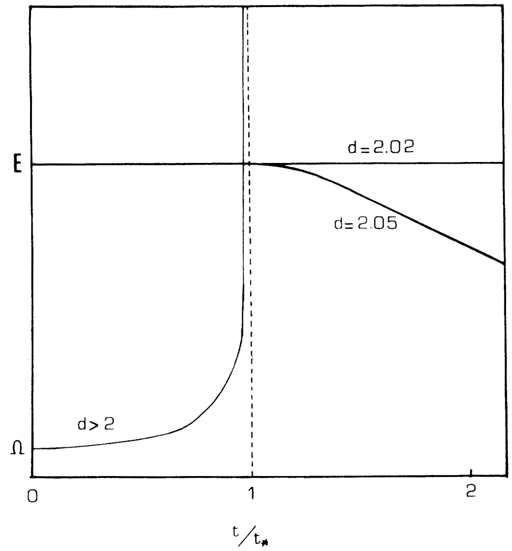

FIG. 3. Evolution of the energy E and entropy Ω without forcing in the limit of infinite Reynolds number. The catastrophe time $t_*(d)$ varies like $(d-2)^{-1}$ near $d=2$.

served quantity. This leads us to conjecture the existence of a similar crossover dimension for the primitive equations.[15]

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[13]Second-order closure does not yield any intermittency corrections.

[14]Another crossover dimension $d_c' \approx 2.208$ may be defined by the condition that for $d < d_c'$ high wave numbers in the $-\frac{5}{3}$ range act like a negative viscosity on small wave numbers as is done in a recent paper of R. H. Kraichnan, "Eddy-Viscosity in Two and Three Dimension" (to be published).

[15]Intermittency corrections to K41 should increase the $\frac{5}{3}$ exponent for $d > d_c$ and decrease it for $d < d_c$; see R. H. Kraichnan, J. Fluid Mech. 67, 155 (1975).

Auxiliary Heating of a θ-Pinch Plasma by Radial Magnetoacoustic Standing Waves

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Auxiliary heating of a linear θ-pinch plasma column by an externally driven radial magnetoacoustic oscillation has been experimentally investigated. The axial field of the θ pinch was modulated in time at the frequency of the plasma's fundamental radial magnetoacoustic oscillation. The dissipation in the plasma column was sufficient to transfer into the plasma at least 9% of the energy stored in the auxiliary capacitor bank used to drive the oscillation.

Driven radial magnetoacoustic waves are a potential form of auxiliary heating in θ-pinch devices following the initial implosion. We report here on preliminary experiments to investigate such heating. Small-amplitude $m=0$, $k=0$ natural radial oscillations were observed[1,2] and explained theoretically[3] on early θ pinches. In the results reported here, the main axial confining field was weakly modulated by an auxiliary bank at the resonance frequency of the fundamental radial oscillation. The amount of additional heating so obtained was inferred from the plasma temperature, at a later time after the column had become quiescent. This temperature was compared with that measured in the absence of resonant modulation of the confining field.

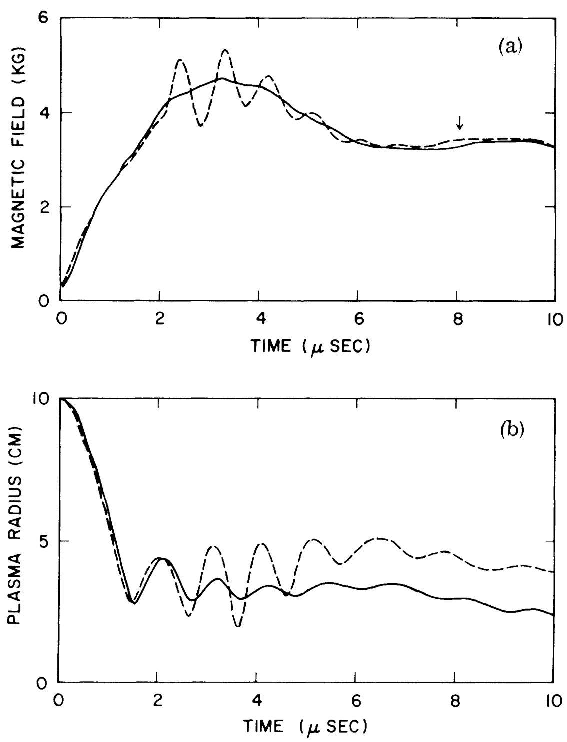

FIG. 1(a). Magnetic field without (solid curve) and with (dashed curve) resonant modulation. The gas has been preionized prior to the application of the fields shown here. The arrow indicates when $T_e + T_i$ is inferred from pressure balance. (b) Effective $\beta = 1$ radius, as derived from excluded flux data, without (solid curve) and with (dashed curve) resonant field modulation. The timing is the same as in 1(a).

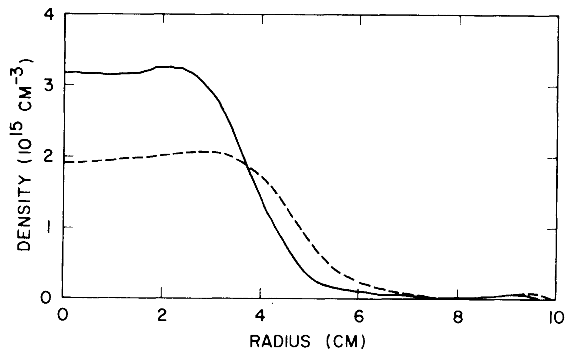

FIG. 2. Electron density profiles at $t = 8.2$ μs [see arrow on Fig. 1(a)] without (solid curve) and with (dashed curve) resonant field modulation.

