We note that Eq. (7) remains valid in the classical theory also [although Eq. (6) does not] so that it should be valid even for large values of ϵ.

In their measurements of ultrasonic absorption and dispersion of longitudinal waves in a sodium-borosilicate melt, Simmons and Macedo[6] have observed anomalous behavior, interpreted as due to mode-mode coupling, only at temperatures $\approx 250°$ in excess of T_c (at 1000 to 1200°C). As this corresponds to relatively large values of ϵ and the classical theory may be valid in this region, it is relevant to note that classical theories of coupling between ultrasonic waves and composition fluctuations have also been worked out.[10] From their results and Eq. (7) they estimate $\tau_K \approx 15$ and 1 sec at 1 and 5°C above T_c, respectively. The value for 800°C is less than 10^{-3} sec.

These estimates are in agreement with our results since they indicate that (a) a thermodynamic equilibrium for the composition fluctuation is reached during our minimum heat-treatment time of 15 min at all temperatures above T_c by at least 1°C; (b) it is possible to quench these fluctuations with our quenching rate of 10°C/sec from temperature above T_c but not from 800°C.

While our results show the possibility of studying quenched supercritical fluctuations in real space, the viscosity of our system is not high enough to permit a quenching in a sufficiently extended range of temperatures. In addition, the use of a binary system would permit an easier determination of the exact critical composition, thus permitting the study of larger stable fluctuations. We are presently working on these problems.

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Measurements of Enhanced Absorption of Electromagnetic Waves and Effective Collision Frequency Due to Parametric Decay Instability*

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Enhanced absorption of an electromagnetic wave near ω_{pe} was observed coincident with the onset of parametric decay instability in a Q-device plasma. The effective collision frequency $\nu_{\text{eff}} = \nu_{ei}(E/E_c)^2$.

Recent results on heating of ionospheric and laboratory plasmas by intense electromagnetic waves near the plasma frequency have focused interest on parametric instabilities, which are expected to produce enhanced resistivity at the driving frequency through enhanced momentum transfer from electrons to ions by wave-particle interactions in addition to binary particle collisions. Although extensive theoretical work on parametric instabilities[1] has been reported and numerical simulation[2] has indicated concomitant enhanced plasma heating, the causal, direct relation between well-identified parametric instability, enhanced resistivity, and plasma heating has not been demonstrated conclusively in prior experiments.[3,4]

The parametric decay instability is destabilized when the electron drift velocity due to an rf electric field at $\sim\omega_{pe}$ approaches $\sim 0.05 v_{\text{theor}}$. The incident electromagnetic wave decays into two electrostatic waves. Enhanced absorption arises because the instability extracts energy from the pump field, which is then transferred to the particles.

The principal result of the present work is the measurement of such enhanced absorption and the resulting plasma heating, coincident with destabilization of the parametric ion-acoustic decay instability. This result is based on (1) the observed reduction of the transmission coefficient (ratio of transmitted to absorbed microwave power) and of the Q (i.e., increase in plasma dissipation) of a resonant cavity containing the plasma when the pump field is increased above a threshold; (2) the simultaneous onset of the well-identified instability; and (3) plasma heating, measured as an increase in electron temperature, also coincident with instability onset. The measured dependences of instability threshold on plasma density and excitation electric field strength agree with those predicted by linear, infinite-plasma theory. Finally, in the unstable regime, the dependence of pump field E on absorbed power is $P_{abs} \propto E^4$ and the effective collision frequency $\nu_{eff} \propto E^2$, in agreement with recent theoretical predictions.[5]

The experiments were performed on the Princeton Q-1[6] thermally ionized potassium plasma, 126 cm long and 3 cm in diameter, with $T_i \gtrsim T_e \simeq T_{ionizer} = 2800°K$. The neutral pressure is below 2×10^{-7} Torr, so that collisions with neutrals are negligible. Two resonant cavities, operating in the TM_{010} and TM_{020} modes, were used to excite the instability at two different densities. The rf electric field is aligned parallel to the external magnetic field. Chokes at the cavity ends allow plasma to pass, but prevent microwave power losses. $\omega_{ce}/\omega_{pe} \simeq 6$, $\nu_{ei} \simeq \omega_{pi}$, and the collisionless skin depth $(c/\omega)(\omega_{pe}^2/\omega^2 - 1)^{-1/2} \gtrsim r_{plasma}$, so that wave penetration is assured. Thus, the plasma is expected to introduce only a small perturbation to the cavity field, which is substantiated by direct probe measurements. To have available a range of frequencies and hence densities, grids immersed in the plasma were also used to generate the destabilizing field.

