by USDOE.

¹Lena Oren and R.J. Taylor, B.A.P.S. 23, 802 (1978).

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