These investigations were conducted on the staged θ pinch[4] at the Los Alamos Scientific Laboratory. The coil length is 450 cm; the discharge-tube inner diameter is 20 cm. The gas fill was 10 mTorr of D_2. A 670-μF capacitor bank provided a peak field of 4.5 kG rising in 2.8 μs, which was then crowbarred. This main field was modulated at the radial resonance frequency by firing into the coil a smaller, 6.6-μF capacitor bank with a ringing period of 0.9 μs. The modulation amplitude was small: $\Delta B/B \lesssim 0.2$. The 6.6-μF bank was fired as the main field peaked, and the resulting modulation damped after a couple of cycles. The transient oscillation as well as late-time quiescent density profiles of the plasma column were measured by holographic interferometry.[5] In addition, magnetic probe measurements on axis verified that $\beta \geq 0.95$ at the center of the column.

Prior to obtaining the results reported here, the natural $m = 0$, $k = 0$ oscillation of the column was studied by varying the fill pressure, p_0, and the confining magnetic field. The peak natural frequency was found to scale with $B_{peak}/\sqrt{p_0}$ as predicted by theory.[3] The gas fill and magnetic field used in the demonstration of wave heating were chosen to match the natural frequency to that of the 1.1-MHz auxiliary capacitor bank available for driving the oscillation.

Figure 1(a) shows the magnetic field wave form which immediately followed the preionization phase of the discharge, both without and with the addition of resonant modulation. The downward arrow indicates the time at which the temperature of the plasma was inferred from pressure balance. This time was chosen late enough to allow the plasma to become quiescent but well before particle end loss became significant. Figure 1(b) shows the effective plasma $\beta = 1$ radius, as derived from excluded flux data, for the same two discharges. The large-amplitude oscillation and resultant heating led to increased radius (and therefore temperature) in the case of resonant field modulation. Figure 2 shows the quiescent electron density profile at $T = 8.2$ μs both with and without resonant field modulation. From pressure balance, $T_e + T_i \simeq 60$ eV on axis for the case of no modulation. With the rippled wave form, $T_e + T_i \simeq 90$ eV, indicating a 50% increase in the plasma temperature due to the small amount of resonant field modulation.

The detailed time history of the radial oscillations during the external field modulation was documented by a closely spaced sequence of holographic interferograms.[5] Figure 3 shows the density as a function of time at several radii, as well as the modulated confining field. The zero of the time scale is the instant when the modulation begins [see Fig. 1(a)]. Because the densities

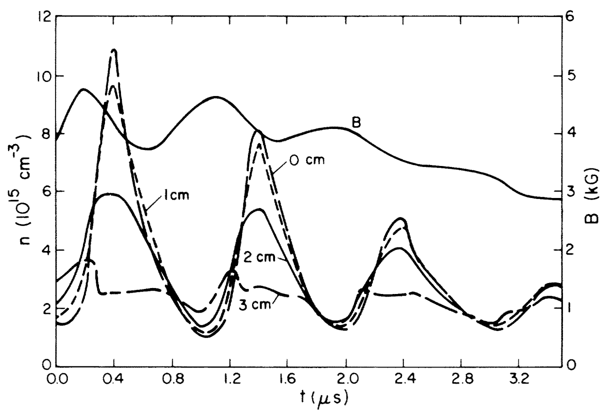

FIG. 3. External magnetic field and density at four radii as functions of time during resonant modulation. The zero of time scale is taken as the onset of resonant modulation, i.e., 2.1 μs into the main discharge.

at all radii appear to oscillate in phase with each other, and because the column radius is a half wavelength, the plasma column seems to support a large-amplitude standing wave. Because the density oscillation is roughly 90° out of phase with the external field modulation, a resonant behavior is indicated. Taking the average electron density during the peak modulation to be 6×10^{15} cm^{-3} on axis, the pressure-balance total temperature is $T_e + T_i \simeq 100$ eV. Assuming that $T_i = T_e$ (the electron temperature was not explicitly measured), we find that the Spitzer[6] ion-ion collision frequency is $\nu_{ii} \simeq 6\times 10^6$ s^{-1}. This is comparable to the radian frequency (6.9×10^6 s^{-1}) of the driven oscillation, and so the plasma regime is not highly collisional. Ohmic heating due to the field modulation is at least an order of magnitude too small to explain the experimental results.

A check was made of nonresonant excitation of the plasma column. A different auxiliary capacitor bank was discharged into the θ-pinch coil with a ringing frequency of 0.7 MHz, well below the column's natural frequency. For the same modulation field amplitude as in the resonant case (1.1 MHz), this off-resonant excitation yielded less than half as much heating.

An externally driven radial magnetoacoustic plasma oscillation has been shown to be an effective method of providing auxiliary heating for a θ-pinch plasma. Energy stored in the auxiliary capacitor bank was converted to plasma thermal energy with an efficiency of ~ 9% for the resonant condition. The increase in temperature would have been more dramatic if the plasma column had not adiabatically expanded between the application of the resonant modulation and the measurement of the quiescent profile.

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Laser Compression Studies with Neon-Filled Glass Microballoons

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We have measured the strong x-ray emission of compressed neon gas fill in glass microballoons, irradiated by a four-beam laser system. X-ray pinhold imaging and spatially resolved x-ray spectroscopy lead to estimates of the compressed-gas temperature and the compression of the glass shell. We find that the product of glass shell thickness and density at maximum compression is less than 2.5×10^{-3} g/cm^2. This is consistent with a degraded compression of the so-called "explosive-pusher mode."

Deuterium-tritium–filled glass spherical shells have yielded[1] the first direct evidence of target compression by laser irradiation. If such targets are filled with a heavier gas they can give very useful additional information even though the neutron emission is lost. We report here on x-ray measurements of neon-filled glass microballoons which yield estimates of the neon electron temperature at maximum compression as well as the maximum compression of the glass shell (through