Identification of the parametric instability is based on the following agreements of experiment with theory: (a) The frequencies obey the sum rule $\omega_{pump} = \omega_{pe} + \omega_{acoustic}$; (b) for grid-launched waves the wave numbers obey the sum rule $k_{pump} = k_{pe} + k_{acoustic}$ (in the cavity k's cannot be measured because of the small wavelengths at the cavity frequency and the perturbation problems with axially movable probes in the axial electric field); and (c) the measured onset field agrees with that predicted by infinite-plasma theory. In addition, this identification is substantiated by the following supporting evidence from the spectrum measured by probes: (i) The radial extent of the instability is comparable to the radial density distribution, consistent with the structure of the radial eigenmodes expected to occur in a strongly magnetized plasma column; (ii) the instability can only be excited at frequencies below or close to the plasma frequency of the maximum density, as expected from the dispersion relation of the ω_{pe} waves; (iii) the total power of the instability at saturation is comparable to that of the pump field, as observed also in computer experiments[2]; and (iv) the intensity of the high-frequency ω_{pe} wave is much higher than that of the ion-acoustic wave near ω_{pi}, in agreement with predictions.[1] We note that the purely growing mode has not been observed in the present experiment.

The cavity simultaneously serves as diagnostics and supplies the destabilizing pump field. In the stable regime, when the cavity field is below threshold, Q can be measured by the sweep method,[7] $Q = f/\Delta f$ (Δf is the half-width of the resonance curve), since the implicit assumption that the dissipation (or Q) is independent of (sweep or pump) field strength and frequency is valid. Earlier work[4] on anomalous microwave absorption also utilized the (pump) frequency-sweep Q measurement in the anomalous absorption regime (direct observation of instability was not achieved). Since both amplitude and frequency of the pump, i.e., the cavity field, are varying throughout the Q measurement, the instability amplitude, effective collision frequency, and (hence) Q are not constant, and the frequency-sweep method cannot produce correct Q values (although the numbers so obtained trend in the right direction). In addition, for sweep times comparable to instability growth times, the (apparent) growth rates become a function of the sweep rate, and the measured onset pump fields for fast sweep are too high by an amount depending on the sweep rate.

In the present work, the cavity Q in the unstable regime was measured by a method which makes use of transmitted and absorbed powers at constant pump frequency and amplitude, i.e., at constant effective collision frequency, during the measurement. The cavity power balance gives

$$P_{inc} - P_{refl} = P_{abs} = P_{tr} + P_{Cu} + P_{coll} + P_{instab} = cE^2/Q_{unst}, \quad (1)$$

where the power losses on the right side are

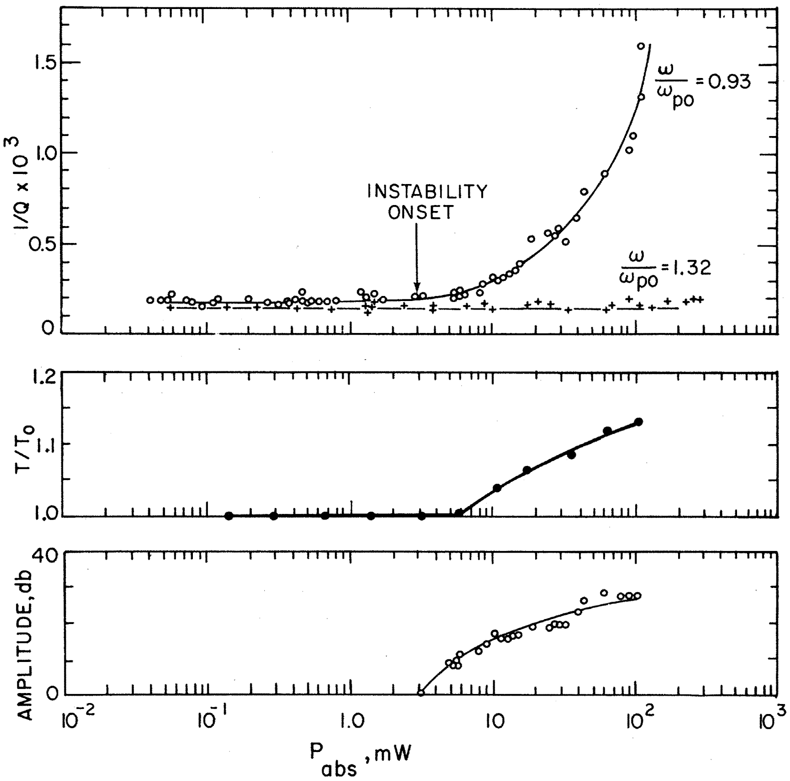

FIG. 1. Measured cavity $1/Q$ values, T/T_0, and instability (lower sideband) amplitude versus absorbed power. The electron temperature is determined from dc conductivity; the measured T_0 is equal to the plate temperature, 2800°K.

those due to transmission, cavity copper-wall resistance, plasma collisions, and instability; and c can be calculated from the geometry and frequency of the cavity. Observing that the transmitted power is uniquely determined by E, whether the plasma is stable or unstable, we obtain, using (1),

$$Q_{\text{unst}} = cE^2/P_{\text{abs}} = cc_1P_{\text{tr}}/P_{\text{abs}}, \tag{2}$$

where c_1 can be determined[8] in the stable state.

In Fig. 1 are shown the measured $1/Q$ (inversely proportional to the transmission coefficient), electron-plasma wave amplitudes, and electron temperatures versus absorbed power, with ω_{pe} evaluated for center density. For empty and plasma-filled cavities with $\omega/\omega_{pe} \gtrsim 1.3$, and for $\omega/\omega_{pe} < 1$ below threshold, Q is nearly constant as power is increased. Above threshold, Q decreases rapidly with increasing absorbed power. These Q changes are comparable to, but smaller than, those of Ref. 4, and threshold values are lower, as expected, because of the recognition of the effects of the sweep method. We note that the error in the measurement of absolute density may be 40%.

Simultaneous with onset of enhanced dissipation, the instability destabilizes at ω_{pe} and ω_{pi}, and both amplitudes increase with increasing absorbed power. The electric field at onset is in good agreement with linear, infinite-plasma theory, assuming electron-ion collisional damping for the electron plasma wave and Landau damping for the ion-acoustic wave. We note that according to theory,[9] the present Q-device plasma must be considered a homogeneous plasma, since radial density scale length and mean free path are comparable, a result which is consistent with our measurement: The onset value agrees with that of homogeneous theory. Electron heating resulting from the power absorbed by the instability is shown in Fig. 1(b). The electron temperature was determined from a dc conductivity measurement; the local temperature increase is expected to be higher.

For P_{abs} versus E below threshold, we find good agreement between experiment and theory (Fig. 2), with collision frequency according to Dawson and Oberman.[10] Above threshold an effective collision frequency ν_{eff} can be assumed which depends on pump (or instability) amplitude.

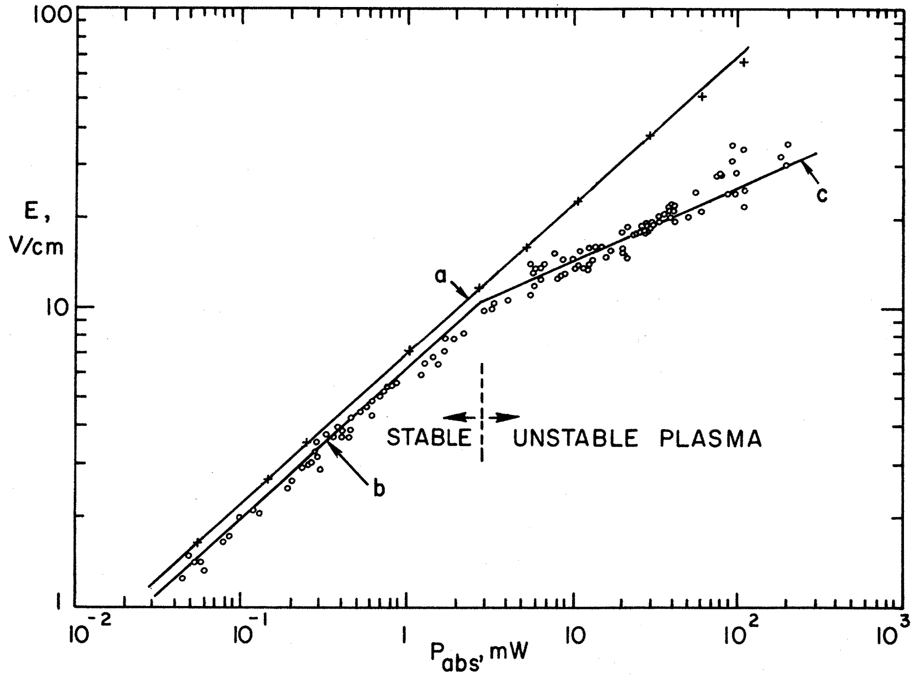

FIG. 2. Measured pump field versus absorbed power. Crosses, cavity without plasma; circles, cavity with plasma. Curve *a*, empty cavity, indicating $P \propto E^2$; curve *b*, calculated from *a* and classical plasma dissipation (Ref. 10); curve *c*, obtained by using an effective collision frequency $\nu_{eff} \propto E^2$; measured $E_{onset} \simeq 12$ V/cm, theoretical $E_{onset} \simeq 8$ V/cm, $\omega/\omega_{pe} = 0.93$. For a stable plasma [as in the case of $\omega/\omega_{pe} = 1.32$ in Fig. 1(a)] the corresponding line *b* remains straight up to the highest power used.

Recent theoretical results based on nonlinear ion Landau damping indicate $\nu_{eff} \propto E^2$, in agreement with the experimental results $\nu_{eff} \simeq \nu_{ei}(E/E_c)^2$, although the requirements of low pump field energy $(E^2/4nkT \ll \omega_{pi}/\omega_{pe})$ and $\nu_e \ll \omega_{pi}$ are not well met in the experiment. In addition, the highest attained experimental value of $v_d/v_{theor} = (eE/m\omega)/v_{theor} \simeq 0.15$ does not allow a check of numerical simulation results[2] for $v_d/v_{theor} > 1$, where it was shown that ν_{eff} is independent of E.

Several important considerations arise from this work. Firstly, the present results confirm predictions of the linear and nonlinear theories of the parametric instability for an infinite homogeneous plasma. Secondly, the instability can be excited over a wide range of frequencies as a result of the dispersion relation for plasma waves in a finite-size plasma. Thirdly, since instability can be destabilized at very low pump intensities (at onset, drift over thermal energy ~ 5%), parametric effects may play a significant role in many rf heating methods. To sum up, this work presents conclusive evidence for the existence of a dissipation mechanism for electromagnetic waves not based on particle-particle collisions but on wave-particle interactions, which can lead to power absorbtion much larger than the dissipation due to classical rf heating.

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Dynamical Behavior of a Nematic Liquid Crystal just above the Nematic-Isotropic Transition from Spin-Lattice Relaxation

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We report here the proton spin-lattice relaxation time $(T_1)_{CF}$ measured in *p*-methoxybenzylidene *p-n* butylaniline at two frequencies in a temperature range of about 25°C just above the nematic-isotropic transition. We have determined the correlation time for critical fluctuations, τ_{CF}, using a simple extension of the Bloembergen-Purcell-Pound theory which relates τ_{CF} and $(T_1)_{CF}$. The temperature dependence τ_{CF} is in good agreement with the de Gennes theory and with experimental results of Stinson and Litster.

The dynamical behavior of a nematic liquid crystal just above the nematic-isotropic transition temperature T_c is of great interest from both experimental and theoretical standpoints. Experimental studies show clearly that this is a weak first-order transition[1] (low latent heat) while both the static and dynamical behaviors of the isotropic phase close to T_c demonstrate characteristics of a second-order transition[2] having a critical temperature $T^* < T_c$; T^* is usually within 1°C of T_c. This behavior strongly suggests that this phase would be about to undergo a second-order transition at T^* with the lowering of temperature unless it were intercepted by a first-order transition at T_c. As a result, many characteristics of the low-temperature phase persist above T_c, although to a lesser extent, just as in a magnetic transition.[3] For example, the long-range order characteristic of the nematic phase persists no longer above T_c but the short-range order does. Suggestions of the existence of this short-range order were made earlier by Blinc *et al.*[4] and by Weger and Cabane.[5] Litster and Stinson[6] and, more recently, Chu, Bak, and Lin[7] have demonstrated the short-range-order effects in a nematic system very convincingly. Theories[2,8,9] based on Landau's theory of second-order transitions[10] have been very successful in explaining these results.

We report in this Letter studies on the dynamical behavior of the nematic liquid crystal *p*-methoxybenzylidene *p-n* butylaniline (MBBA) in the isotropic phase close to T_c from proton spin-lattice relaxation. Our results are in good agreement with the Landau-de Gennes theory[2,8] and with experimental results of Stinson and Litster,[6] obtained by a light-scattering technique. Attempts were made earlier, with limited success, to correlate the dynamical behavior and the nuclear relaxation time T_1 or T_2 (or linewidth).[4,11] The main problem of such a correlation is to determine the true contribution of critical fluctuations characteristic of dynamical behavior to the total spin relaxation tine T_1 or T_2 which is measured experimentally. Since even in the nematic phase many aspects of molecular dynamics are close to those of an isotropic liquid, such as rotation about the molecular axis and random translational motion of the centers of gravity of molecules, it is expected that the experimental T_1 should not be solely due to critical fluctuations, but rather should have two contributions in general. As a result, we can write

$$(1/T_1)_{\text{expt}} = (1/T_1)_{\text{CF}} + (1/T_1)_0, \qquad (1)$$

where the subscripts CF and 0 denote, respec-